SACE TWO - AUSTRALIAN CURRICULUM

BIOLOGY

WORKBOOK
SECOND EDITION

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Essentials education.

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PUBLISHING INFORMATION

This Workbook is part of the Essentials Education series, designed to support the teaching of SACE Stage 1 and 2 subjects in South Australia. It is specially designed to meet the requirements of the SACE Stage 2 Biology Subject Outline.

The Essentials Education series is published by
Essentials Education
PO Box 997, North Adelaide SA 5006
TELEPHONE (08) 8180 0695
www.essentialseducation.com.au

LIBRARY CATALOGUE:

Carey, Christopher - Crierie, Alan - Greig, David - Ruthven, Simon
1. Biology, SACE2 Australian Curriculum - 2. **E**ssentials Workbook.

ISBN - 978-1-925505-50-4

First edition (Revised) 2018. Second Edition 2023.

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All of the authors trust that these learning materials will assist and even inspire, in some small way, the next generation of biology students and biologists in South Australia.

Acknowledgments

Andrew J Thiel <www.capstonemedia.com.au> for some of the illustrations

<http://www.sciencephoto.com/images> for most of the images (as credited separately)

Jenna Crierie for her artwork and proofreading

Jane Hosking for helping to develop the Science Inquiry Skills activities and the Lab Notes

Catherine Jones for her involvement in testing the Science Inquiry Skills activities

Dianne Crierie for her proofreading

Dr Ray Tobler (and ACAD) for his contributions in Chapter 4.2 regarding the aboriginal genomic studies

Dr Lauren Thurgood (Chapter 2.8) and Dr Wendy Telfer (Chapter 4.7) for their personal profile contributions

Greg Mutze for his contributions in Chapter 4.7 regarding rabbits and permission to use artwork

Terry Reardon for his contributions in Chapter 4.7 regarding bats and permission to use artwork

Dylan Sortino for his contributions in Chapter 4.7 regarding Christmas Island and permission to use photos

Various staff at the 'Department of Environment, Water and Natural Resources' (DEWNR) for assistance

Our friends and families for their untiring patience and support

Topic 1 DNA and proteins

Chapter 1.1 DNA structure

Science Understanding

DNA stores and transmits genetic information; it functions in the same way in all living things.

DNA is a helical double-stranded molecule.

In eukaryotes, DNA is bound to proteins (histones) in linear chromosomes, which are found in the nucleus.

DNA is unbound and circular in the cytosol of prokaryotes and in the mitochondria and chloroplasts of eukaryotes.

- Compare chromosomes in prokaryotes and eukaryotes.

Replication of DNA allows for genetic information to be inherited.

Base-pairing rules and method of DNA replication are universal.

- Describe the structural properties of the DNA molecule, including:
  - nucleotide composition and pairing
  - the weak bonds between strands of DNA that allow for replication.
- Explain the importance of complementary base pairing (A–T and C–G).
- Recognise that DNA strands are directional and are read 5' to 3'
- Describe and represent the process of semi-conservative replication of DNA.

DNA

Large molecules that are found in living organisms are called macromolecules. They usually consist of smaller units that are joined together.

Deoxyribonucleic acid (**DNA**) is a macromolecule found in all living cells, and is the chemical that controls virtually everything that happens in cells. It is the most fundamental chemical of life, believed to have been formed some 3 billion years ago when the first forms of life arose.

DNA was first isolated in 1869 by a Swiss chemist, *Friedrich Miescher,* who discovered it was acidic and contained the element phosphorous. It was found mainly in the **nucleus** of cells and was thus named a nucleic acid. It was in the 1940s that the structure of DNA began to be discovered. The two scientists credited with the work were a young American scientist, *James Watson* and a British scientist, *Francis Crick*. Refer to the '*Science as a Human Endeavour*' Activity at the end of this chapter for more details on the discovery of DNA structure, as a double-stranded molecule. *Figure 111* shows a section of a DNA molecule and the highly recognisable DNA **double helix** structure.

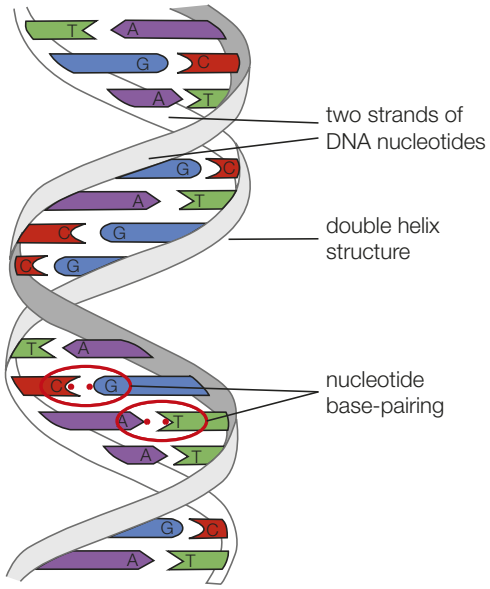


Figure 111 A section of a double stranded DNA molecule

Chromosomes and DNA

DNA in cells is found in structures called **chromosomes.** These are often referred to as the structural unit of information in cells. DNA stores and transmits **genetic information**, managing the requirements and activities of the cell. DNA is **universal** and functions the same way in all living things. This means that DNA from one species can be inserted into the genome of another species and the message can still be transmitted (these concepts will be explored further in this Topic).

Two different types of cells have evolved over time: **prokaryotic cells** and **eukaryotic cells.** Prokaryotic cells are thought to have existed first, they are relatively unspecialised and do not contain membrane-bound organelles. The cells of all bacteria are prokaryotic.

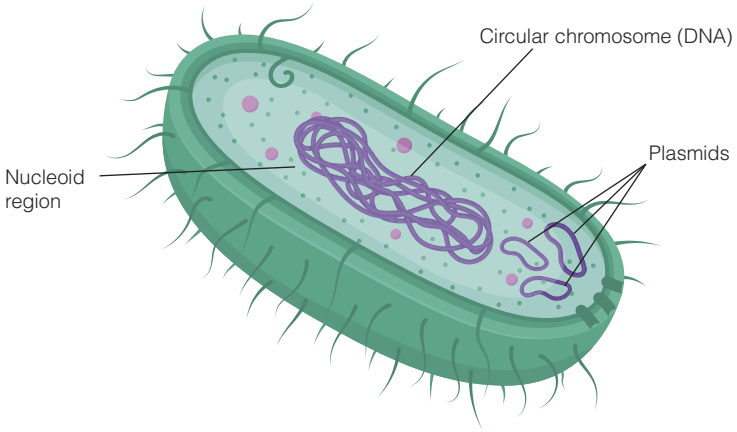


Figure 112 The circular chromosome and separate plasmids of a prokaryotic cell

As can be seen in *Figure 112*, the DNA is located in the liquid part of the cytoplasm (or cytosol). The location of DNA in the cytosol is called the **nucleoid region.** The **DNA is circular**, consisting of **one chromosome** and is double-stranded. This region also contains another nucleic acid called RNA (ribonucleic acid) and proteins which are another type of macromolecule. Also found in many types of prokaryotic cells are **plasmids** which are small amounts of **circular**, double-stranded DNA that are **separate** from the cell's chromosomal DNA.

The cells that make up large, complex, multicellular organisms are termed eukaryotic cells. The cells of all animals, plants and fungi are eukaryotic cells. These cells are highly organised and more specialised than prokaryotic cells. They contain smaller internal structures, called membrane-bound organelles, that have specific functions in the cells. Examples of these organelles include the nucleus, mitochondria, chloroplasts, Golgi bodies and endoplasmic reticulum.

Most of the DNA in a eukaryotic cell is found in the **nucleus** of that cell. Human somatic (body) cells consist of **46 chromosomes**, which are organised into 23 pairs. There are 22 pairs of autosomal (non-sex) chromosomes and one pair of sex chromosomes (either XX for female or XY for male). A set of human chromosomes is known as a **karyotype** (see *Figure 113*).

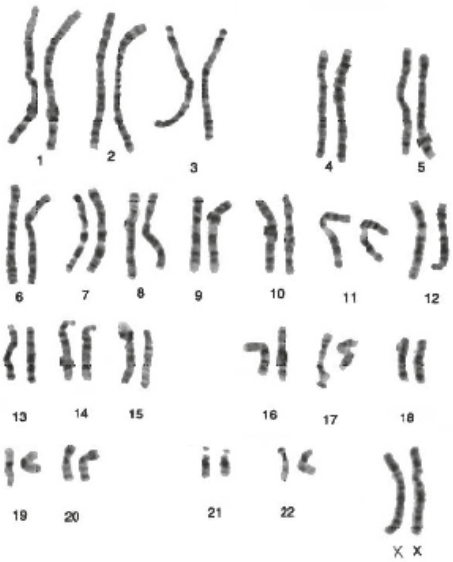


Figure 113 A human karyotype of a female

The chromosomes are arranged into **condensed linear** strands consisting of a double stranded **DNA molecule** and **histone proteins** (see *Figure 114*). The ends of chromosomes have short lengths of DNA called telomeres. These protect the tips of chromosomes from breakdown and stop chromosomes from binding to one another. Chromosomes are **only visible** under a light microscope **during cell division** when the DNA is tightly coiled around histone proteins (condensed). The **decondensed** form of chromosomes is called **chromatin** (see *Figure 114*). Chromatin is present in the nucleus of cells throughout the cell cycle (excluding cell division). It is important that the **genetic code is accessible** during the growth and development of a cell so that DNA synthesis, protein synthesis and RNA synthesis can occur. If the DNA molecule is condensed, the genetic code is very hard to access, and these processes are unlikely to occur. Conversely, it is important for the chromatin to condense into chromosomes prior to cell division to **protect the genetic code** and ensure identical copies are transferred to both daughter cells. Each human somatic (body) cell contains about 2 to 3 metres of DNA when completely decondensed to linear form. If chromatin was present during cell division, it is likely that the decondensed DNA would get tangled and result in DNA breakages.

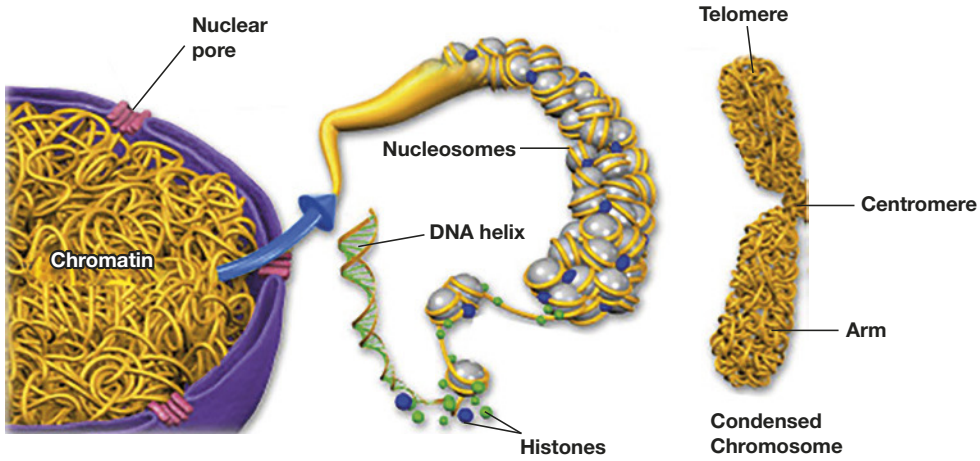


Figure 114 The structural difference between chromatin and chromosomes

Two types of eukaryotic membrane-bound organelles also contain DNA, **mitochondria (mtDNA) and chloroplasts (cpDNA).** mtDNA and cpDNA are both double stranded, circular and not bound to histone proteins (similar to prokaryotic cells). There are theories for the existence of DNA in these organelles, including the fact that mitochondria and chloroplasts were once 'free-living' unicellular organisms that were capable of their own independent existence. *The table below provides a comparison of DNA molecules in prokaryotic cells, mitochondria, chloroplasts and eukaryotic cells:*

	Prokaryotic DNA	Mitochondria & chloroplasts DNA	Eukaryotic DNA
Number of DNA strands	Two	Two	Two
Number of chromosomes	One	One	Two or more in pairs (generally)
Shape of chromosome(s)	Circular	Circular	Linear
Location in cell	Nucleoid region	Mitochondrial matrix, stroma	Nucleus

DNA structure

It has been stated that DNA stores and transmits genetic information. For this to be possible, the molecule must be capable of enormous variation to be able to code for the endless variety that is seen across life on the planet. The structure of DNA enables it to perform two vital functions necessary for life:

1. Make identical copies of itself so that genetic information can pass from cell to cell and can be inherited or passed on to the next generation.
2. Provide a code that can be used by cells to manufacture protein molecules.

DNA is a large macromolecule made up of repeating units called **DNA nucleotides** (see *Figure 115*). Nucleotides are complex molecules made up of three smaller molecules that are linked together by covalent bonds:

- a pentose (or 5-carbon) sugar called **deoxyribose**
- a **phosphate** group, and
- one of four **organic bases:** adenine (A), cytosine (C), thymine (T) and guanine (G).

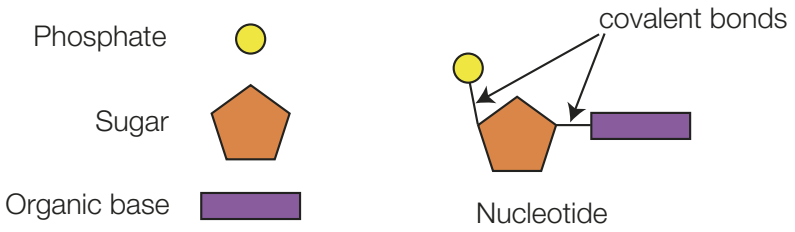


Figure 115 The components of a nucleotide

The phosphate of one nucleotide is attached to the sugar of the next nucleotide, this results in a backbone of alternating phosphates and sugars from which the bases project. This structure of the phosphate-sugar backbone results in one end of the DNA strand ending in a phosphate, and the other ending in a sugar. This gives the DNA strand **directionality**. The end of the DNA strand with the phosphate (PO_4^{3-}) sticking out is called the **5' end** (pronounced 5 prime) and is the **beginning** of the DNA strand. At the opposite end of the chain, a sugar molecule is exposed with a hydroxyl group (OH) sticking out. This is called the **3' end** (pronounced 3 prime) of the DNA strand (see *Figure 116*). The sequence of DNA is therefore written in the 5' to 3' direction. Additionally, the phosphate group is **negatively charged**, giving the DNA molecule an overall negative charge. This charge can be used to help separate DNA molecules and will be re-visited in Chapter 1.7.

Each base forms **weak hydrogen bonds** with its complementary base located at the same position on the other strand (see *Figure 116*). Weak hydrogen bonds between complementary base pairs in DNA are an advantage to cells because they are easy to break and re-form. This is important in **DNA replication** which involves breaking apart the DNA double helix to expose its organic bases for base pairing. The base pairing rules are:

Adenine only bonds to Thymine with two hydrogen bonds forming (A=T).

Guanine only bonds to Cytosine with three hydrogen bonds forming (C≡G).

Evidence for complementary bonding is supported by DNA analysis which reveals that each species has identical amounts of adenine and thymine and also identical amounts of guanine and cytosine. For example, if there is 20% thymine in a DNA molecule there will also be 20% adenine and therefore 30% guanine and 30% cytosine.

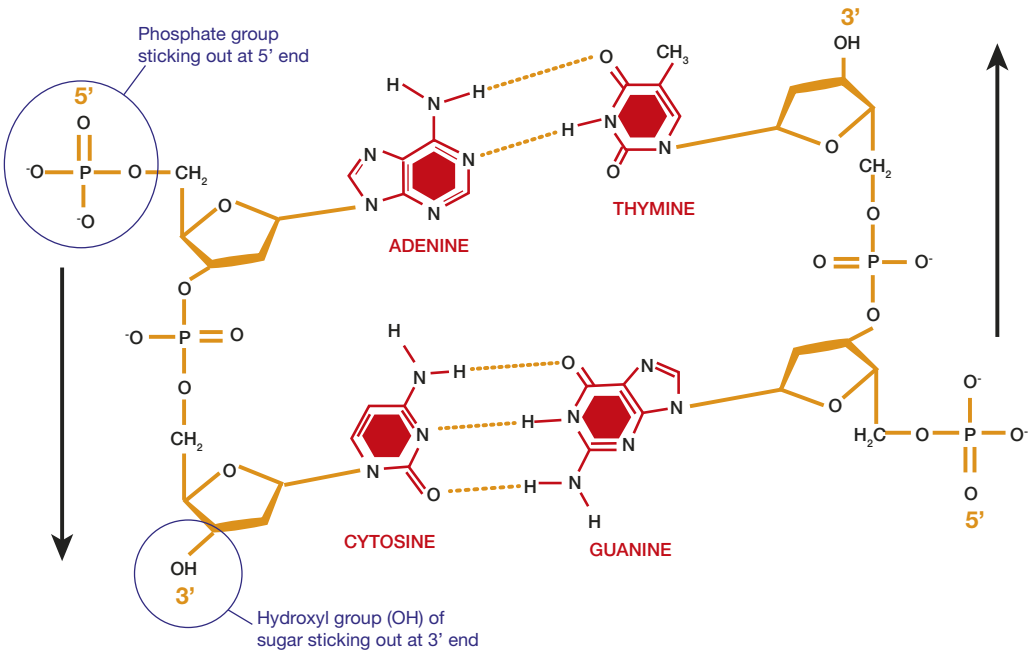


Figure 116 A small section of DNA illustrating the number of hydrogen bonds that form between complementary DNA bases

When DNA is assembled, it consists of **two complementary strands** linked by the complementary base pairs. As the two strands are complementary, they are **read in opposite directions**. With reference to *Figure 117*, the DNA strand on the left is read from top to bottom in the 5' to 3' direction; however, the DNA strand on the right is read from bottom to top in the 5' to 3' direction. It is important to note that both strands are read in the 5' (yellow phosphate) to 3' (orange sugar) direction.

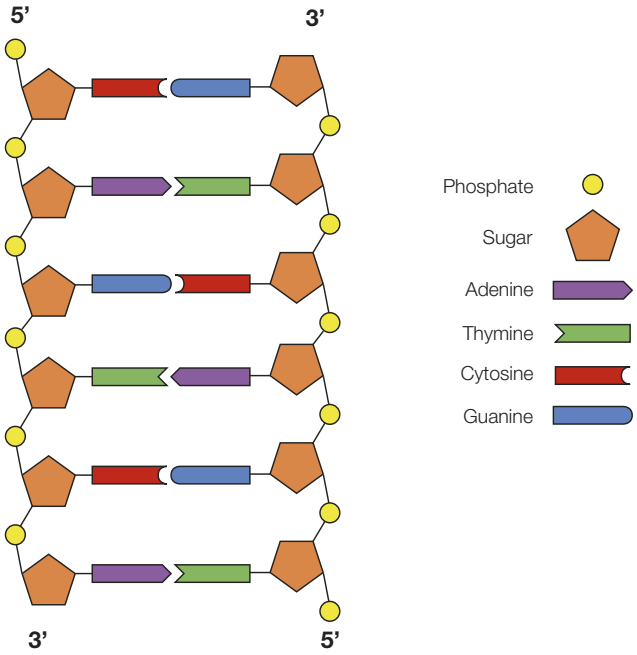


Figure 117 A section of unwound DNA illustrating the two DNA strands running in opposite directions

A chromosome is made up of many functional units of information called **genes**. Each gene is a unique sequence of bases on one strand of DNA (the coding strand). The sequence of bases in genes varies from one DNA molecule to another and it is this variation in the base code that enables DNA to be such a versatile and diverse molecule.

Different species have different characteristics and therefore different numbers of genes and chromosomes. For example, simple bacterial cells require hundreds of genes because they require hundreds of proteins to function. Different species on Earth differ in:

- the number of chromosomes found in cells (and therefore, number of genes)
- the base sequences of genes found in their DNA
- the length of the DNA molecules and hence the number of bases.

The table below illustrates the chromosome number of a few common organisms:

Organism	Number of chromosomes per cell
Human	46
Bacterium	1
Rock Dove	80
Pea	14
Simple alga	16

Helpful online resources

Cognito: GCSE Biology - What is DNA? (Structure and Function of DNA)
<https://www.youtube.com/watch?v=T6_wKPAbf2k>

TED-Ed: The twisting tale of DNA - Judith Hauck
<https://www.youtube.com/watch?v=0_b80fHmuWw>

Stated Clearly: What is a Chromosome?
<https://www.youtube.com/watch?v=lePMXxQ-KWY>

DNA replication

In an earlier section of this chapter, it was noted that one of the vital functions of DNA is the ability to make copies of itself so that genetic information can be inherited by daughter cells and descendants. The process that enables this to occur is called **DNA replication** and occurs in both prokaryotic and eukaryotic cells. DNA replication is the mechanism for copying (or doubling) DNA. It takes place in the **nucleoid region** of prokaryotic cells and the **nucleus** of eukaryotic cells. DNA replication is said to be **semi-conservative** because each double-strand of DNA consists of one old strand (retained or conserved from the original parent DNA molecule) and one newly synthesised strand. As the two DNA strands of the parent DNA molecule are complementary, the DNA nucleotides are **added in opposite directions**. DNA nucleotides are **added in the 5' to 3' direction** by DNA polymerase to the exposed bases of the existing 'old' strands. The product is **two identical** double-stranded DNA molecules that contain the same genetic information as the original DNA molecule (see *Figures 118 and 119*). Refer to the following table for a summary of the steps involved in DNA replication:

Summary of DNA replication	
1.	The enzyme **helicase** breaks the hydrogen bonds between the complementary bases joining the two strands, unwinding, and exposing their bases (see *Figure 119*).
2.	Each strand serves as a template for making a new complementary strand.
3.	Enzymes, called **DNA polymerase**, add free DNA nucleotides to the exposed corresponding bases on the separate strands, according to complementary base pairing rule: A binds with T and C binds with G (see *Figure 119*).
4.	The new DNA is **synthesised in the 5' to 3' direction**; therefore, DNA polymerases add DNA nucleotides to the 3' end of the DNA strands (see *Figures 118* and 119).
5.	Each new double-stranded DNA molecule rewinds into a double helix and are joined at the centromere (see *Figure 1110*).

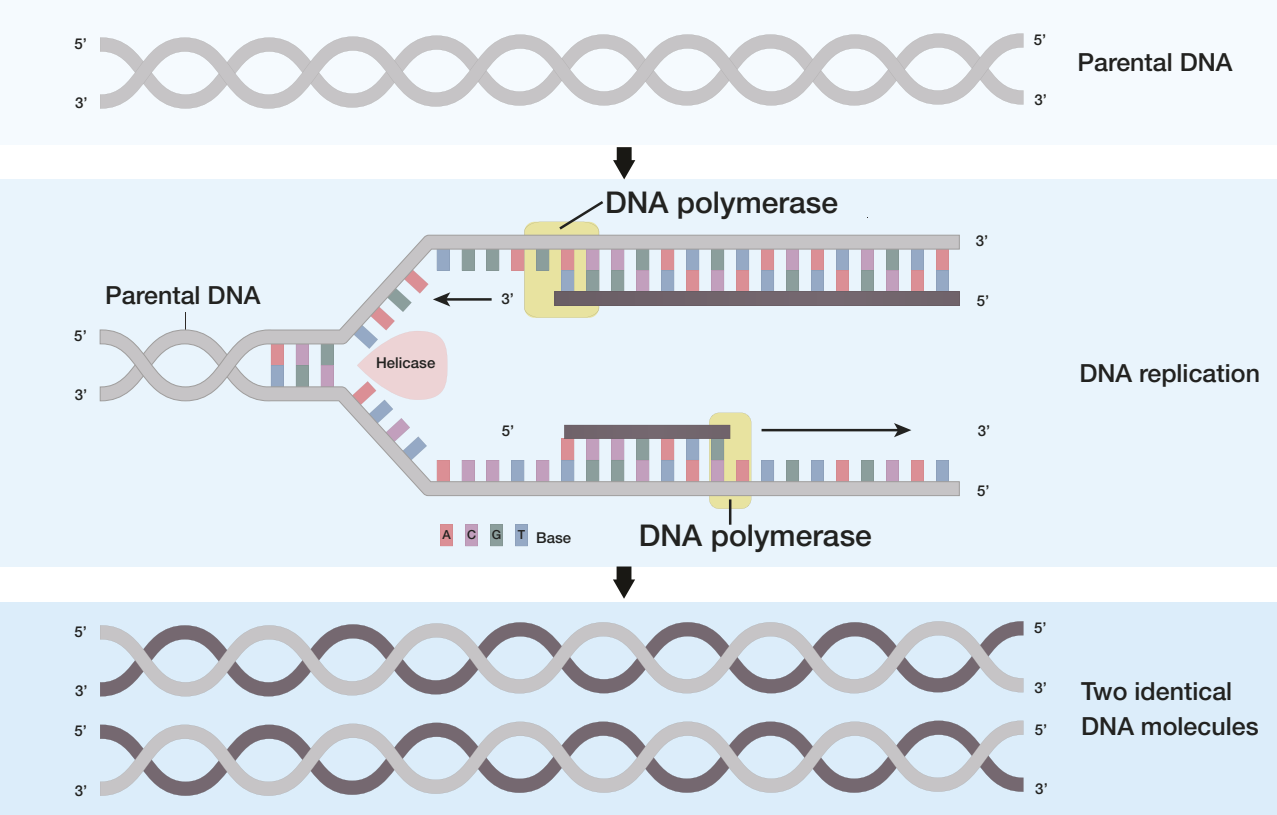


Figure 118 The production of two identical DNA molecules through semi-conservative DNA replication

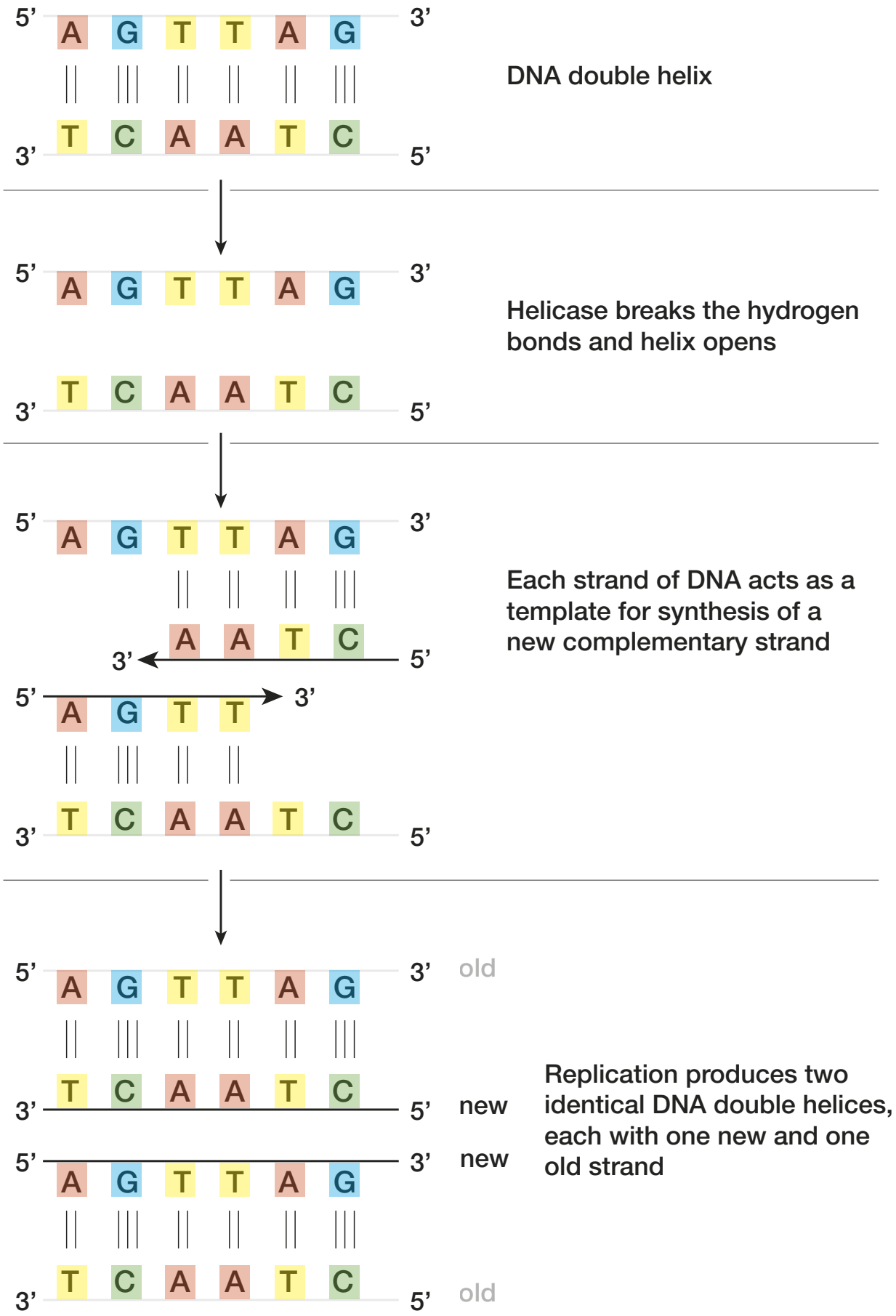


Figure 119 A summary of the DNA replication process

Following DNA replication, the DNA is doubled and all chromosomes in the cell consist of **two identical sister chromatids** (see *Figure 1110*). DNA can therefore be seen in three forms:

- decondensed chromatin
- as a condensed chromosome
- after DNA replication as a chromosome consisting of two identical sister chromatids

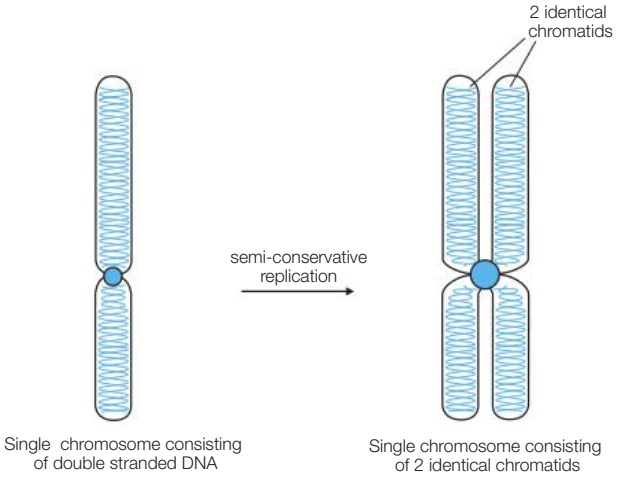


Figure 1110 The process of DNA replication at the chromosome level

The number of times DNA replication can occur is limited. This is because every time DNA in chromosomes is replicated, the **telomeres** at the ends of the chromosome shorten. After a certain number of DNA replications, the telomeres are too short for further replication to occur.

Each strand of a DNA molecule has the information necessary to construct the other strand. DNA replication occurs **prior to cell division** in both prokaryotic cells (binary fission) and eukaryotic cells (mitotic division) so that each daughter cell produced contains **identical DNA to the parent cell.**

As seen in *Figure 1111*, the amount of DNA in the original cell **doubles during replication,** although the number of chromosomes remains the same, before the chromosomes separate during cell division. The result is that each new cell formed has the same number of chromosomes and the same amount of DNA as in the original cell.

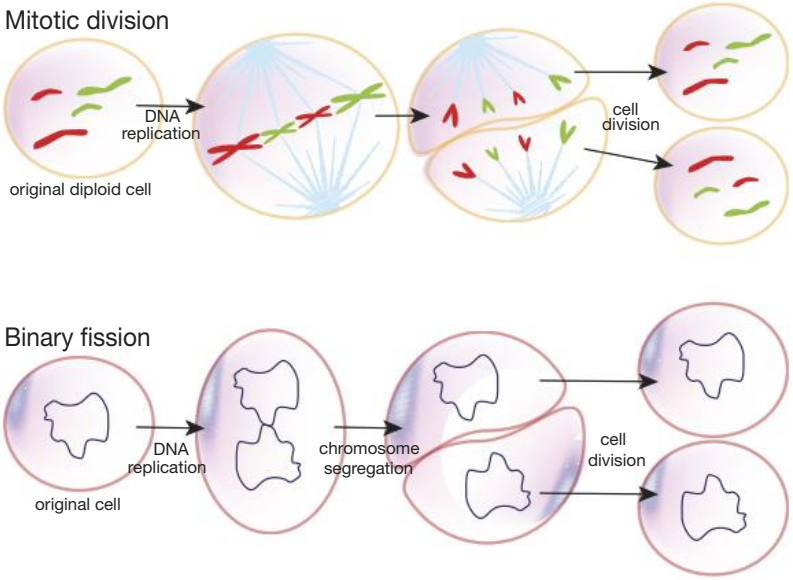


Figure 1111 DNA replication ensures that the amount of DNA doubles prior to cell division

Helpful online resources

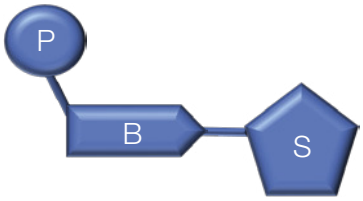
Fuse School - Global Education: DNA Replication | Genetics | Biology | FuseSchool
<https://www.youtube.com/watch?v=lSvF5-rBRGQ>

1.1 Review questions

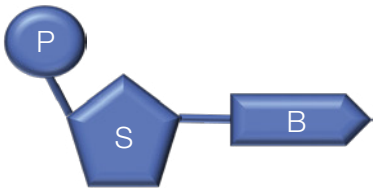
Multiple choice questions

1. Which one of the following drawings represents the correct orientation of molecules in a nucleotide?

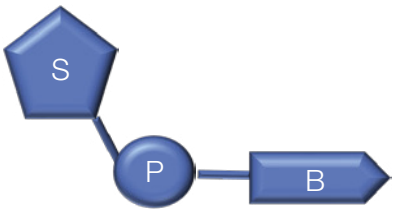
J.



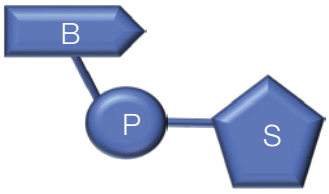
K.



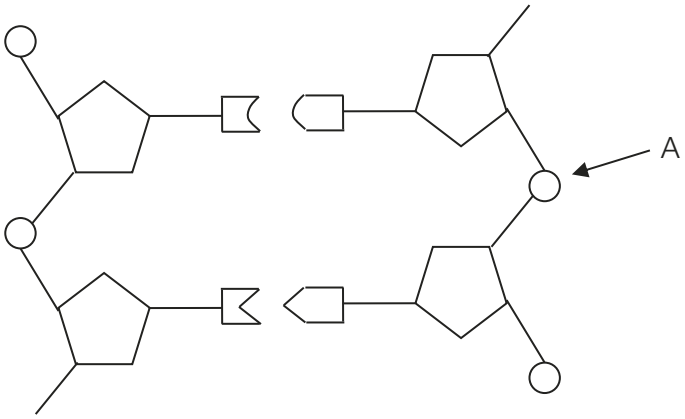
L.



M.



2. Refer to the diagram below of a molecule of DNA to answer the question that follows.



DNA molecule DNA molecule

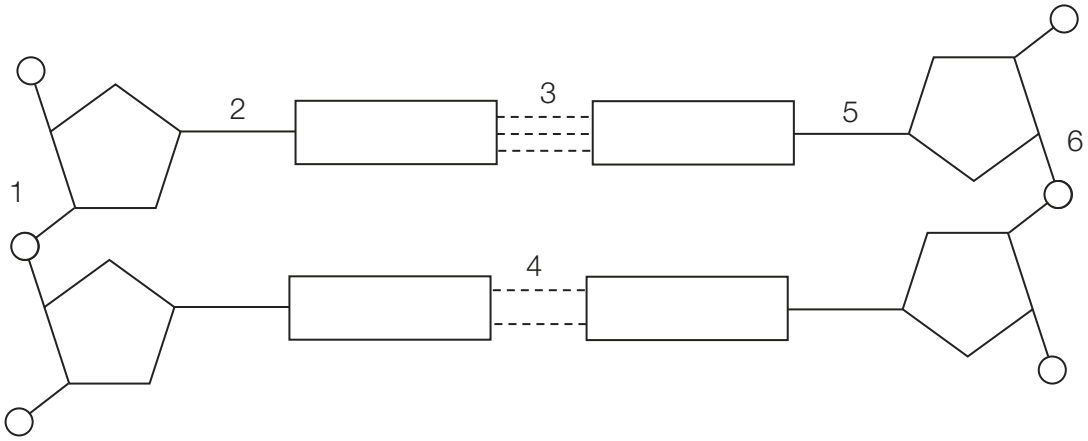
What does component A represent?

J Phosphate
K Deoxyribose sugar
L Nitrogen base
M Ribose sugar

3. Replication of DNA….

J is necessary for the process of transcription.
K occurs prior to protein synthesis.
L occurs prior to mitosis.
M does not occur in binary fission.

4. *Refer to the diagram below of part of a DNA molecule to answer the question that follows. The numbers refer to the bonds in the DNA molecule.*



During the process of semi-conservative replication which bonds are broken?

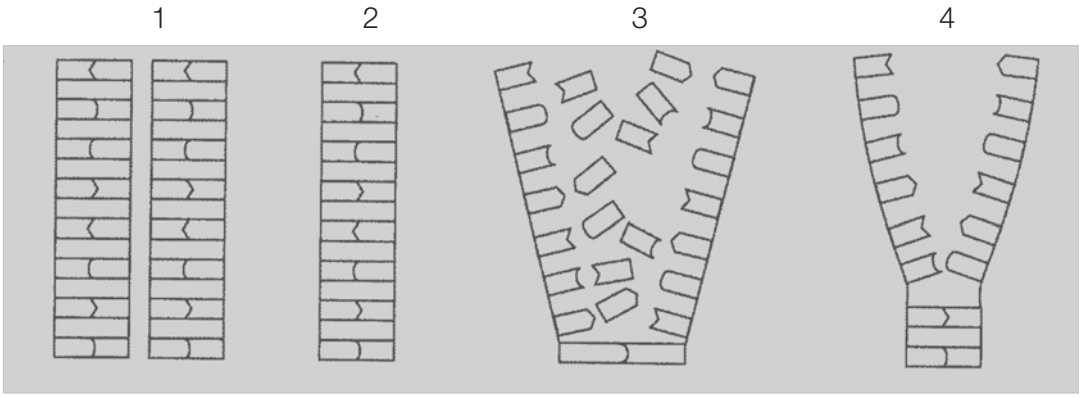
J 2 and 5

K 1, 2, 3, 4, 5 and 6

L 2, 3, 4 and 5

M 3 and 4

5. *Refer to the diagram below showing the steps in the semi-conservative process of DNA replication to answer the question that follows.*



The correct order of the steps in DNA replication is:

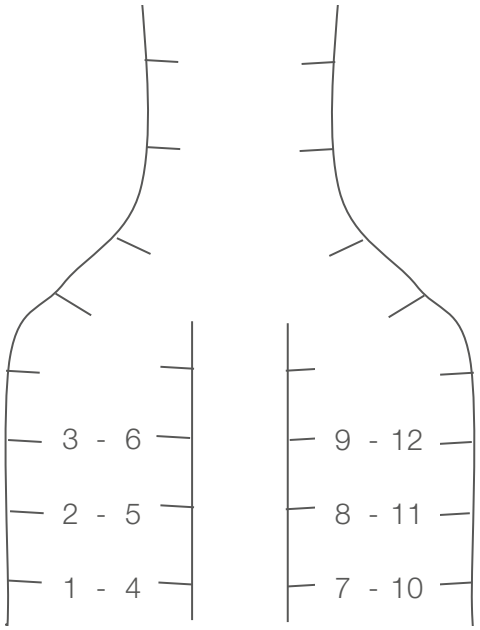
J 4 3 2 1

K 4 3 1 2

L 2 4 3 1

M 2 3 4 1

6. *Refer to the diagram below representing DNA replication to answer the question that follows.*



If bases 1, 2 and 3 respectively represent Adenine, Guanine and Thymine which other 2 bases would also represent thymine?

J 8 and 11

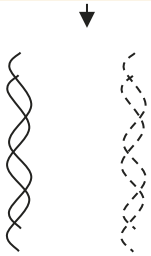
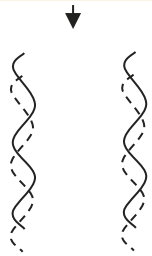
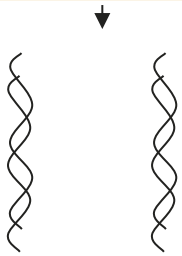
K 9 and 10

L 7 and 12

M 10 and 12

7. Refer to the diagrams below to answer the question that follows:

Four theoretical models of DNA replication

1	2	3	4
			
One round of DNA replication (newly synthesized DNA is shown as dotted lines)			
			

Which number represents the model of DNA replication that occurs in human cells?

J 1

K 2

L 3

M 4

8. Which of the following statements is correct with regards to the bonds in a DNA molecule?
   - J The bonds between the bases in a DNA molecule are strong covalent bonds.
   - K Adenine and thymine bases form two strong covalent bonds.
   - L The bonds between the bases in a DNA molecule cannot be broken.
   - M Cytosine and guanine bases form three hydrogen bonds.
9. During DNA replication, DNA polymerase adds DNA nucleotides:
   - J in the 3' to 5' direction for both exposed strands.
   - K in the 3' to 5' direction for one exposed strand and 5' to 3' direction for the other exposed strand.
   - L in the 5' to 3' direction for both exposed strands.
   - M in the 5' to 5' direction for both exposed strands.
10. Identify the true statement comparing prokaryotic and eukaryotic chromosomes.
    - J Prokaryotic chromosomes are circular and consist of a DNA molecule bound to histone proteins.
    - K Eukaryotic chromosomes are linear and consist of a DNA molecule bound to histone proteins.
    - L Mitochondria and chloroplasts of eukaryotes contain chromosomes that consist of a DNA molecule bound to histone proteins.
    - M Mitochondria and chloroplasts of eukaryotes contain a pair of circular chromosomes.

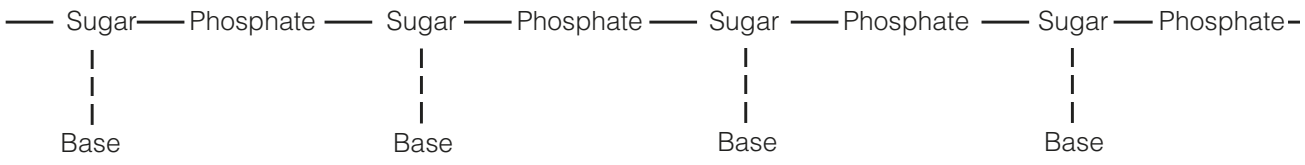
Free response questions

1. State the differences between linear and circular chromosomes, giving examples of the types of species in which each might be found.

2. Describe why chromosomes are not visible in cells that are not dividing.

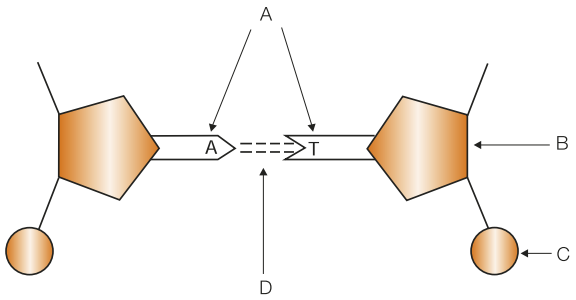
3. Name the four possible complementary base pairings that can be found in a DNA molecule.

4. *Refer to the diagram below of one strand of a DNA molecule to answer the questions that follow:*



   a) Circle one nucleotide.
   b) State the number of nucleotides shown in this diagram.

5. Refer to the figure below to identify structures A, B, C and D.



6. Explain why DNA replication is called ‘semi-conservative’.

7. It is stated that DNA is the molecule that stores and transmits genetic information.
   a) State how DNA stores information.

   b) State how DNA transmits information from parent cells to daughter cells.

8. Name two organelles, other than the nucleus, in which DNA might be found in a eukaryotic cell. Suggest one possible reason for the presence of this DNA.

9. Discuss the differences between a chromosome and a sister chromatid.

10. Explain the significance of different species having different numbers and types of chromosomes.

11. Discuss the likely reasons that chromosomes are often referred to as ‘structural units of information in organisms’.

12. A section of DNA molecule is analysed and it is found that 30% of its bases are guanine. Using your understanding of complementary base pairing, predict the percentage of bases that would be thymine.

13. The following sequence of bases was found in a segment of DNA.

    Write the sequence of bases that would be found in the complementary strand including 5' and 3' labelling.

    5' ...A A G G C T T G C... 3'

14. Watson and Crick, who were credited with discovering the structure of DNA, stated:

    "*It has not escaped our notice that the specific base pairing we have postulated, immediately suggests a possible copying mechanism for genetic material.*"

    a) Using your knowledge of DNA structure provide reasons to justify this statement.

    b) Explain why DNA replication is essential for the production of new cells.

Science as a Human Endeavour 1.1 - A model for the structure of DNA

The work of *James Watson* and *Francis Crick* in determining the structure of DNA did not involve their original research but used the findings of other scientists. It started in 1869, when *Friedrich Miescher* from Switzerland identified a compound inside cell nuclei that was unknown until that time.

Phoebus Levene, from Russia, not only identified components of nucleotides but also suggested in 1919 that nucleic acids were polymers and that their monomers were nucleotides.

Oswald Avery was born in Canada but moved to the US when he was 10 years old. He demonstrated in 1944 that DNA carried genetic information.

Erwin Chargaff from Austria (emigrated to the United States in 1935), worked on the concept that the organic base adenine always seems to be present in the same amount as thymine and that the same applies to cytosine and guanine. In a discussion with Watson and Crick in 1952, this led to the idea of complementary base pairs.

Around this time, *Linus Pauling* suggested a helix shape for some proteins, using a relatively new technique at the time, called X-ray crystallography.

Rosalind Franklin, from the UK, used the same technique and found that DNA must also have a helical shape. From her X-ray patterns, she calculated the basic dimensions of the DNA molecule. Apparently, *Maurice Wilkins* (UK) showed Franklin's findings to Watson and Crick without her knowledge or permission.

Using all this information, Watson and Crick's first realisation, using cardboard cut-outs, was that the organic bases which are found between the sugar-phosphate backbones are paired only A-T and C-G. Then, using pieces of metal, they were able to build a model of DNA and found, among other things, that the sugar-phosphate backbones would have to run in opposite directions to satisfy known facts on bond angles and the way to account for the base-pairing.

The practical approach of Watson and Crick, building a model and checking it against known information, changing it and checking again, helped them make rapid progress in the discovery of the structure of DNA. One of the actual models they made is now on display in the National Science Museum in London.

Watson, Crick, and Wilkins received the Nobel Prize for their work on DNA in 1962. Since *Rosalind Franklin* had died in 1958, she could not be nominated for her vital contribution to this breakthrough in science. Wilkins was able to share the prize because of his working relationship with *Rosalind Franklin.*

Please refer to the online resource below to help answer question 2.

1. Discuss how developing the model for the structure of DNA relied on evidence across different disciplines of science.

Our understanding of the genetic code has continued to increase, especially since the completion of the Human Genome Project, which mapped every base of all 46 chromosomes.

Scientists now want to build the entire genome to increase our understanding of the human genome even further.

2. Discuss one positive and one negative impact that could possibly arise from building the human genome.

Helpful online resources

Columbia University Irving Medical Center: Building a human genome from scratch

<https://www.youtube.com/watch?v=Y0Ani2aw6cM>

Chapter 1.2 RNA and protein synthesis

Science Understanding

A gene consists of a unique sequence of nucleotides that codes for a functional protein or an RNA molecule.

- Distinguish between exons and introns as coding and non-coding segments of DNA found in genes in eukaryotes.
- Describe how both exons and introns are transcribed but only the information contained in exons is translated to form a polypeptide in eukaryotes.

Protein synthesis involves transcription of a gene into messenger RNA (mRNA) and translation of mRNA into an amino acid sequence at the ribosomes. In eukaryotic cells, transcription occurs in the nucleus.

- Describe and illustrate the role of DNA, mRNA, transfer RNA (tRNA) and ribosomal RNA (rRNA) in transcription and translation.
- Describe the relationship between DNA codons, RNA codons, anticodons, and amino acids.
- Distinguish between coding (gene) and template strands of DNA.
- Recognise that DNA strands are directional and are read 5' to 3'.

Genes and chromosomes

A **gene** consists of a unique sequence of DNA nucleotides (or bases) that code for a **polypeptide chain**, protein or an **RNA** molecule. Genes are heritable factors that control specific characteristics (e.g. eye colour) and are located at specific points on a particular chromosome. The location of a gene on a chromosome is called a **locus.**

With the exception of sperm and ova, human cells carry about 21,000 genes. Individual chromosomes have varying numbers of genes linked to them that ranges from several hundred to a few thousand.

Genome is a term used to describe the total number of genes of an organism. The scientific study of genomes is called genomics. In 1990 an international effort was directed at mapping the entire human genome. Scientists set themselves the goal of working out the location of all of the genes on the 46 human chromosomes and the actual sequence of the DNA bases. The first draft sequence was published in 2001 and this data is now used worldwide in a range of biomedical, forensic and other related fields.

Refer to *Figure 121* which shows an approximate representation of chromosome 21 and a range of genes associated with diseases that have been linked with specific loci on this chromosome.

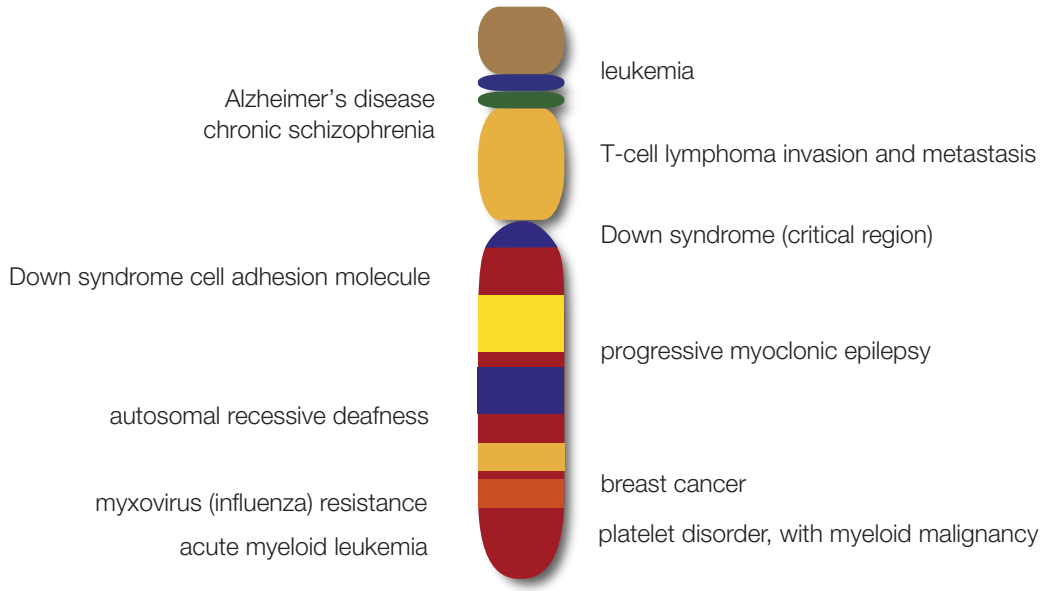


Figure 121 Some of the known genes associated with diseases on human chromosome 21

RNA

Ribonucleic acids (RNA) are present in all living cells and are essential to the expression and regulation of genes. RNA molecules are also made up of repeating units called nucleotides; however, there are a few differences between RNA and DNA nucleotides (see *Figure 122*). An RNA nucleotide consists of:

- a pentose (or 5-carbon) sugar called **ribose**
- a **phosphate** group,
- one of four **organic bases:** adenine (A), cytosine (c), guanine (G) and **uracil (U)**

When RNA molecules are synthesised, the RNA nucleotides will temporarily bond with their complementary base on the template strand of the DNA molecule. The base pairing rules for RNA are:

- Adenine only bonds to Uracil with **two** hydrogen bonds forming (A=U).
- Guanine only bonds to Cytosine with **three** hydrogen bonds forming (C≡G).

There are four major types of RNA: messenger RNA (mRNA), transfer RNA (tRNA), ribosomal RNA (rRNA) and micro RNA (miRNA) and they are all **single stranded**:

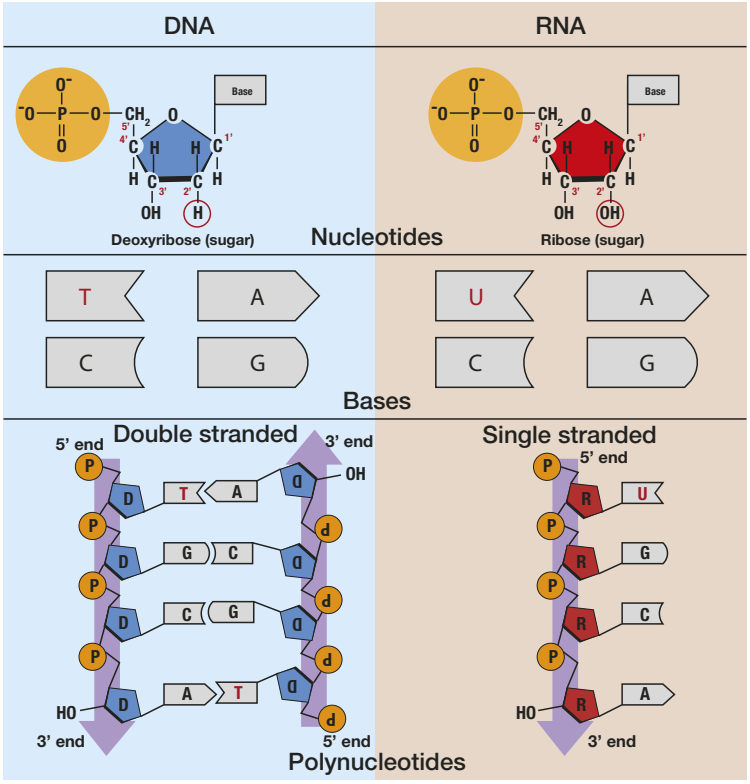


Figure 122 The similarities and differences between DNA and RNA molecules

Exons and Introns

Eukaryotic species contain two types of DNA in their genomes, **exons** and **introns**. Exons are the **coding** sequences of DNA that is translated into polypeptides/proteins. Introns are the **non-coding** sections of the DNA and do not code for polypeptides/proteins. Introns can be transcribed into RNA molecules though, such as ribosomal RNA (rRNA), transfer RNA (tRNA) and micro RNA (miRNA). The roles of these RNA molecules are explored later in this chapter. Genes consist of both introns and exons (see *Figure 129*). Genes are transcribed into **premature messenger RNA (pre-mRNA) strands** in the nucleus as part of the protein synthesis process. However, as genes consist of both introns and exons, the introns must be **spliced out** of the pre-mRNA forming **mature mRNA** before being translated into the amino acid sequence. This process is called **RNA splicing** and it ensures the synthesis of the correct sequence of amino acids, and hence protein.

The evidence to date suggests that approximately 98% of DNA in humans are introns and only about 2% are exons. Because exons are coding sections of the DNA, they are highly conserved, because changes to the code of exons could result in changes to the translated protein, affecting its function. Introns are less conserved than exons because they are non-coding.

The DNA of most prokaryote cells does not contain introns; however, they do contain exons because all prokaryotes require coding sections to code for the proteins that are essential for their survival.

Molecules involved in protein synthesis

All functional cells need to make or synthesise proteins. In this section, the structures and functions of the most important molecules involved in protein synthesis will be presented.

DNA

A summary of the structure and functions of DNA is provided below. For more detailed information, please refer to Chapter 1.1.

DNA:

- is a double helix molecule consisting of two strands of nucleotide building blocks (see *Figure 123*).
- has four organic bases: adenine (A), thymine (T), guanine (G) and cytosine (C).
- has two strands that are complementary to each other and joined by weak hydrogen bonds (A=T and C≡G).
- is directional and read 5' to 3'.
- contains genes that are hereditary units.
- has one strand that can act as a template to synthesise a molecule of mRNA and a second coding (non-template) strand (not directly involved in mRNA synthesis).

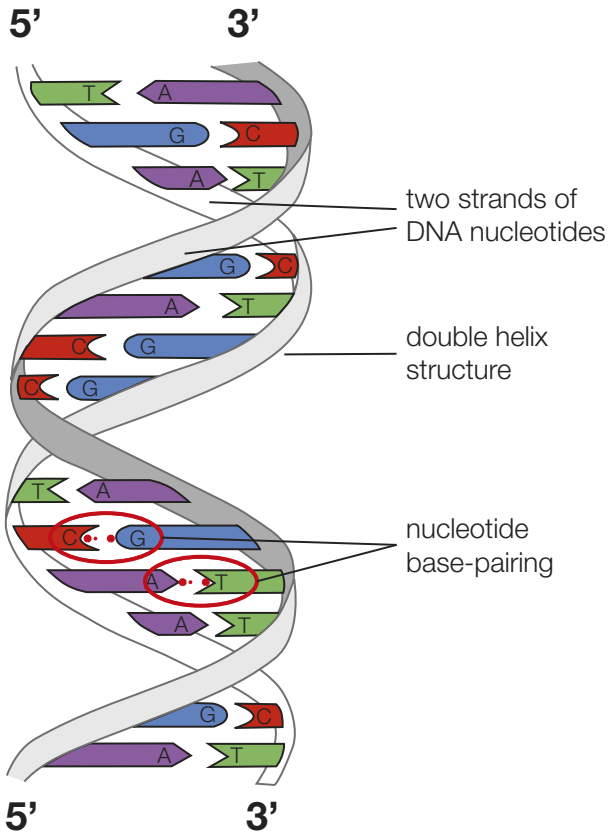


Figure 123 A section of DNA highlighting the complementary bonding of the four organic bases

Messenger RNA (mRNA)

In eukaryotic cells, mRNA is synthesised using DNA as a template in a process called transcription. This occurs in the nucleus of cells and following some post-transcriptional modification to become mature mRNA, it moves to the cytosol (the fluid part of the cytoplasm of a cell). mRNA is a single-stranded molecule consisting of a sequence of RNA nucleotides, varying in length from hundreds to thousands of nucleotides. The mRNA strand codes for a specific sequence of amino acids, as every three bases, called an RNA codon, codes for one specific amino acid (see *Figure 124*). This will be explained in greater detail later in this chapter.

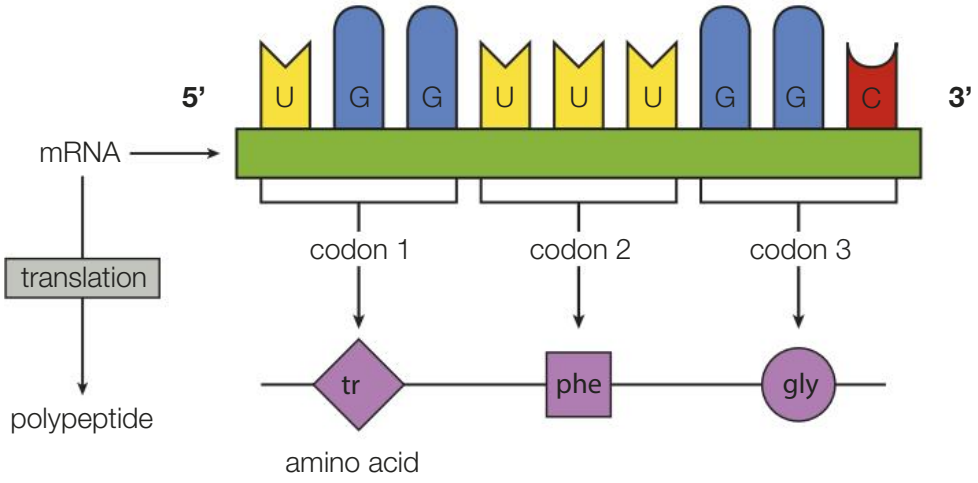


Figure 124 Messenger RNA molecules contain codons

Transfer RNA (tRNA)

A tRNA molecule is about 80 nucleotides long and has a three-dimensional clover-leaf shape (see *Figure 125*). Each tRNA molecule contains an **anticodon**, consisting of three bases that are complementary to a specific mRNA codon. tRNA also carry **a specific amino acid** at the opposite end to the anticodon. The function of a tRNA molecule is to place a specific amino acid into its correct sequence in the polypeptide being synthesised. This is specified by the sequence of bases on the mRNA. After a tRNA molecule has transferred its specific amino acid to the growing polypeptide, it can collect another corresponding amino acid in the cytosol. The attachment of an amino acid to a tRNA molecule involves enzymes that have specific shapes to ensure each of the 20 amino acids are only ever attached to their corresponding tRNA(s).

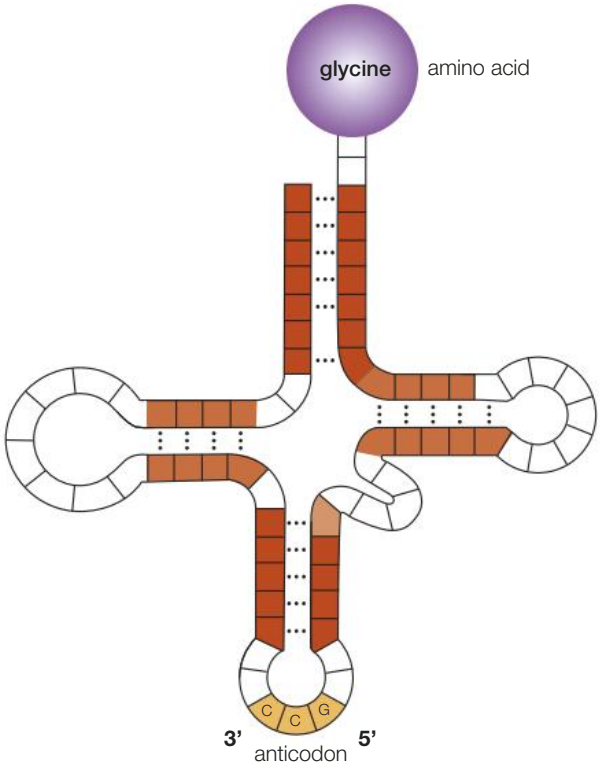


Figure 125 tRNA molecules contain an anticodon

Ribosomal RNA (rRNA)

Ribosomes are made up of **ribosomal RNA (rRNA)** and **protein** molecules. Ribosomes are the sites of translation during protein synthesis. They are often found attached to an endoplasmic reticulum (ER) in the cytoplasm, which are therefore referred to as a rough endoplasmic reticulum (RER). Ribosomes move along the mRNA strand (see *Figure 126*) translating the mRNA code into a sequence of amino acids, called a polypeptide molecule.

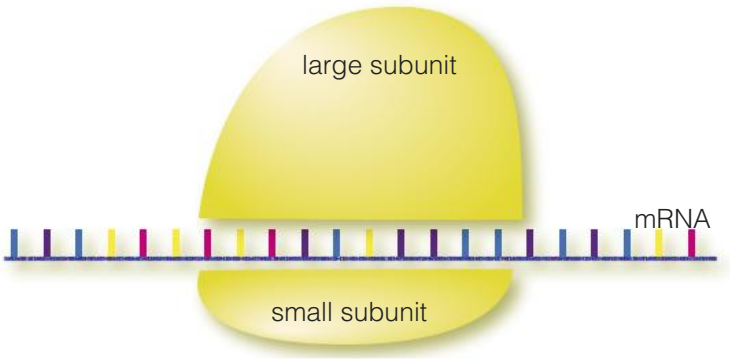


Figure 126 Translation occurs on ribosomes

MicroRNA (miRNA)

Micro RNA (miRNA) are a class of small non-coding RNA molecules consisting of approximately 22 nucleotides. They have a very important role in **regulating gene expression after transcription** has occurred. They exert their regulatory action by binding to a small section of a specific messenger RNA (mRNA) molecule, preventing it from being translated (see *Figure 127*). This process is explored further in Chapter 1.5.

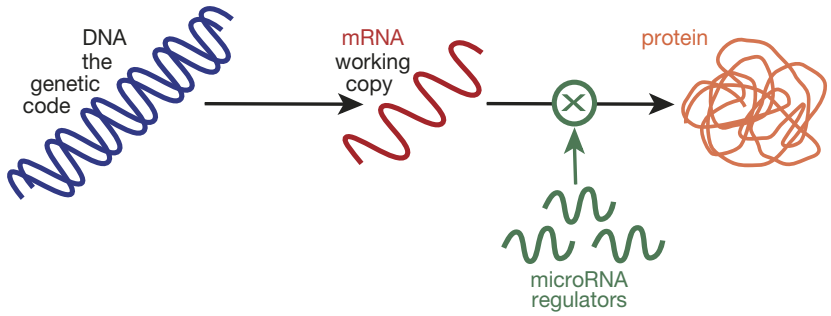


Figure 127 miRNA binds to mRNA preventing its translation into proteins

Amino Acids (aa)

There are 20 different amino acids, which are the building blocks of polypeptides and protein molecules. A polypeptide consists of a specific sequence of amino acids linked together by strong peptide bonds (see *Figure 128*). Some protein molecules consist of only one polypeptide chain folded into a precise 3-D shape; however, several others consist of more than one polypeptide chain that are linked together to form a functional protein. Proteins differ in their number, type and sequence of amino acids.

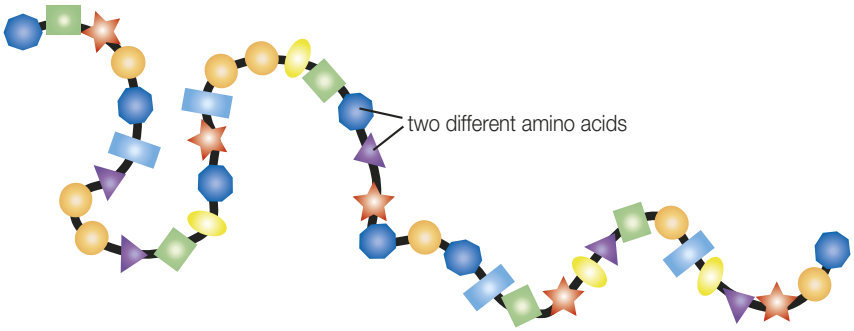


Figure 128 A short polypeptide chain

DNA strands and the relationship between codons and anticodons

DNA molecules consist of two strands (see *Figure 1210*):

- The **coding (non-template) strand**, codes for the gene of interest. The coding strand determines the correct mRNA sequence, but does not directly take part in transcription (i.e. the mRNA produced from transcription will have the same code as the coding strand, except T is replaced with U).
- The **template strand**, which is complementary to the coding strand and provides the template genetic code for a growing mRNA strand to form against (i.e. mRNA produced is complementary to the template strand, except T is replaced with U).

The coding strand consists of triplets of bases called **DNA codons**. As the template strand is complementary to the coding strand it consists of triplets of bases called **DNA anticodons**. During transcription, mRNA molecules are synthesised against the template strand in a complementary fashion and therefore consist of **mRNA codons** (which correspond with the coding strands DNA codons). During translation, tRNA molecules with complementary **anticodons** to the mRNA codons, bring specific amino acids to the growing polypeptide chain.

A summary of these triplets of bases on DNA and RNA molecules is shown in the table below:

DNA	Coding strand (DNA codons)	5'…… CGC ACC TTA ……3'
	Template strand (DNA anticodons)	3'…… GCG TGG AAT ……5'
RNA	Messenger RNA (mRNA codons)	5'…… CGC ACC UUA ……3'
	Transfer RNA (tRNA anticodons)	3'…… GCG UGG AAU ……5'
Protein	Amino acid sequence	…… arg thr leu ……

The genetic code

Triplets of bases, known as codons, are the smallest units necessary to code for all 20 amino acids. These codons make up both the coding DNA strand and mRNA strands. The use of the word codon generally refers to mRNA codons. This is because mRNA molecules transmit a copy of a gene from the coding strand, from the nucleus to the ribosomes, where the sequence of codons are translated into amino acids. This is also reflected in *Figure 129*(a). As codons are triplets of bases, the number of nucleotides that make up the mRNA must be three times the number of amino acids in the protein.

Figure 129 (a) shows the 64 possible combinations of three base sequences (4^3). The codons are from mRNA molecules and the abbreviations listed against each triplet stand for one amino acid, the names of the amino acids are shown in *Figure 129(b)*. Note that some triplets are 'stop' codons that terminate the production of the polypeptide sequence and that AUG is both a 'start' codon and a codon for the amino acid methionine.

UUU	phe	UCU	ser	UAU	tyr	UGU	cys
UUC	phe	UCC	ser	UAC	tyr	UGC	cys
UUA	leu	UCA	ser	UAA	stop	UGA	stop
UUG	leu	UCG	ser	UAG	stop	UGG	trp
CUU	leu	CCU	pro	CAU	his	CGU	arg
CUC	leu	CCC	pro	CAC	his	CGC	arg
CUA	leu	CCA	pro	CAA	gln	CGA	arg
CUG	leu	CCG	pro	CAG	gln	CGG	arg
AUU	ile	ACU	thr	AAU	asn	AGU	ser
AUC	ile	ACC	thr	AAC	asn	AGC	ser
AUA	ile	ACA	thr	AAA	lys	AGA	arg
AUG	start/met	ACG	thr	AAG	lys	AGG	arg
GUU	val	GCU	ala	GAU	asp	GGU	gly
GUC	val	GCC	ala	GAC	asp	GGC	gly
GUA	val	GCA	ala	GAA	glu	GGA	gly
GUG	val	GCG	ala	GAG	glu	GGG	gly

Figure 129 (a) The mRNA codons for all amino acids and start/stop signals

ala = alanine	gly = glycine	pro = proline
arg = arginine	his = histidine	ser = serine
asn = asparagine	ile = isoleucine	thr = threonine
asp = aspartic acid	leu = leucine	trp = tryptophan
cys = cysteine	lys = lysine	tyr = tyrosine
gln = glutamine	met = methionine	val = valine
glu = glutamic acid	phe = phenylalanine	

FIgure 129(b) The names and common abbreviations for the 20 amino acids

Helpful online resources

Amoeba Sisters: How to Read A Codon Chart

https://www.youtube.com/watch?v=LsEYgwuP6ko

Transcription

The process of **transcription** occurs in the **nucleus of a eukaryotic cell** and is where the mRNA molecule is synthesised from a gene on the DNA. It could be understood as a process in which the genetic code is transcribed or re-written from DNA into mRNA.

Transcription starts with the enzyme **RNA polymerase** separating the two strands of DNA and annealing RNA nucleotides together in the **5' to 3' direction**, as they base pair along the **DNA template strand**. This means that the RNA nucleotides are added to the 3' end of the DNA template strand (see *Figure 1210*). After transcription, the premature mRNA (pre-mRNA) dissociates from the template strand and the two DNA strands will re-form the double helix as it was originally.

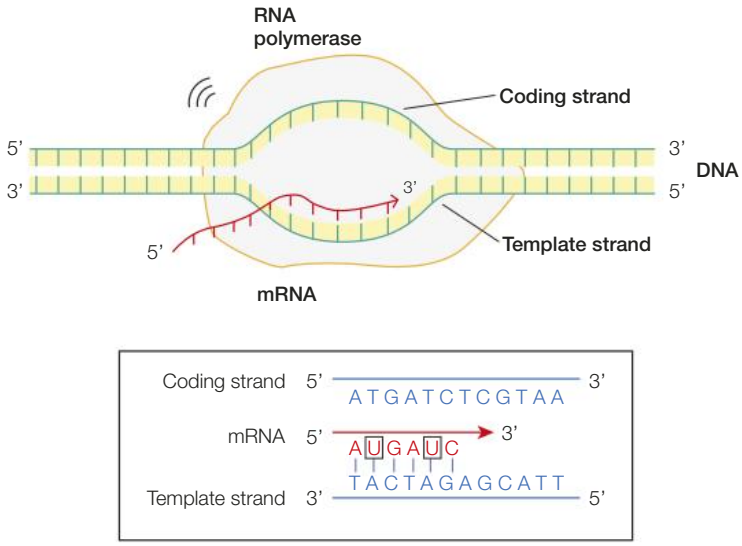


Figure 1210 During transcription, RNA nucleotides are added in the 5' to 3' direction to produce an mRNA strand

As previously noted, DNA consists of coding and non-coding regions and it is only the coding regions (or exons) that are ultimately expressed as the polypeptide. The introns present in the pre-mRNA molecule, after the initial process of transcription, need to be removed by a process called **RNA splicing**. RNA splicing occurs in the nucleus producing a mature mRNA molecule, which can then be translated into polypeptides/proteins by ribosomes in the cytoplasm.

Refer to *Figure 1211* which shows the formation of pre-mRNA and the RNA splicing necessary to remove the intron sections so that the mature mRNA is formed.

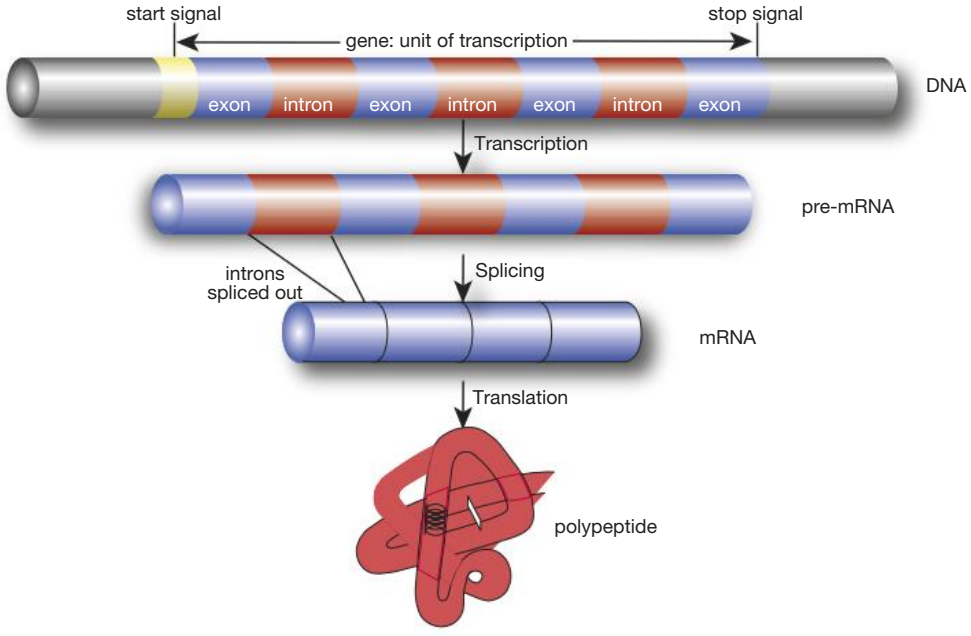


Figure 1211 The process of RNA splicing

Helpful online resources

Khan Academy: Transcription and mRNA processing | Biomolecules | MCAT | Khan Academy
<https://www.youtube.com/watch?v=JQIwwJqF5D0>

Yourgenome: From DNA to protein - 3D
<https://www.youtube.com/watch?v=gG7uCskUOrA>

Translation

In the process of **translation**, a polypeptide chain is built using a sequence of codons in a mature mRNA molecule. Translation can be broken down into three stages, as illustrated in *Figure 1212*.

1.Initiation	The use of the start codon AUG.
2. Chain elongation	The building of the amino acid sequence from the codons.
3.Termination	The completion of the mRNA sequence with a stop codon: UAG, UAA or UGA.

Figure 1212 The stages of translation

The site of translation is the ribosome in the cytoplasm. Ribosomes are generally located on a rough endoplasmic reticulum (RER) in eukaryotic cells and consist of two tRNA binding sites. **Ribosomes read the mature mRNA strand in the 5' to 3' direction** starting at the start codon (AUG). Two tRNA molecules move to the ribosome sites and bond with the mRNA strand as determined by their complementary codons and anticodons (see *Figure 1214*). The ribosome facilitates the formation of a **peptide bond** between the two amino acids. The ribosome moves along the mRNA resulting in a **growing polypeptide chain** (see *Figure 1213*). tRNA molecules continue to bring amino acids to the ribosome until a **stop codon** is reached. When a stop codon is reached, the polypeptide chain is complete and it is released from the ribosome into the RER.

Many ribosomes can move along the mRNA one after the other, leading to the synthesis of many copies of the polypeptide chain in a short period of time. This is advantageous because large numbers of proteins are required for multicellular organisms, such as insulin in humans.

The mature mRNA will continue to be translated forming multiple copies of the polypeptide chain until a **miRNA** message is sent and binds to the mature mRNA (in a complementary fashion). This deactivates the mature mRNA, either by promoting its destruction or by blocking the translation of it, preventing the expression of this gene. Refer to *Figure 1215* for a summary of the main steps involved in protein synthesis.

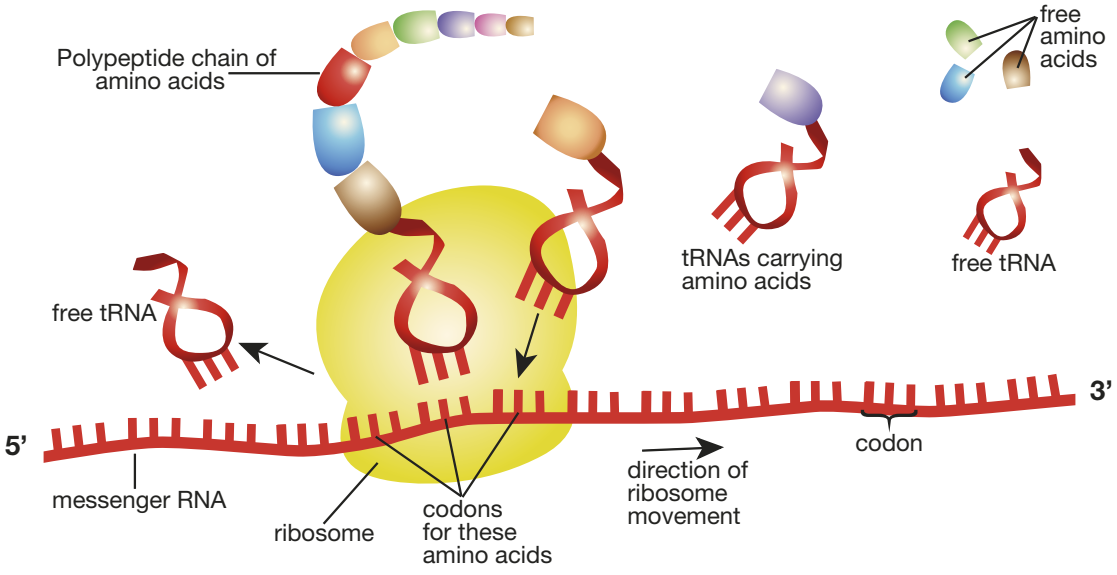


Figure 1213 The process of translation

DNA anticodon (on template strand)	mRNA codon transcribed	tRNA anti-codon	Amino acid
AAA	UUU	AAA	phenylalanine
GCG	CGC	GCG	arginine
TAT	AUA	UAU	isoleucine

Figure 1214 Examples of how specific amino acids are coded for

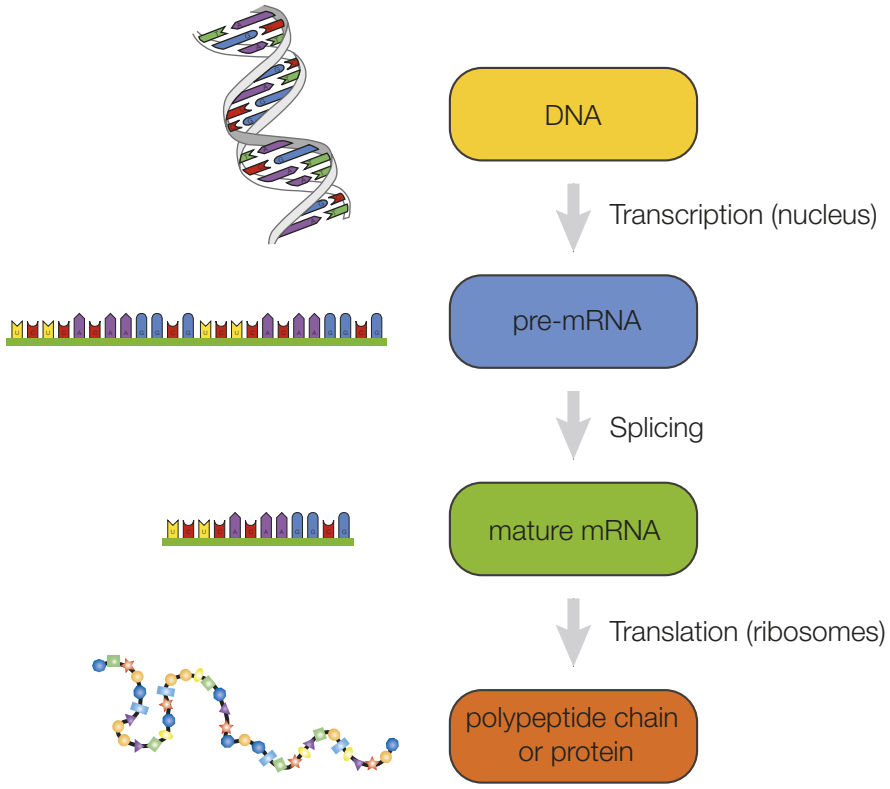


Figure 1215 The main steps involved in protein synthesis

Helpful online resources

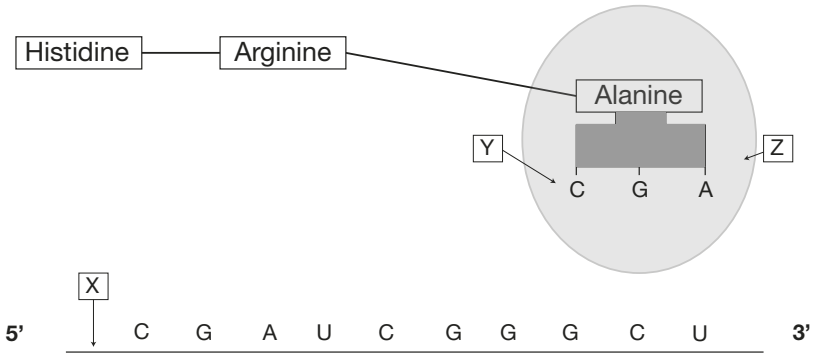
Cognito: How are Proteins Made? - Transcription and Translation Explained
<https://www.youtube.com/watch?v=ubdoUqmNF98>

Amoeba Sisters: Protein Synthesis (Updated)
<https://www.youtube.com/watch?v=oefAI2x2CQM>

1.2 Review questions

Multiple choice questions

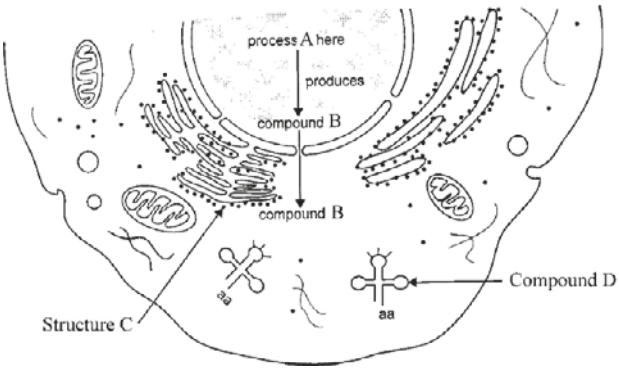
1. Which one of the following statements best describes the relationship between proteins and polypeptides?
   J Proteins are macromolecules, but polypeptides are not.
   K Proteins are a product of protein synthesis, but polypeptides are not.
   L Proteins are made up of polypeptides.
   M Polypeptides are made up of proteins.
2. *Refer to the diagram below representing a stage in the process of protein synthesis.*



Which one of the following correctly identifies X, Y and Z.

	X	Y	Z
J	DNA	codon	ribosome
K	DNA	anticodon	tRNA
L	mRNA	codon	tRNA
M	mRNA	anticodon	ribosome

3. *Refer to the diagram below of processes occurring in cells to answer the question that follows:*



Which one of the following is correct?
J Compound B binds to tRNA molecules.
K Structure C is a membrane bound organelle.
L D contains a 3 base sequence called a codon.
M Process A is translation.

4. Introns are:
   J coding sections of a gene that form pre-mRNA following RNA splicing.
   K sequences of RNA nucleotides that are spliced out to form mature mRNA in eukaryotic cells.
   L sections of a gene that remain in mature mRNA after exons have been spliced out.
   M sequences of RNA nucleotides that are spliced out to form mature mRNA in prokaryotic cells.
5. The DNA coding strand determines the amino acid sequence of a polypeptide. A function of the DNA template strand is to:
   J provide a sequence of bases needed to produce a copy of the coding strand during transcription.
   K provide a complementary code to form a mature mRNA molecule from directly.
   L directly enable translation of the message on the ribosomes.
   M provide the complementary bases for the process of transcription.
6. Semi-conservative replication differs from transcription in that:
   J transcription occurs in the nucleus, but replication occurs in the cytoplasm.
   K replication involves copying both strands of the DNA molecule, but transcription only copies one strand.
   L transcription copies the whole DNA molecule, but replication copies only a particular portion of the DNA.
   M replication involves helicase to unzip and unwind the DNA molecule.
7. *Refer to the following table, which shows the triplet code on three tRNA molecules, and the amino acid carried by each tRNA molecule.*

Triplet code on tRNA molecule	Amino acid carried by tRNA molecule
AAU	leucine
GUG	histidine
UUA	asparagine

Which one of the following is the corresponding DNA coding strand sequence for the amino acid sequence leucine, histidine and asparagine?

   J 5’ TTA CAC AAT 3’
   K 5’ AAT GTG TTA 3’
   L 5’ UUA CAC AAU 3’
   M 5’ AAU GUG UUA 3’

8. *Refer to the information in the table below comparing the β haemoglobin for humans, chimpanzees and mice to help you answer the question that follows.*

Organisms being compared	Sequence similarity (%)	
	DNA	Amino acid
Human vs chimpanzee	98.7	100
Human vs mouse	83.1	80.4

Using the information in the table above, which of the following statements is correct?

   J Chimpanzees and humans have the same number and type of genes.
   K DNA sequences in the genome of humans are the same as chimpanzees.
   L Every change to a DNA codon does not necessarily change the amino acid coded for by the codon.
   M Not all of the DNA in the coding strand of β haemoglobin in mice codes for an amino acid.

9. *Refer to the following partial sequence of amino acids from a polypeptide:*

– Asn – Gly – Pro – Arg – Ser –

1st position (5' end) ↓	2nd position U	C	A	G	3rd position (3' end) ↓
U	Phe	Ser	Tyr	Cys	U
	Phe	Ser	Tyr	Cys	C
	Leu	Ser	STOP	STOP	A
	Leu	Ser	STOP	Trp	G
C	Leu	Pro	His	Arg	U
	Leu	Pro	His	Arg	C
	Leu	Pro	Gln	Arg	A
	Leu	Pro	Gln	Arg	G
A	Ile	Thr	Asn	Ser	U
	Ile	Thr	Asn	Ser	C
	Ile	Thr	Lys	Arg	A
	Met	Thr	Lys	Arg	G
G	Val	Ala	Asp	Gly	U
	Val	Ala	Asp	Gly	C
	Val	Ala	Glu	Gly	A
	Val	Ala	Glu	Gly	G

Using the mRNA codon table above, determine the DNA template sequence that could code for this amino acid sequence:

J 5' AAC / GGA / CCC / CGC / AGU 3'

K 5' TTG / CCC / GGT / GCC / TCT 3'

L 5' AAC / GGA / CCC / CGC / AGC 3'

M 5' TTG / CCC / GGT / GCC / TCG 3'

10. Duchenne muscular dystrophy (DMD) is a genetic disease that causes muscle weakness and wastage. DMD is caused by mutations to the gene coding for the dystrophin protein.

The DMD gene contains 79 exons. Genetic testing has revealed that some individuals with DMD have a duplication of one exon. The number of nucleotides in the duplicated exon is divisible by three.

Which one of the following statements is correct based on the information above?

J The normal dystrophin protein will be shorter than the dystrophin protein produced in an individual with DMD.

K The mRNA for dystrophin of individuals with DMD will be one anticodon longer compared to normal dystrophin.

L All 79 exons will increase in length by a number of nucleotides divisible by three.

M The duplicated exon will get spliced out of the pre-mRNA with the other 79 exons in affected individual.

Free response questions

1. Explain what it means when it is stated that a particular gene is linked to a specific chromosome.

2. Genes are unique sequences of bases that code for a polypeptide or an RNA molecule.
   a) Name three different types of RNA that genes can code for and state the function of each type of RNA.

   b) Describe what it means when a gene is termed the 'unit of heredity'.

3. Exons and introns are both found in eukaryotic DNA.
   a) State the approximate percentage of each found in the human genome.

   b) Introns are often termed "junk DNA". Explain why it is naive to disregard introns as useless DNA.

4. Write the name of the appropriate nucleic acid(s) after each one of the following statements.
   a) has a double helical structure
   b) resides in the cytosol
   c) is found primarily in the nucleus of a cell
   d) contains the base thymine
   e) contains the base uracil
   f) is involved in the process of replication
   g) carries amino acids to the ribosomes
   h) has triplets of bases called codons
   i) is found in both the nucleus and cytoplasm
   j) has three bases which comprise the anticodon.

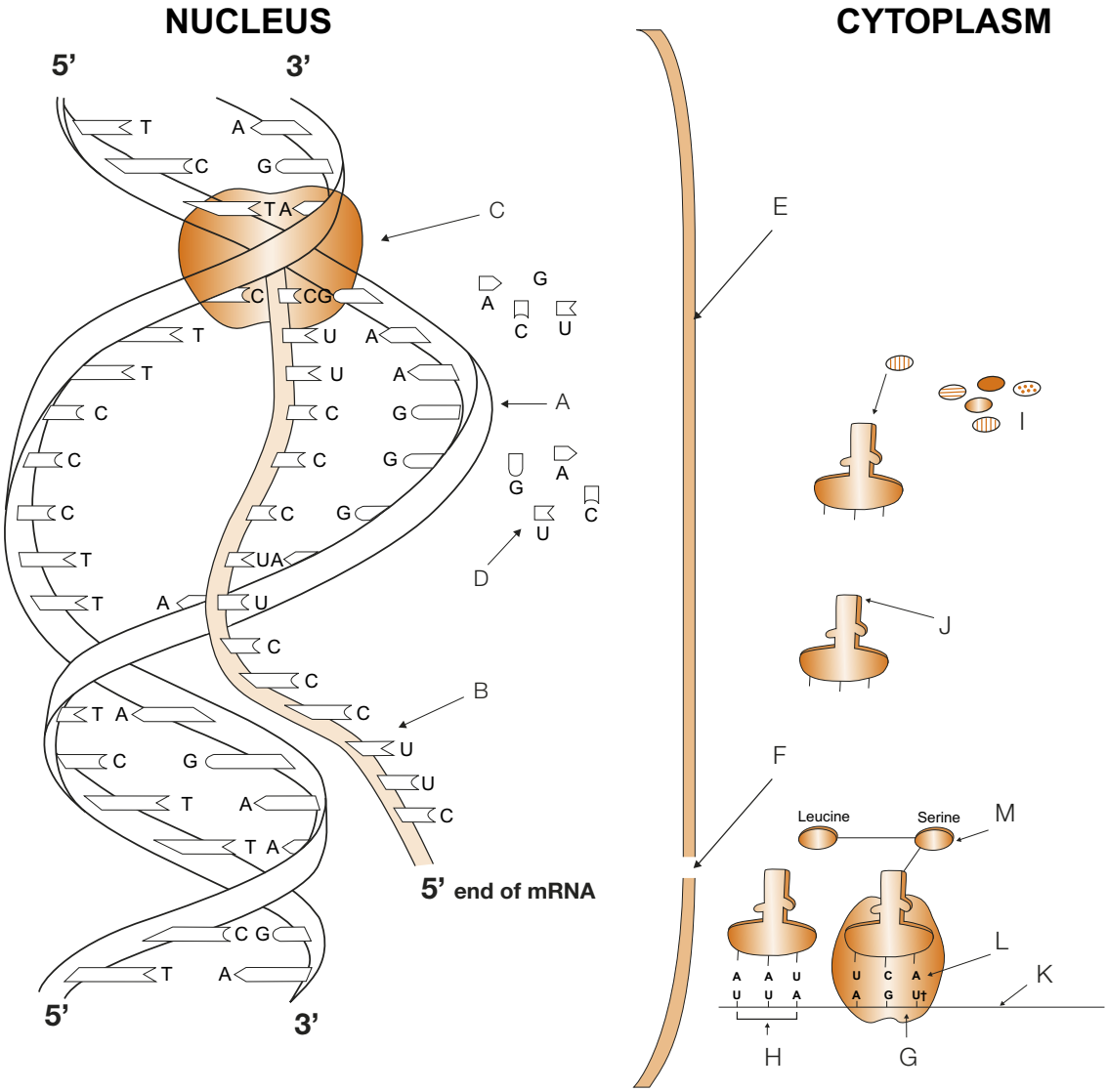
5. Complete the following base pairing rules that apply during the processes of transcription and translation:

DNA	→	mRNA	→	tRNA
A	→		→	
T	→		→	
G	→		→	
C	→		→	

6. A particular protein was found to contain 12,300 amino acids.
   a) How many codons are needed for this protein?.
   b) How many mRNA nucleotides would be required to code for this protein?.
7. Complete the following table.

DNA anticodons	AGA		
mRNA codons		CGG	
tRNA anticodons			CUG

8. Use the diagram below, which shows a simplified summary of the process of protein synthesis, to write the names and roles of the structures labelled.



A.
B.
C.
D.
E.
F.
G.
H.
I.
J.
K.
L.
M.

9. Explain how miRNA molecules silence mRNA translation.

10. DNA consists of two strands; the template and the coding strand.
    a) Outline why the coding strand is most similar to the mRNA molecule made during transcription.

    b) State two ways that the mRNA molecule would differ from the coding strand.

11. Compare the processes of transcription and DNA replication.

12. RNA splicing refers to the removal of intron sections of pre-mRNA molecules.
    a) Explain why it is necessary to remove the intron sections of pre-mRNA molecules.

    b) 'Alternative splicing' refers to the way that different combinations of exons can be joined together. Describe how different combinations of exons from one gene could code for different proteins.

13. Explain how the structure of a tRNA molecule enables it to function in the process of translation during protein synthesis.

14. Each tRNA molecule can only carry one specific amino acid but some amino acids may be transported by several different tRNA molecules. Explain how this is possible.

15. *Refer to the table of mRNA codons and their corresponding amino acid codes to answer the following question.*

UUU	phe	UCU	ser	UAU	tyr	UGU	cys
UUC	phe	UCC	ser	UAC	tyr	UGC	cys
UUA	leu	UCA	ser	UAA	stop	UGA	stop
UUG	leu	UCG	ser	UAG	stop	UGG	trp
CUU	leu	CCU	pro	CAU	his	CGU	arg
CUC	leu	CCC	pro	CAC	his	CGC	arg
CUA	leu	CCA	pro	CAA	gln	CGA	arg
CUG	leu	CCG	pro	CAG	gln	CGG	arg
AUU	ile	ACU	thr	AAU	asn	AGU	ser
AUC	ile	ACC	thr	AAC	asn	AGC	ser
AUA	ile	ACA	thr	AAA	lys	AGA	arg
AUG	start/met	ACG	thr	AAG	lys	AGG	arg
GUU	val	GCU	ala	GAU	asp	GGU	gly
GUC	val	GCC	ala	GAC	asp	GGC	gly
GUA	val	GCA	ala	GAA	glu	GGA	gly
GUG	val	GCG	ala	GAG	glu	GGG	gly

3' A G G A A G T C C G A G G G T A A G G T A 5'

Determine the corresponding sequence of amino acids for the above section of DNA coding strand.

	Nucleotide sequences and corresponding amino acid codes
DNA coding strand	
DNA template strand	
Messenger RNA	
Transfer RNA	
Amino acid code	

Chapter 1.3 Structure and function of proteins

Science Understanding

The folding of a polypeptide to form a protein with a unique three-dimensional shape is determined by its sequence of amino acids.

- Describe the factors that determine the primary, secondary, tertiary and quaternary structure of proteins.

Proteins are essential to cell structure and function.

Examples of proteins with specific shapes include enzymes, some hormones, receptor proteins, and antibodies.

- Explain why the three-dimensional structure of a protein is critical to its function.

Protein structure

Proteins are large macromolecules constructed from 20 different types of building blocks called amino acids. It has already been noted that the human genome contains around 21,000 protein-encoding genes. The number of proteins in cells, however, ranges from somewhere between 250,000 to 42 million. The number and types of proteins can vary between one individual and another and vary in one person on a daily basis.

These molecules are made up of varying combinations of the 20 different amino acids, so different proteins can vary in the number, type and sequence of the amino acids. Each protein is therefore unique, suiting its special role or function in the cell and organism.

Proteins are dynamic molecules, they are continually undergoing changes, binding to **receptors** on the cell membrane, forming complexes with other molecules, being synthesised and broken down.

Proteins have many different functions, including:

- catalysing reactions; e.g. **enzymes**
- being involved in cellular communication; e.g. **hormones**
- inactivating or neutralising invading molecules, substances or organisms (**antigens**); e.g. **antibodies**
- providing structure; e.g. hair and nails
- transport of substances; e.g. oxygen via haemoglobin
- contraction and movement; e.g. muscles
- regulation of genes; e.g. **activator proteins** and **repressor proteins**

The **unique shape** of each and every protein **determines the specific function** of that protein. These molecules consist of one or more **polypeptide** chains that are folded to produce a specific shape. Functional proteins work by recognising and binding to other molecules that are described as being complementary in structure. In studying and understanding the structure and function proteins, four different levels of structural organisation are recognised: primary, secondary, tertiary and quaternary.

Helpful online resources

FuseSchool - Global Education: What Are Proteins | Cells | Biology | FuseSchool
<https://www.youtube.com/watch?v=JGZj6DsUZhE>

Primary structure

It has been noted that during the process of translation each protein consists of a specific sequence of amino acids, the formation of which is directed by the codons on the mRNA. This linear sequence of amino acids is held together by chemical bonds called **peptide bonds** and affects all of the subsequent levels of structure; this is as a result of the interactions between the amino acids in the primary structure. Refer to *Figure 131* which represents primary structure of a chain of amino acids, otherwise known as a polypeptide.

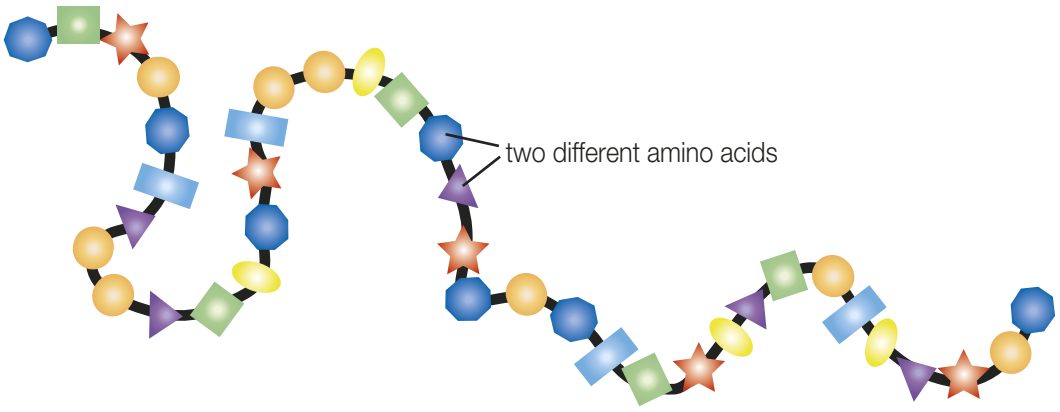


Figure 131 Primary structure of a polypeptide

Secondary structure

The secondary structure is the localised **coiling or folding** of the polypeptide chain and is caused by **hydrogen bonding between amino acids**. This level of structure can be seen as an intermediate between the primary structure and before the polypeptide folds into its three-dimensional (3-D) shape associated with the tertiary structure.

The two most common shapes are the **alpha (α) helix (coiling)** and the **beta (β) pleated sheet (folding).** Myoglobin is an example of a protein that mostly consists of alpha helices. Many antibodies have a structure mostly made up of beta pleated sheets.

Refer to *Figure 132* (a) and (b) which shows a representation of these two common shapes.

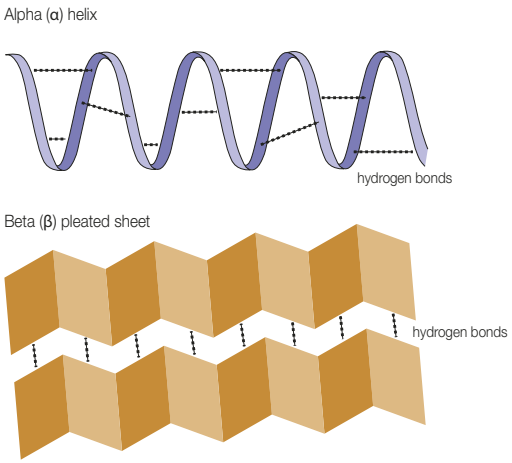


Figure 132 (a) and (b)
Secondary structures of proteins

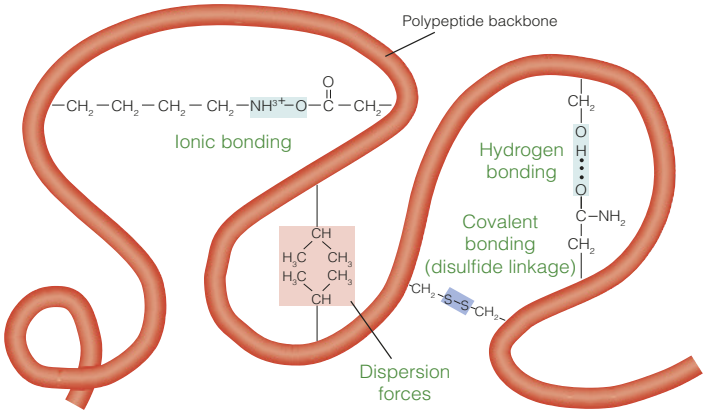


Figure 133 Tertiary structure results from complex interactions between many parts of the protein

Tertiary structure

This refers to the **3-D shape** of the polypeptide caused by the way the polypeptide chain is folded. The tertiary structure forms spontaneously because of **forces of attractions between amino acids** in the polypeptide chain. There are multiple types of interactions between the amino acids that contribute to the tertiary structure including hydrogen bonds, ionic bonds and strong covalent disulfide bonds (see *Figure 133*). Proteins which have a folded shape such as hormones are called globular proteins. It is the special 3-D shapes with their unique folds, grooves and clefts which determines the function of the proteins; therefore, the 3-D structure of a protein is critical to its function.

Quaternary structure

Many proteins consist of multiple polypeptide chains and therefore require multiple genes to code for them. If the **protein consists of two or more polypeptide chains**, the quaternary structure forms from the polypeptides chemically bonding together. Globular proteins are good examples of proteins that possess this quaternary structure; for example, haemoglobin is made up of four polypeptide chains, two alpha and two beta chains.

Refer to *Figure 134* which illustrates a representation of the four levels of structure seen in haemoglobin. The first three diagrams refer to the structure of one of the polypeptide chains of haemoglobin. *Figure 135* demonstrates an analogy for the four levels of protein structure using the English language to help with your understanding.

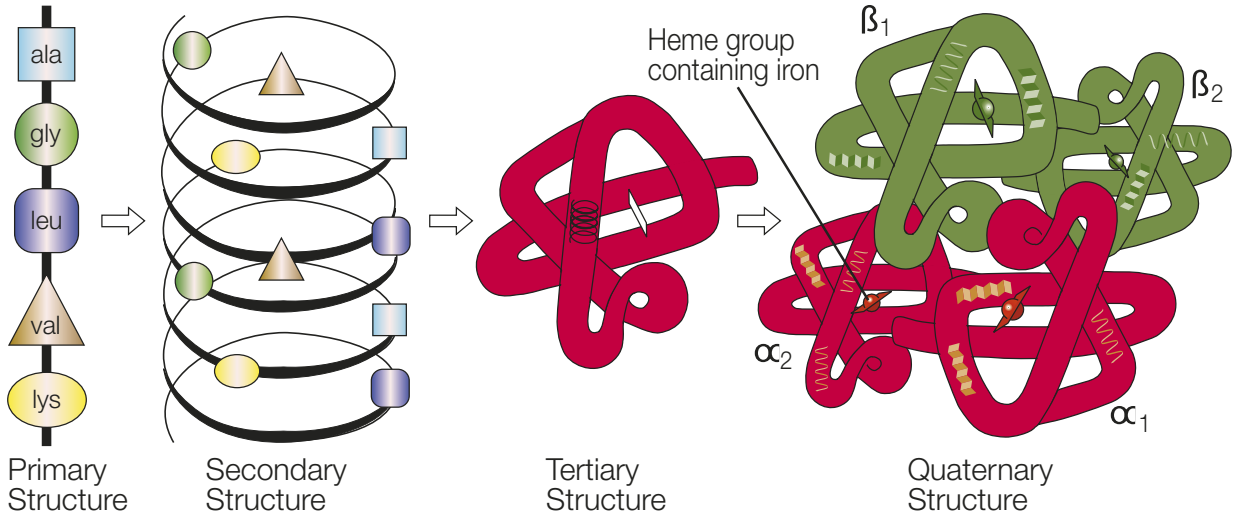


Figure 134 Levels of structure in polypeptides and proteins

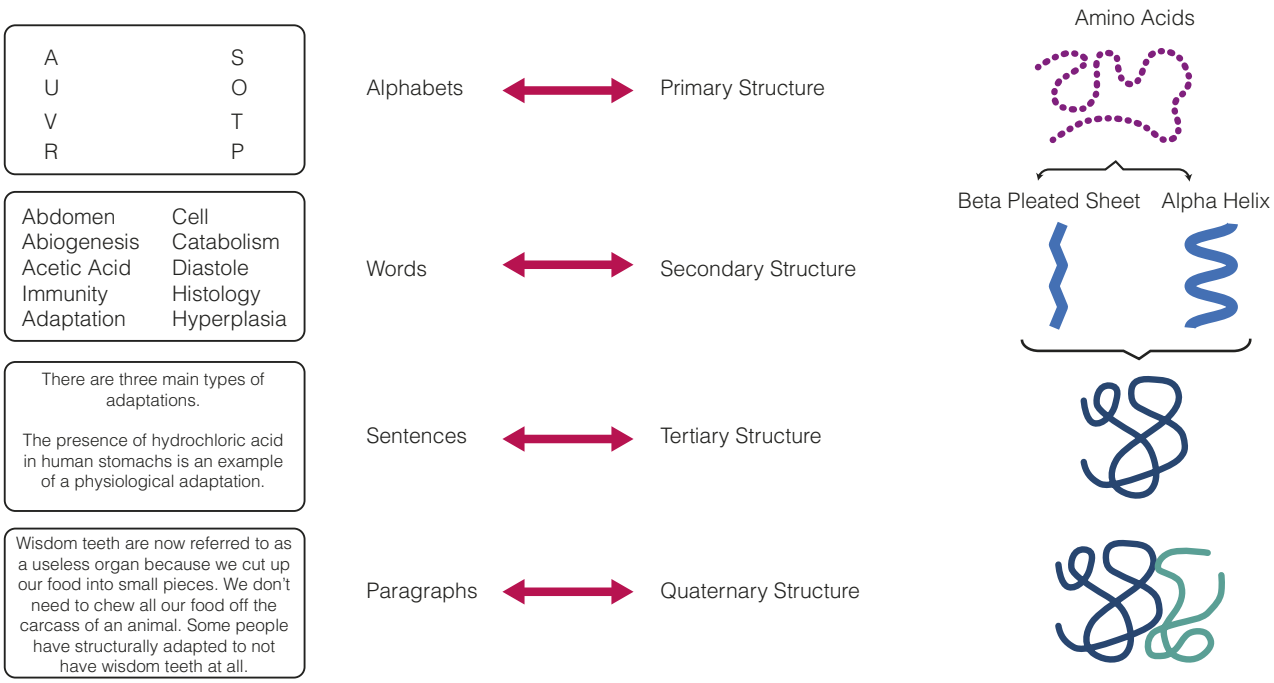


Figure 135 An analogy for the four levels of protein structure

Some different proteins

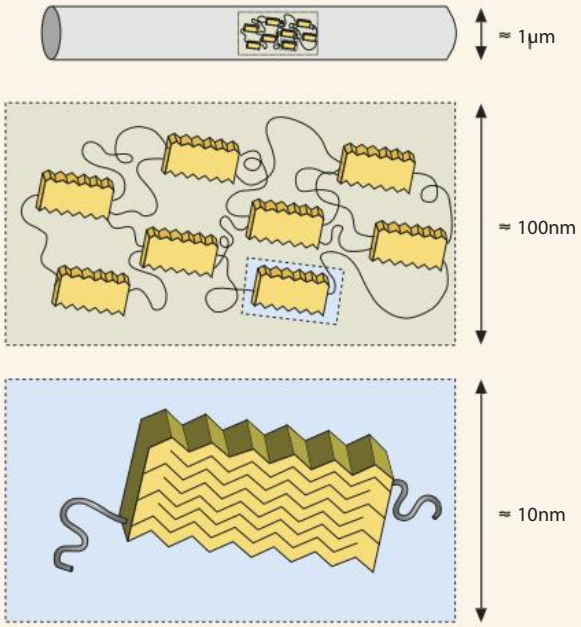
All enzymes are globular proteins.

Rubisco is the name for the enzyme officially known as 'Ribulose biphosphate carboxylase'. It catalyses one of the reactions in photosynthesis that involves carbon dioxide.

Insulin is a protein hormone. It allows cells in the liver, muscles and fat tissue to take up glucose from blood for use in the cell.

Immunoglobulins are globular proteins, also known as antibodies. They are released in response to the presence of a foreign substance, cell or virus (antigen) and bind to it. This inactivates the antigen and is part of the immune system.

Rhodopsin is a chromoprotein (a protein attached to a pigment) found in rods in the human eye. In the presence of light , rhodopsin changes into retinal (the pigment) and opsin (the protein). This change causes a nerve impulse to be sent to the brain which interprets it as seeing light. In the dark, rhodopsin is reformed.



Collagen is a fibrous, structural protein which makes up tendons and is an important part of human skin.

Haemoglobin is the protein responsible for transporting most of the oxygen in human blood.

Fibroin or spider silk is a structural protein with many sections of beta pleated sheet in its secondary structure. *Refer to the Figures above (N.B. 1000nm = 1µm)*.

Helpful online resources

Amoeba Sisters: Protein Structure and Folding

<https://www.youtube.com/watch?v=hok2hyED9go>

Functional Proteins

Enzymes

Most enzymes are globular protein molecules that increase the rate of a specific chemical reaction, or catalyse it. Enzymes have an active site, formed by the folding and binding of the polypeptide chain, to which the substrate(s) or reactant(s) bind. Due to the shape of the active site, enzymes are said to possess **specificity** which means that usually each enzyme only has one substrate. Refer to *Figure 136*. A sequence of enzyme-catalysed chemical reactions in the cells of a living organism is called a metabolic pathway. Enzymes will be explored further in Chapter 1.4.

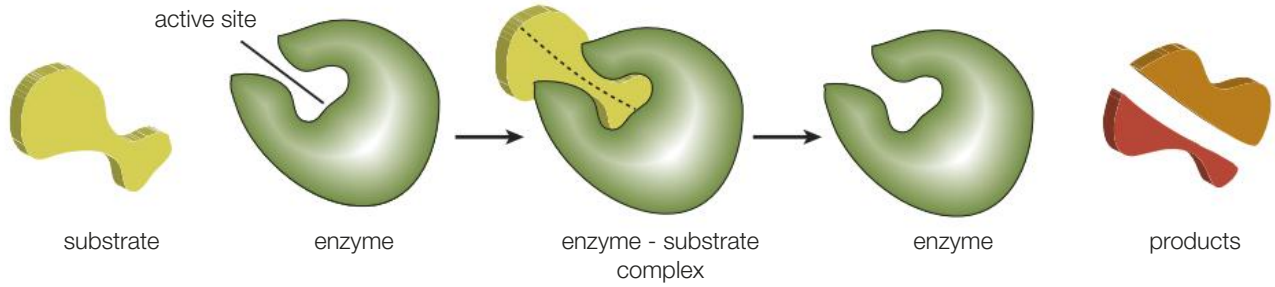


Figure 136 The action of an enzyme

Receptor proteins and peptide/protein hormones

Proteins are found on both the inner and outer surface of cell membranes and play a major role in membrane structure and function. Some of these are receptor proteins that have a specific shape that will bind to one specific messenger molecule with a complementary shape; for example, a specific hormone.

Hormones are important chemical messenger molecules used by both plants and animals. Hundreds of hormones regulate processes such as growth, development, response to chemicals or other stimuli.

Not all hormones are proteins, some are lipid-based, but many are and it is the differences in their primary, secondary, tertiary and quaternary structures that allow them to bind to specific cell membrane receptors and bring about their action. Examples of human hormones include thyroxine which is involved in metabolic activity and insulin which regulates glucose concentration in the blood.

Hormone signalling in humans and other vertebrates is a form of cell communication (see *Figure 137*) and involves the following processes:

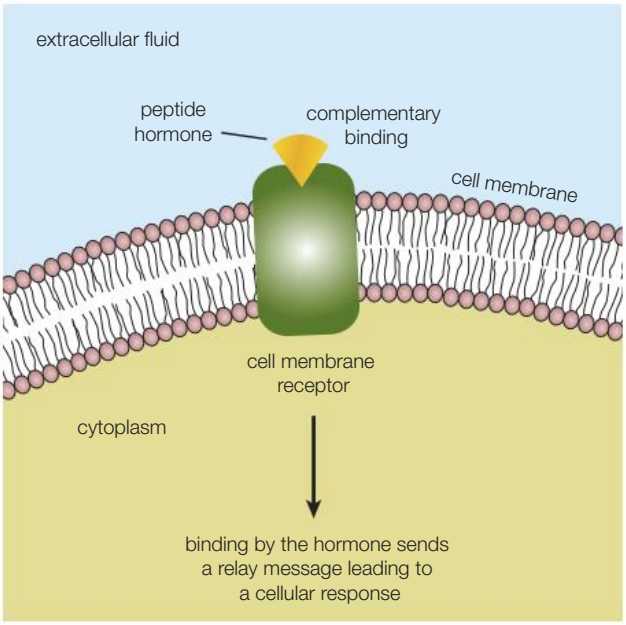


Figure 137 A typical hormone signalling pathway

- synthesis of the hormone
- storage of the hormone in a gland, then secretion into the bloodstream
- transport via the blood to certain types of cells called target cells
- binding to a complementary receptor protein in the cell membrane of the target cell
- relaying a message to the cell nucleus which leads to a cellular response (e.g. gene expression is altered to produce specific protein(s) via protein synthesis)

Antibodies

Antigens are foreign molecules (non-self) usually found embedded in the surface of viruses or cells e.g. bacteria. Special cells, called lymphocytes, produce protein molecules called antibodies as part of the specific defence mechanisms of many organisms and these act by binding to specific antigens in a complementary manner, leading to their deactivation or neutralisation. For more information on this topic refer to Chapters 2.7 and 2.8 in the Stage 1 (Year 11) Essentials Biology Workbook.

It is the particular 3-D shape of the quaternary structure of the antibody that enables it to bind with, and inactivate the antigen.

Refer to *Figures 138* illustrating antibody-antigen binding.

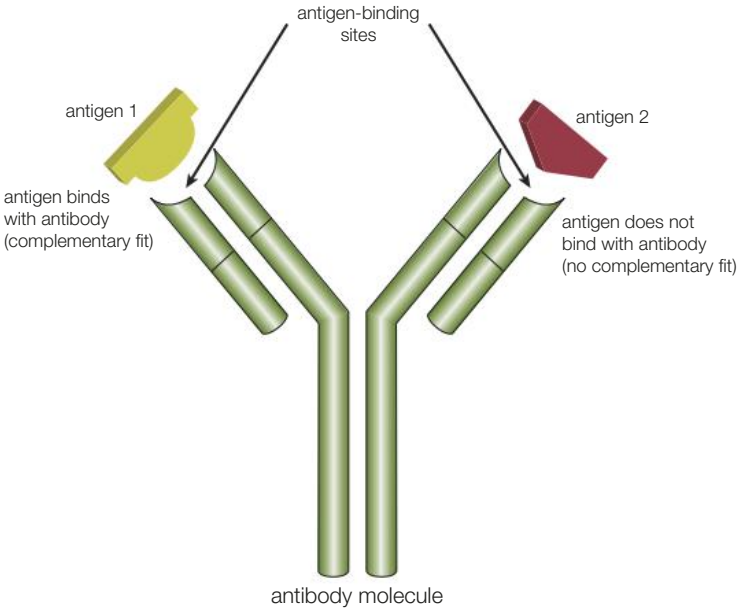


Figure 138 Antibody - antigen binding

Regulatory proteins

This is an important area of contemporary research. Cells have many mechanisms for regulating or controlling either the switching on or off of genes. Genes are switched on when transcription is able to take place and switched off when transcription is prevented. Proteins called repressors bind to sections of DNA near genes, called promoters, which prevents RNA polymerase from binding, thus preventing transcription. The binding of other proteins, called activators, to DNA near genes assists the binding of RNA polymerase and therefore promotes transcription. Regulation of genes is discussed in more detail in Chapter 1.5. Refer to *Figure 139,* which illustrates the action of a repressor.

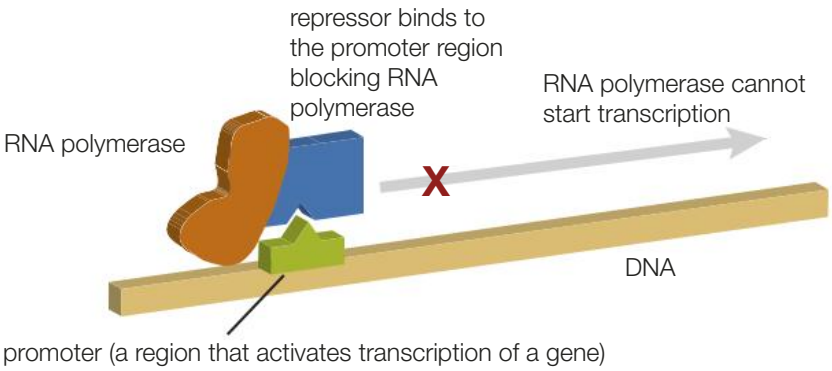


Figure 139 How a repressor works

Proteomics

The term **proteome** is used to describe all of the proteins found in a cell or organism at a specific time. A cell will need different proteins at different times throughout the day and its life. It will differ from cell to cell; a cell on the scalp responsible for hair protein will produce a different set of proteins compared to gastric gland cell in the stomach. Each cell will use or express a specific section of the genome to make the proteins it requires.

The term proteomics refers to the study of proteins, including the abundance, variations and modifications to proteins. **Biomarkers** are molecules, such as proteins found in blood and often give indications of abnormal processes or disease. It is often stated that genes are the 'blueprint' of the cell, but the proteins they code for are the molecules of structure and function in cells and organisms.

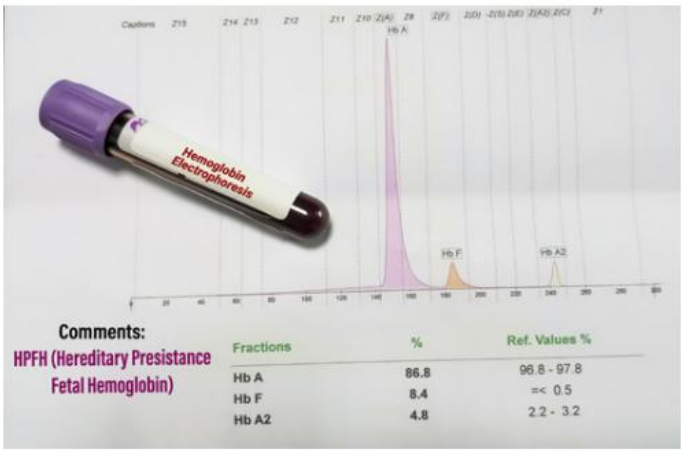


Figure 1310 A haemoglobin electrophoresis report from a blood sample

A range of tools and technologies are used in order to understand proteins and their functions. Some of these include electrophoresis, mass spectrometry, protein microarrays and various nanotechnologies. Refer to *Figure 1310* which shows a proteomics application of testing blood samples for specific proteins, in this case haemoglobin.

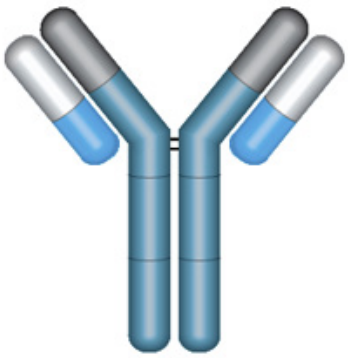
Helpful online resources

BioTechniques: Introducing advanced proteomic analysis
<https://www.youtube.com/watch?v=k2ie0sWZKkc>

ARC CIPPS: What is proteomics?
<https://www.youtube.com/watch?v=fQXbTaQNolk>

1.3 Review questions

Multiple choice questions



1. *Refer to the diagram to the right to answer the following question:*

   The function of this protein is:

   J to catalyse reactions.

   K to bind to specific messenger and communicate message to cell nucleus.

   L to have a specific shape determined by the genetic code.

   M to recognise specific antigens.

2. Which one of the following statements is **not** correct about the secondary structure of proteins?

   The secondary structure of proteins:

   J involves the folding and coiling of localised sections of the polypeptide.

   K contains α sheets and β helices.

   L helps determine the protein's function.

   M is caused by hydrogen bonds between amino acids.

3. Which one of the following statements is the most correct regarding protein structure?

   J Proteins consist of one polypeptide chain.

   K A change in amino acid sequence has no effect on protein structure.

   L Every hormone has a specific shape determined by the unique folding of its polypeptide chain(s).

   M The tertiary structure of proteins is determined by forces of attractions between amino acids in the polypeptide chain.

4. Which one of the following hormones would **not** contain peptide bonds?

   J Insulin

   K Oestrogen

   L Antidiuretic hormone (ADH)

   M Glucagon.

5. *Refer to the diagram to the right which shows the structure of the haemoglobin protein, to answer the following question:*

   Which one of the following statements about haemoglobin is correct?

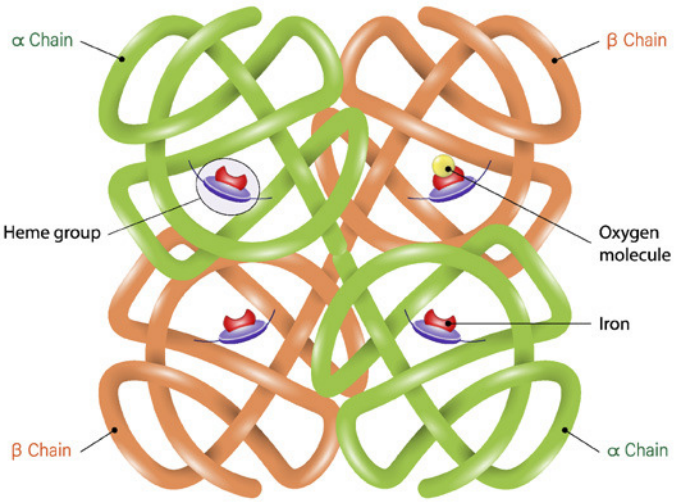
   Haemoglobin:

   J consists of four polypeptide chains and therefore is coded for by four genes.

   K does not have a quaternary structure.

   L is coded for by two genes.

   M is involved in regulating gene expression.



Free response questions

1. Describe what it means to say that protein structure is linked to the function of that protein. Give an example to illustrate your answer.

2. Briefly outline the main factors that determine the primary, secondary, tertiary and quaternary structure of proteins.

3. Describe why some proteins do not have a quaternary structure.

4. Haemoglobin is a protein molecule that consists of 4 polypeptide chains; 2 alpha and 2 beta chains.
   a) How many genes are required to code for two molecules of haemoglobin?

   b) Describe what is required to form the quaternary structure of this molecule.

5. Explain how it is possible for each different protein molecule to have a unique primary structure.

6. Describe how it is possible for a cell to make hundreds of thousands of different protein using only 20 amino acids.

7. State four functions of proteins in cells and give an example of each.

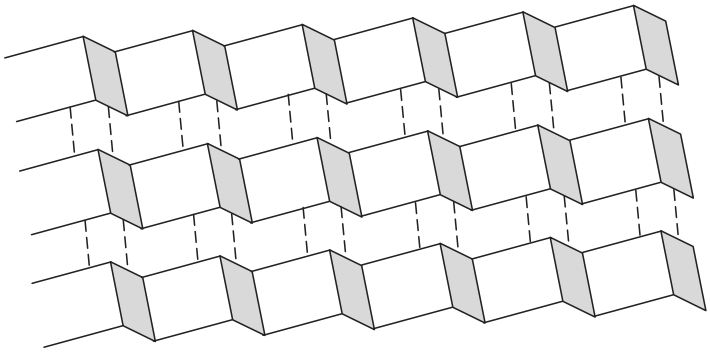
8. Explain how it is possible for the estimated 21,000 genes in the human genome to code for over 250,000 different protein molecules.

9. Explain how the different shapes and chemical properties of hormones enable these molecules to control metabolic pathways.

10. Adrenalin is a hormone that binds to receptor proteins in the cell membrane of target cells. This binding causes glycogen stored in the cells to be broken down to form glucose. Explain why adrenaline can act on liver cells and not all cells in the organism.

11. Foreign substances, such as poisons that have been ingested or surface molecules on bacteria and viruses, are called antigens. Detection of antigens in a human stimulates lymphocyte cells to release antibodies. Explain how antibodies inactivate invaders, such as bacteria and viruses.

12. A lysozyme is a compact enzyme made up of 129 amino acids. This enzyme is found secreted in tears and serves as a mild anti-bacterial agent by breaking down polysaccharides, which is a component of some bacterial cell walls. Its secondary structure is characterized by five regions of beta pleated sheets, as represented in the diagram below.



a) Describe the importance of the primary structure in determining the pleated sheet arrangement, as shown in the diagram above.

b) Explain how this secondary structure is important for the function of the lysozyme enzyme.

13. Explain the following observations:

a) All cells have the same DNA but are capable of producing different types of protein molecules.

b) The same cell produces different proteins at different times.

14. Refer to the diagram below of a metabolic pathway to answer the questions that follow:

A → B → C → D

a) Suggest how the final product might act as a repressor protein on a gene to stop the production of molecule A.

b) Predict how this might be an advantage to the cell in which this interaction occurs.

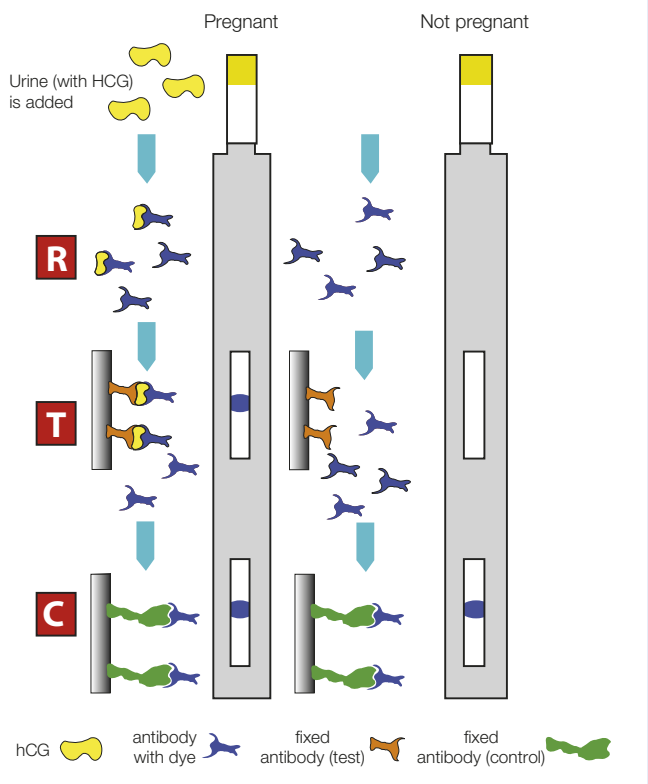
Science as a Human Endeavour 1.3 - Pregnancy testing

Monoclonal antibodies are antibodies that have been produced in the lab by a culture of identical cells (or clones), all of which are products of a single cell. This means they will only bind to or recognise one antigen. Monoclonal antibodies have a broad range of applications, including to predict whether or not a woman is pregnant; for example, as part of a home pregnancy test. This is because monoclonal antibodies can be produced that recognise a hormone in a woman's blood (antigen) that is only produced by an early embryo called HCG (human chorionic gonadotrophin).

The method used to make a pregnancy kit, which makes a reliable prediction of pregnancy, is as follows:

1. Obtain and purify monoclonal antibodies that recognise HCG.
2. Fix the monoclonal antibodies on a testing stick/strip.
3. Add urine from the woman being tested to the stick/strip.

If HCG is present in the woman's urine it will bind to the monoclonal antibodies on the stick/strip. The test is designed so that the monoclonal antibody-HCG binding will produce a specific colour. Refer to the diagram below and the text that follows.



In the diagram, three regions are visible: R (Reaction), T (Test) and C (Control).

Region R: A monoclonal antibody is placed here that will react to HCG. This antibody has a colour attached to it. If HCG is present in the urine, it will bind to the antibody. Either way, the urine continues to be drawn along the stick to region C, carrying along the antibody with the attached colour.

Region T: Here immobilised (fixed) antibodies to HCG are found. If HCG is present, it will attach to the antibodies on the strip, together with the antibody and the colour it picked up in region R. The antibodies and the colour will be concentrated into a visible line.

If there is no HCG, the antibodies from region R will simply move on with the urine to region C.

Region C: Here there are immobilised antibodies against the antibodies that were placed in region R. Any antibody that was not bound in region T (which would be all of them if the woman is not pregnant), will bind here and concentrate the colour into a visible line to show that the test is working properly.

Science as a Human Endeavour 1.3 - Pregnancy testing (continued)

You may need to refer to the online resources below to answer the questions that follow.

1. Using knowledge of protein structure, explain how scientific knowledge and understanding has enabled women to carry out a reliable home pregnancy test.

2. Discuss another way that this antibody based technology could be applied to benefit society.

3. Discuss some limitations that might be associated with the reliability of the test.

Helpful online resources

Cognito: GCSE Biology - How do Pregnancy Tests Work?
<https://www.youtube.com/watch?v=umRe7GBJ5GE>

TED-Ed: How do pregnancy tests work? - Tien Nguyen
<https://www.youtube.com/watch?v=aOfWTscU8YM>

Chapter 1.4 Enzymes

Science Understanding

Enzymes are specific for their substrate and increase reaction rates by lowering activation energy.

- Describe the induced-fit model of enzyme–substrate binding.

Enzymes have specific functions and are affected by factors including:

- temperature
- pH
- presence of inhibitors.

The rate of an enzyme-controlled reaction is affected by:

- concentrations of reactants
- concentration of the enzyme.

Enzyme-substrate binding

An **enzyme** is a globular protein that speeds up or catalyses a specific chemical reaction in cells. An enzyme is therefore a **catalyst**, speeding up the rate of reaction without any other changes. During enzyme-catalysed reactions, molecules of a substance called **reactant(s)** (or substrates), are chemically converted into one or more new substances called **product(s)**. This involves the breaking of chemical bonds in the substrate and the formation of new bonds in the products. Enzymes are **not used up in the reactions** they catalyse.

After a product is formed, it is released by the enzyme, allowing the enzyme to be used over and over again. The region of the enzyme's surface to which the substrate binds is called the **active site**. This action is referred to as enzyme-substrate binding and is due to the active site's shape to which usually only one specifically-shaped substrate can bind. The shapes of the enzyme and its substrate are said to be **complementary**.

In order for any two molecules to react, they need to collide with sufficient energy and this is usually only possible with the help of enzymes. Generally, enzymes are able to catalyse chemical reactions because, as a result of enzyme-substrate binding, substrate molecules are brought into an orientation that facilitates the breaking and formation of chemical bonds. Bonds in the substrate are put under stress which lowers the amount of energy needed to break them and therefore the amount of energy needed for the reaction to proceed. *An example is shown in the following reaction and in Figure 141:*

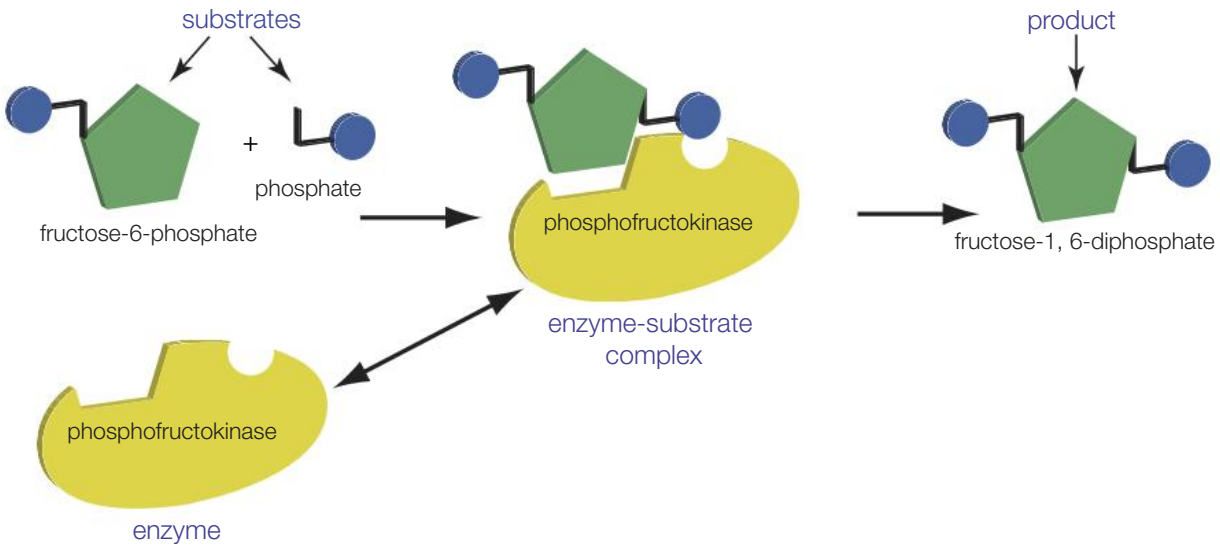


Figure 141 An example of an enzyme-catalysed reaction

In this reaction, the substrates (i.e. fructose-6-phosphate and a phosphate molecule) are complementary to the active site of the enzyme phosphofructokinase. This means they can bind to the enzyme at the active site and thus be chemically changed to form the product fructose-1,6-diphosphate. Refer to *Figure 141*.

Enzyme specificity

Enzymes are specific for their substrate. The complementary binding of one specific substrate to the active site of one type of enzyme is known as enzyme **specificity**. This means only one substrate can be complementary to the active site or 'recognised' by the enzyme

Refer to *Figure 142* showing a 3-D model representing an enzyme, which shows a substrate molecule about to interact with the active site.

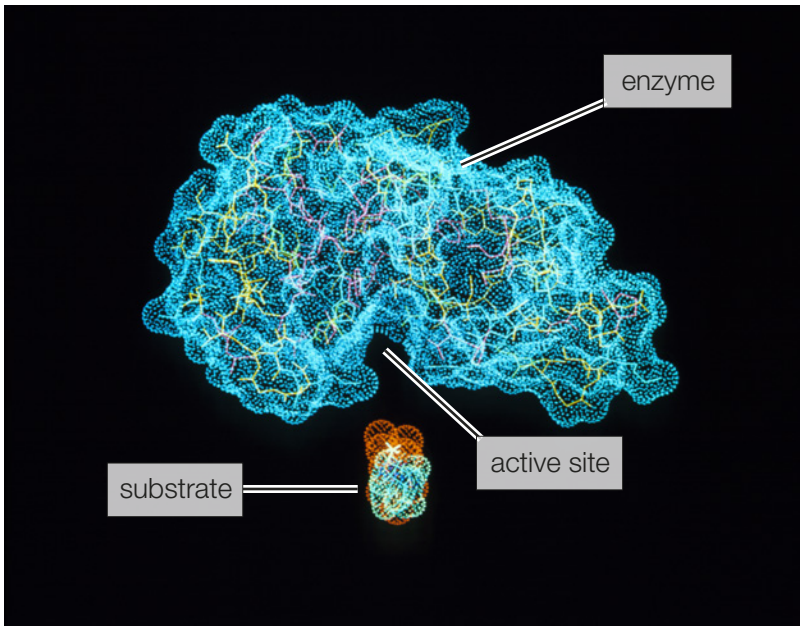


Figure 142 A molecular model of an enzyme

Enzyme-substrate binding is reversible. It has been estimated that some enzymes may convert more than 100,000 substrate molecules into products per second.

Metabolism and metabolic pathways

All the biochemical reactions carried out by a living organism is called **metabolism**. The overall rate of these reactions is called the metabolic rate. The separate biochemical reactions that make up a cell's metabolism are called metabolic reactions. Biochemical processes that are driven by metabolic reactions are called metabolic processes; for example, cell respiration and photosynthesis.

Not many chemical reactions in cells occur as a single reaction or one step. Most reactions form part of a **metabolic pathway** that consists of chains and cycles of many separate enzyme-catalysed reactions or many steps. Each step in the metabolic pathway is catalysed by a **specific enzyme.**

Figure 143 shows a simple metabolic pathway. The substrate for the first reaction is converted to a product by the first enzyme. This is the substrate for the second reaction, which is converted to a product by the second enzyme. The sequence of conversions of substrates into products continues until the last product is made.

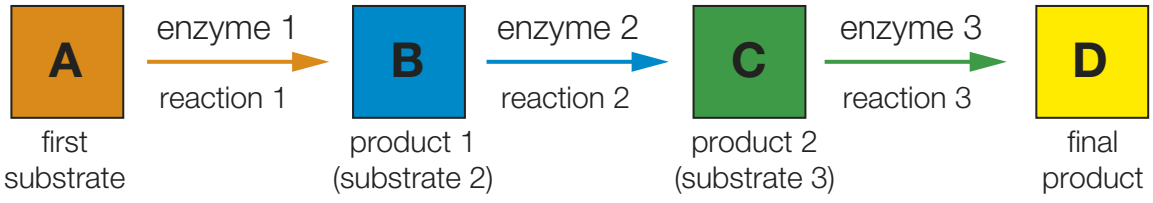


Figure 143 A simple metabolic pathway

The induced-fit model

As can be seen in *Figure 142*, the active site of the enzyme is a groove or cleft on the surface of the enzyme into which the substrate(s) can bind. The specificity of the enzyme and substrate is thus explained by the complementary binding and it is this interaction that forms the basis of how enzymes work. The substrate binds to the enzyme by weak bonds which often **cause changes to the shape of both the enzyme and substrate.**

The original model put forward to explain enzyme action was the "lock and key" model. This suggested that the enzyme had an active site which was like the keyhole for the substrate. Specificity was thus explained like a key and a lock, only the correct key can fit into and work in the lock.

The **induced-fit model**, proposed in the 1950s extends and builds on this original hypothesis. This model does not have the key and lock being a perfect fit but instead binding together and **modifying each other's shape** in the process.

Refer to *Figure 144* which illustrates the induced-fit model with the enzyme and substrate being modified in their shape.

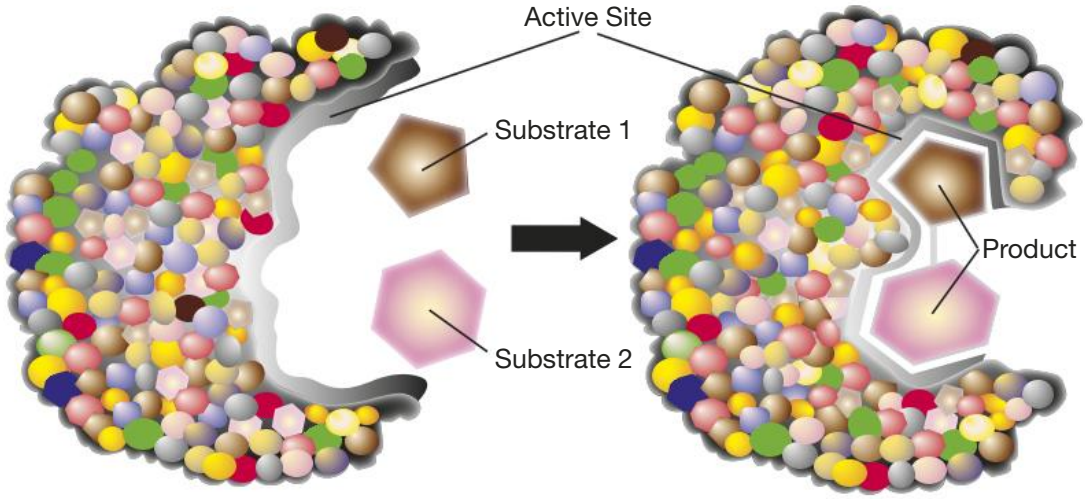


Figure 144 The induced-fit model between an enzyme and substrate

Helpful online resources

RicochetScience: Enzymes: The Induced Fit Model
<https://www.youtube.com/watch?v=pVoytz_3H_s>

Cognito: GCSE Biology - What are Enzymes?
<https://www.youtube.com/watch?v=gUncqL1ul8Q>

Lowering activation energy

Chemical reactions involve the breaking of chemical bonds in the molecules of reactants and the formation of new chemical bonds that hold atoms together in the molecules of products. All reactant molecules require energy for their bonds to break and the energy needed to do this is known as activation energy. The **lower the activation energy** is, the **more quickly a reaction occurs** because less energy is needed to break reactant bonds to initiate the reaction.

Refer to *Figure 145* showing the activation energy necessary to start a typical reaction. The reaction illustrated here would be an energy releasing reaction because after this initial input of energy, there would be an overall or nett release of energy (often known as free energy). As can be clearly seen, the activation energy is much **less when the enzyme is involved**. Hence the statement: "enzymes increase reaction rates by lowering activation energy".

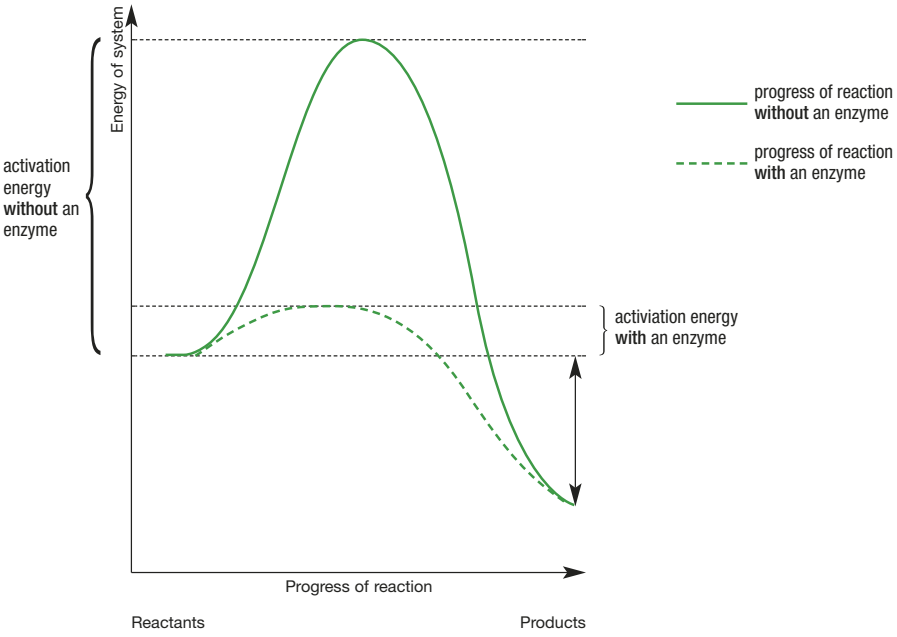


Figure 145 The importance of activation energy

Helpful online resources

RichocetScience: Enzymes and Activation Energy
<https://www.youtube.com/watch?v=ueup2PTkFW8>

Factors influencing enzyme activity

One indicator of enzyme activity is the rate at which reactant is converted into product, or the rate of the enzyme-catalysed reaction. Enzyme activity can be affected by a variety of factors. These include temperature, pH, concentrations of reactants, concentration of enzymes, concentration of products and the presence of molecules called inhibitors.

Temperature

Refer to *Figure 146* which shows the effect of temperature change on the activity of an enzyme.

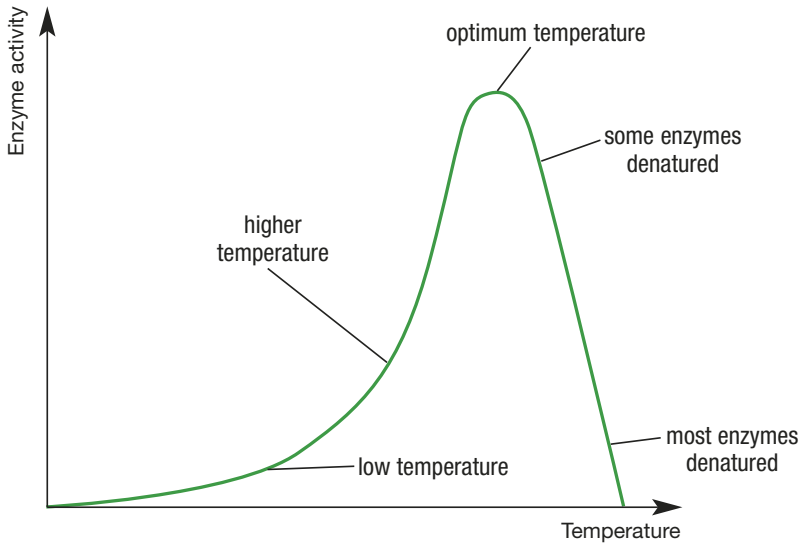


Figure 146 The effect of temperature on enzyme activity

The relationship between the rate of enzyme activity and temperature may be described as follows:

- At low temperatures, enzyme activity is low. This is because there a fewer substrates colliding with the enzyme's active site as they do not have enough energy to overcome the activation energy barrier.
- As temperature increases, the enzyme activity also increases. This is because, according to the kinetic model for matter, enzyme and substrate molecules will move more and more rapidly, resulting in more collisions at the active site and, therefore, a greater rate of reaction.
- Enzyme activity reaches a maximum at the **optimum temperature.**
- Temperature increases above the optimum temperature alter the structure of the active site of enzymes. This process is called **denaturation.** Substrates are unable to bind to the denatured active sites because they are no longer complementary in structure.
- Following denaturation, enzyme activity rapidly reduces to zero.

In humans, the optimum temperature for enzyme activity is about 37°C. The enzymes of some species (e.g. bacteria that live in hot springs) have much higher optimum temperatures and thus are able to function at very high temperatures without denaturing.

pH

Refer to *Figure 147* which shows the effect of different pH levels on the activity of an enzyme.

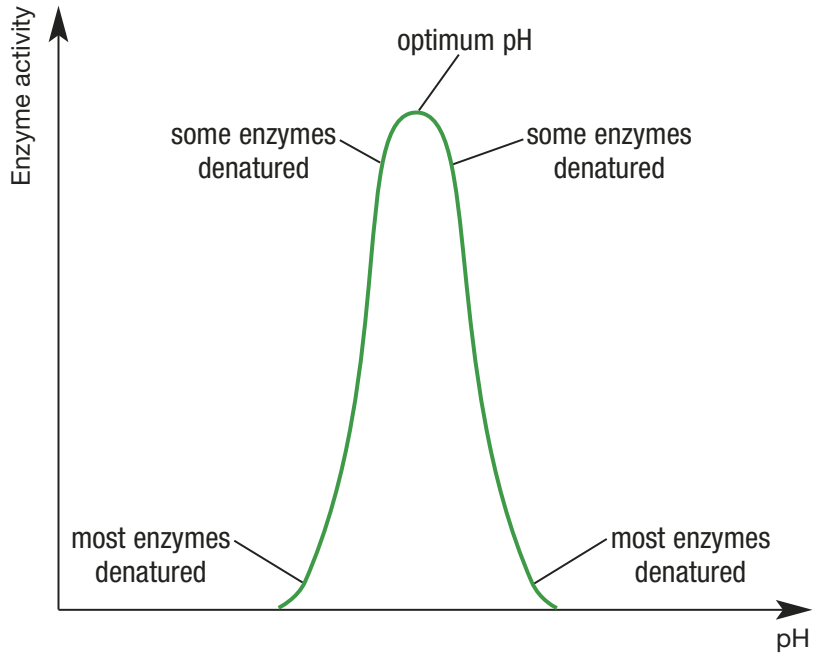


Figure 147 The effect of pH

The relationship between the rate of enzyme activity and pH may be described as follows:

- At **optimum pH**, enzyme activity is at a maximum.
- pH changes **above or below the optimum pH** denature enzymes. Substrates are unable to bind to the denatured active sites.
- Enzyme activity decreases to zero very quickly.
- Enzyme-substrate binding is reduced when changing pH alters the shape of the enzyme or substrate, causing it to no longer be complementary. The optimum pH is not the same for all enzymes: e.g. the optimum pH of enzymes in blood is approximately 7 which is very different from those secreted in the acidic environment of the stomach (optimum pH approximately 2).
- **Chemical buffers** in the body help to stabilise pH and thus allow enzymes to catalyse reactions.

Concentration of reactants

The rate of enzyme activity depends on the concentration of its reactant(s) or substrate(s). The relationship between the rate of enzyme activity and substrate concentration may be described as follows:

- At low substrate concentrations, there are fewer substrates to collide with the active site of the enzymes and therefore enzyme activity is low.
- As the concentration of the substrate increases, so too does the enzyme activity. This results from more collisions between the enzyme and the substrate at the active site.
- At higher substrate concentrations, most of the active sites on the enzymes are occupied by substrate, so increases in substrate concentration cause smaller and smaller increases in enzyme activity.
- Increases in substrate concentration above the optimum substrate concentration do not lead to greater enzyme activity because all the active sites are occupied by substrate (i.e. **saturated**).

Refer to *Figure 148(a)* which shows the effect of substrate concentration on the rate of enzyme activity.

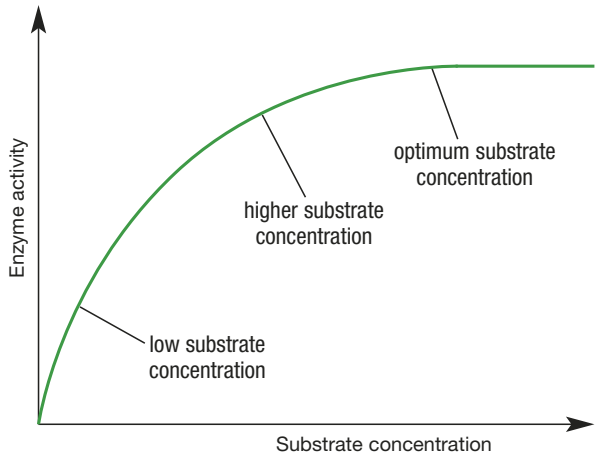


Figure 148(a) The effect of substrate concentration

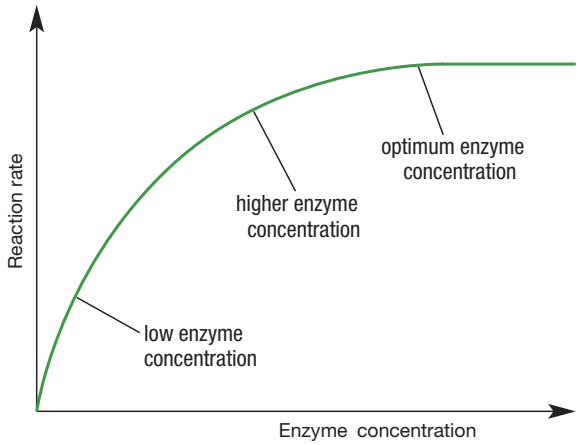


Figure 148(b) The effect of enzyme concentration

Concentration of the enzyme

The rate of an enzyme controlled reaction is also affected by the concentration of the enzyme.

Figure 148(b) illustrates the effect of enzyme concentration on the rate of a reaction.

As the concentration of an enzyme is increased so does the reaction rate as there is ample substrate to bind with the active sites of the enzymes.

When the substrate concentration becomes a limiting factor the addition of more enzyme will not increase the rate of the reaction.

Concentration of products

Authors' Note: *Although the section below about the effect of the concentration of products is no longer listed in the SACE Subject Outline, it is included below to illustrate a specific case of end-product inhibition.*

The activity of some enzymes is regulated by substances which bind to the enzyme, not at the active site but to a region away from this area, called an allosteric site. This binding can cause a reversible change in the shape of the active site and as a consequence alter enzyme-substrate binding.

End products of metabolic pathways can act in this manner and may act as an inhibitor of the pathway. This action is associated with the control of metabolic pathways in cells and is referred to as end-product inhibition.

Figure 141 represents a chemical reaction in cells where fructose 1,6 diphosphate was an end product. The metabolic pathway continues after this ultimately resulting in the production of the energy carrier molecule ATP. In this case the molecule ATP can act as an inhibitor of the reaction seen in *Figure 141* by binding to an alternative site on the phosphofructokinase enzyme.

Refer to *Figure 149* illustrating how the binding of an end-product i.e. ATP, can change the shape of the active site and thus reduce enzyme-substrate binding. The nett effect will be that ATP production will then slow down.

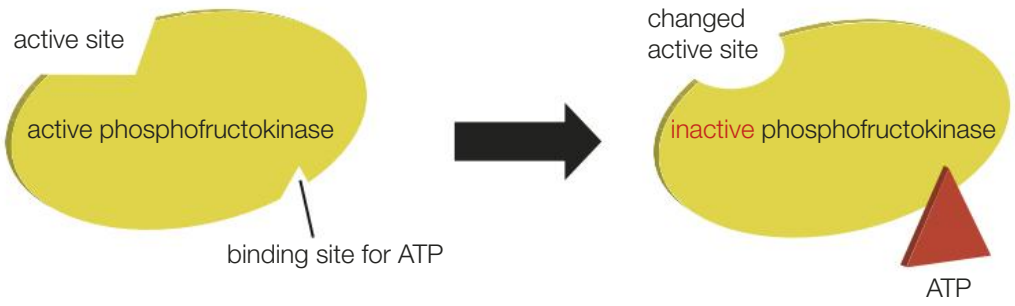


Figure 149 An example of end-product inhibition

End-product inhibition occurs where the presence of a high concentration of an end-product of a metabolic pathway inhibits the production of one of the products that in turn stops the production of the end product.

Inhibitors

A number of molecules exist which can reduce the rate of enzyme-catalysed reactions that may lead to accumulation of the substrate. These molecules are called 'inhibitors'. There are two main kinds of inhibitors:

Competitive inhibitors

These molecules **mimic** or have a structure very similar to the **structure of the substrate**. This means they compete with the substrate by binding to the active site of the enzyme. As a result, enzyme-substrate binding is reduced causing enzyme activity to decrease. Refer to *Figure 1410* illustrating how a **competitive inhibitor** acts.

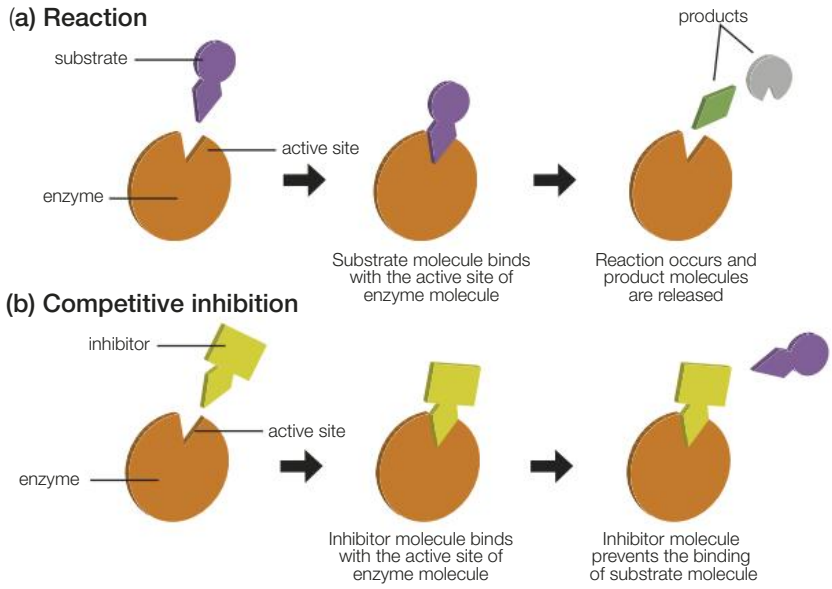


Figure 1410 How a competitive inhibitor works

Non-competitive inhibitors

These molecules do not compete with the substrate but instead bind elsewhere on the enzyme at a site which is not the active site, called the allosteric site (refer to *Figure 149*). As a result of this binding, the structure or shape of the active site changes. This also prevents the binding of enzyme and substrate at the active site and thus a reduction in enzyme activity. This action underpins the control mechanism for metabolic reactions in cells termed 'end-product inhibition' referred to previously. Refer to *figure 1411* which illustrates the action of a **non-competitive inhibitor**.

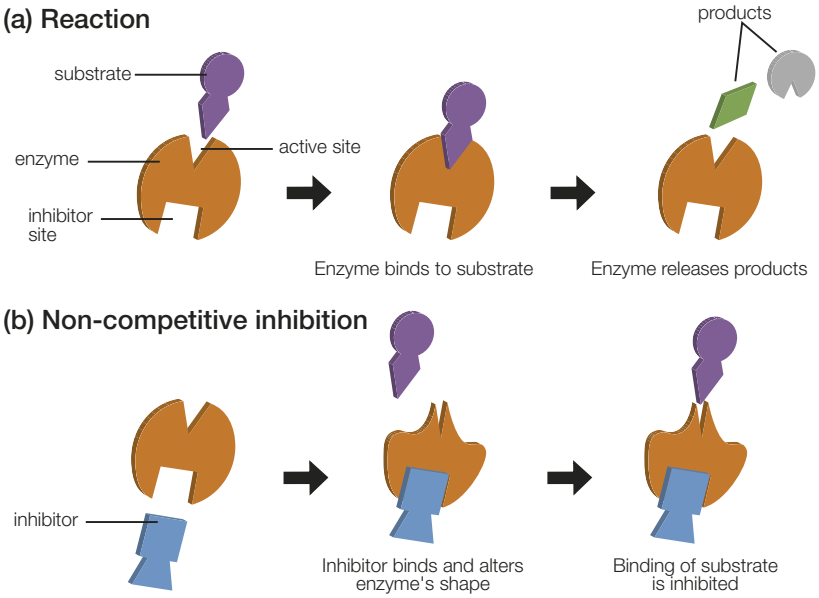


Figure 1411 How a non-competitive inhibitor works

Helpful online resources

Cognito: GCSE Biology - Factors that Affect Enzymes
<https://www.youtube.com/watch?v=qq1foXnvJao>

Amoeba Sisters: Enzyme Examples, Cofactors/Coenzymes, Inhibitors, and Feedback Inhibition
<https://www.youtube.com/watch?v=6EDBlowVST0>

An agricultural application

Understanding of enzyme inhibitors has led to their use in agriculture. One example of this has been the development and use of herbicides or chemicals designed to kill weeds. Herbicides are used to reduce competition with crops so as to maximise crop yields and thus profits.

A widely used agricultural herbicide is glyphosate which is sold as a product typically called *Roundup* or *Zero* (see *Figure 1412*) . When sprayed onto the leaves of weeds, glyphosate quickly passes into the sugar-transporting tissue (or phloem) through which it is transported to all growing part of the weeds. Thereafter glyphosate enters the cytosol of plant cells where it acts as a competitive inhibitor of an enzyme that catalyses one step in a metabolic pathway called the 'shikimic acid pathway'. This pathway begins with shikimic acid and consists of 7 steps all of which contribute to the synthesis of products that plants need to grow; without them they quickly die.

One product is an amino acid called 'phenylalanine' which is essential for the synthesis of specific plant-growth proteins. Plants cells also need phenylalanine to make a substance called lignin which is needed to form new cell walls during mitotic division of plant cells. Lignin also provides support for plant tissues, especially in the leaves and the stem, and strengthens the water-transporting tissue (or xylem) to allow plants to transport materials efficiently from the soil to the leaves.

Figure 1412
'Zero' weedkiller

1.4 Review questions

Multiple choice questions

1. Which one of the following best describes a process that occurs in the induced-fit model of enzyme-substrate binding?

   J The substrate fits into the enzyme like a key in a lock.

   K Competitive inhibitors bind to a site on the enzyme other than the active site.

   L The shape of the enzyme can be changed by the binding of the substrate.

   M Enzyme substrate binding raises the activation energy, ensuring the reactions proceed more quickly.

2. Which of the following statements is **not** supported by the induced-fit model of enzyme-substrate binding?

   J Enzymes are generally highly specific for a particular substrate.

   K Enzymes lower the activation energy necessary for a reaction to proceed.

   L Inhibitors can interfere with the enzyme-substrate binding.

   M Substrates bind tightly to the enzyme's active site to bring the molecules in close proximity to each other.

3. A biological catalyst lowers the activation energy of a chemical reaction and as a result increases the rate of reaction.

   Which one of the following is true regarding enzymes and activation energy?

   J Enzymes lower the energy in the original reactants to allow the reaction to proceed.

   K Enzymes lower the energy in the products to allow the reaction to proceed.

   L Enzymes raise the energy in the original reactants which allows the reaction to proceed.

   M Enzymes do not change the energies of the original reactants or products.

4. An enzyme catalyses the following reaction:

   Chymotrypsinogen $\xrightarrow{\text{Trypsin}}$ π-Chymotrypsin + peptide by-product

   The enzyme was added to the substrate in a test tube at 37ºC and the total amount of products produced were determined.

   According to the induced-fit model for enzyme action, an enzymes active site changes shape:

   J when it binds to its substrate.

   K and therefore, it can work with many different substrates.

   L to be the same as the shape of its substrate.

   M to fit closely to the active site on the substrate.

5. *Use the key provided below to answer the question that follows.*

   E = enzyme, P_1 = product 1, P_2 = product 2, S = substrate

   Which one of the following sequences is the most correct representation of a reaction involving an enzyme.

   J $E + P_1 + P_2 \rightarrow S + E$

   K $E + P_1 + P_2 \rightarrow S$

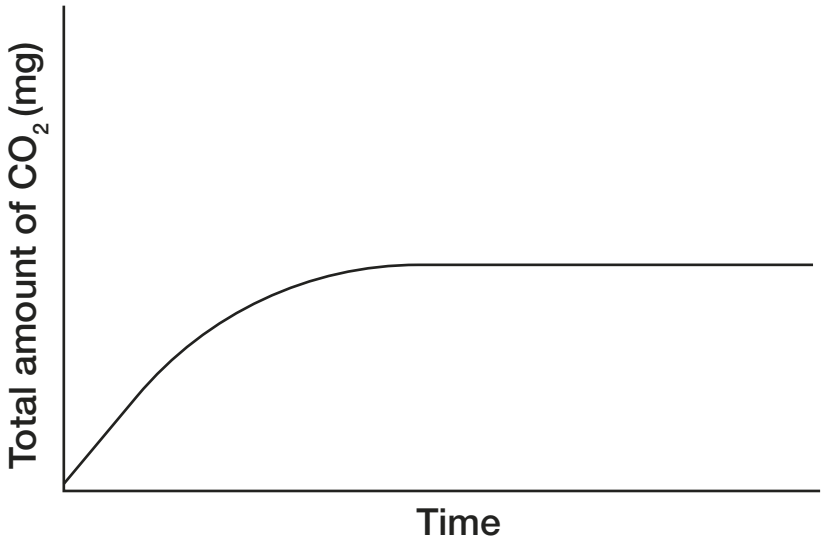
   L $E + S \rightarrow P_1 + P_2 + E$

   M $E + S \rightarrow P_1 + P_2$

6. An enzyme catalyses the following reaction:

The enzyme was added to DAP in a test tube at 37^{0}C and the total amount of carbon dioxide (CO_2) was determined, and the results plotted on the graph below.

Refer to the graph to answer the question below.



The most likely reason for the plateau shape in the graph is that:

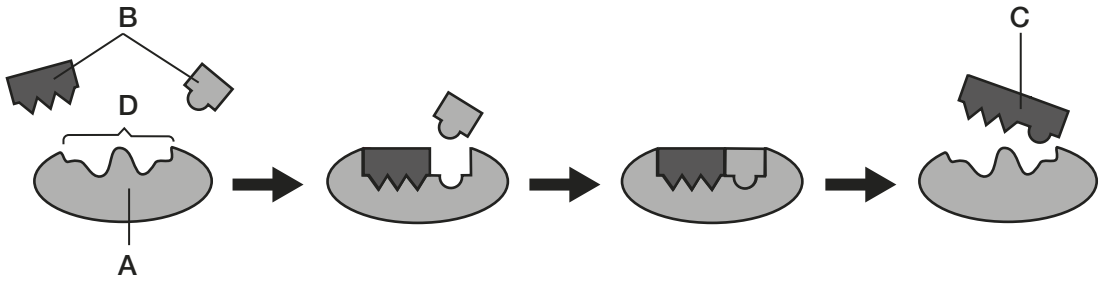
J all of the enzyme has been broken down.

K it has reached a constant rate of reaction.

L all of the enzyme sites are occupied.

M all the DAP has been used up.

Refer to the following diagram to answer questions 7 and 8.



7. This model:

J shows that the substrate can be recovered as enzymes can reverse the reaction.

K demonstrates that enzymes can continue to catalyse reactions as they are unchanged.

L highlights that competitive inhibitors can also be processed by enzymes.

M does not illustrate the induced fit model.

8. Which of the following options is correct?

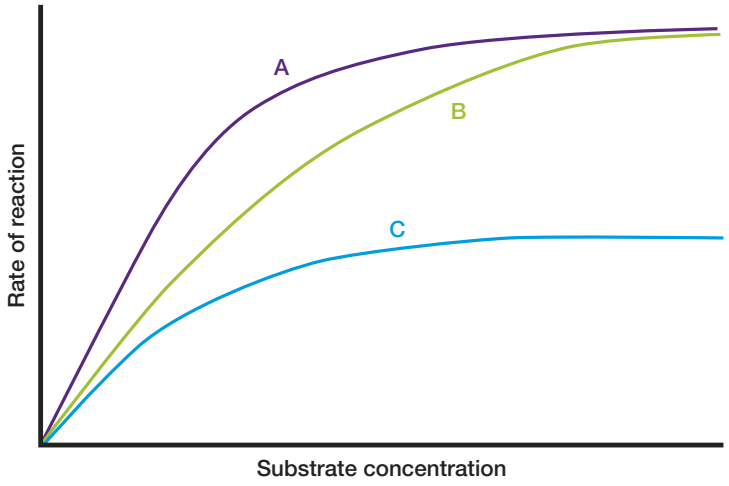
J As pH decreases the production of C increases.

K An increase in pH causes an increase in kinetic energy of B and more contact with D.

L An increase in temperature modifies the chemical structure of B.

M A decrease in temperature causes less C to be produced.

9. *Refer to the graph below to answer the following question.*



Which one of the following options is the most correct?

J Line B shows the effects of a non-competitive inhibitor on rate of reaction.

K Line C illustrates the effects of a competitive inhibitor on rate of reaction.

L Line B shows that a competitive inhibitor can be outcompeted by increasing substrate concentration.

M Line A is plateauing because there is already enough product produced and no more is required.

10. Amylase is an enzyme that catalyses the conversion of starch to simple sugars and the optimum pH for this reaction is between 6.7 and 7. A researcher conducted two trials to investigate the most effective pH to catalyse this reaction.

Refer to the data collected to answer the question that follows.

pH	Reaction Rate (glucose mg/cm^3)	
	Trial 1	Trial 2
3	6.1	5.2
4	6.3	5.7
5	6.2	6.1
6	8.0	6.2
7	8.2	5.9
8	5.2	6.3
9	4.1	6.4

Which one of the following is the correct statement?

The data from:

J Trial 1 is more accurate than trial 2.

K Trial 2 is more precise than trial 1.

L Trial 1 contains more random errors than trial 2.

M Trial 2 contains a systematic error.

Free response questions

1. Name four properties of enzymes.

2. Explain why enzymes are specific to one particular substrate.

3. Draw a labelled diagram illustrating an enzyme binding to its substrate.

4. a) Name the two models to explain enzyme activity.

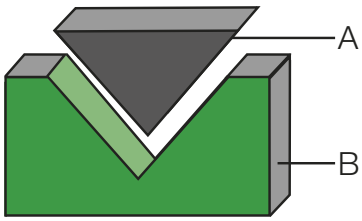
   b) Describe how the more recent model has improved our understanding of enzyme action in comparison to the older model.

5. Explain what it means to say that enzymes are biological catalysts.

6. Name one physical and one chemical factor that changes the activity of enzymes and explain how they do this.

7. Draw a diagram to help explain how a competitive inhibitor such as penicillin, might interfere with the enzyme catalysed reaction of cell wall production in bacteria.

8. Use the reaction below to answer the following questions.



$2H_2O_2 \rightarrow 2H_2O + O_2$

The diagram shows a model for the action of catalase on its substrate hydrogen peroxide.

a) State what the molecules A and B represent in the above diagram?

A.

B.

b) Name the following molecules for the reaction listed above:

substrate .

products .

enzyme .

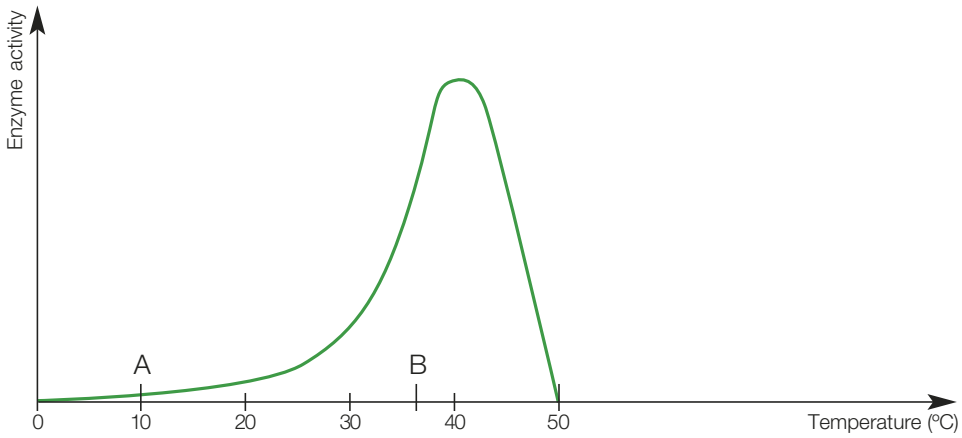
c) Explain the meaning of the term active site and colour the region on the diagram..

d) Explain why catalase cannot catalyse another reaction such as bacterial cell wall synthesis.

e) Name three external factors that could affect the activity of the enzyme catalase.

9. Explain how enzymes lower the activation energy required for a reaction to proceed.

10. The graph below shows the activity of an enzyme at different temperatures.

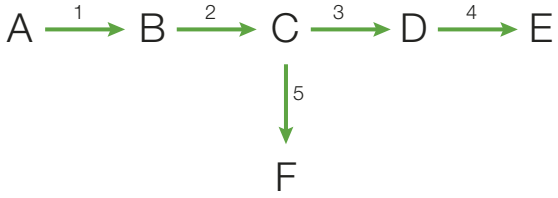


a) Describe the change in enzyme activity between temperatures A and B.

b) What is the optimum temperature of this enzyme?.

c) Suggest how the activity of enzymes in thermophilic bacteria found in very hot (near boiling) springs would differ from this enzyme. Draw another line to indicate this on the graph.

11. The diagram below shows a metabolic pathway that involves substances A-F and enzymes 1-5.

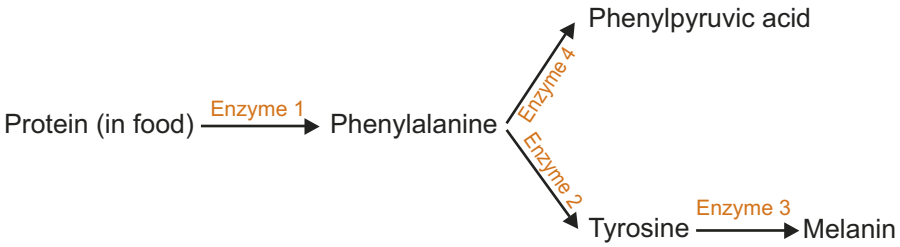


a) Compare the structure of enzymes 1 and 5.

b) A chemical inhibitor halts the activity of enzyme 3. Describe the effect of the presence of this inhibitor to the level of product E?

c) Describe the effect that the inhibitor of enzyme 3 has on the synthesis of product F.

12. Some people suffer from a genetically inherited disease called 'phenylketonuria' in which the amino acid phenylalanine is present in high concentrations in the blood. Phenylpyruvic acid is also present in high concentrations and this can lead to mental retardation. The cause of this disease is an enzyme malfunction. Use the metabolic pathway shown below to answer the questions that follow.



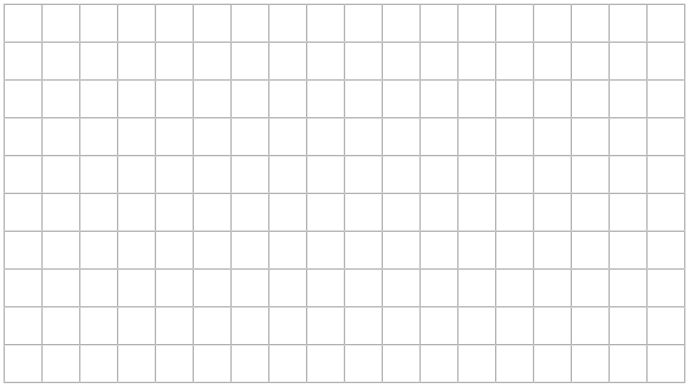
a) With reference to the information above, identify the abnormal enzyme in this metabolic pathway that gives rise to an increase in phenylalanine and justify your answer..

b) Explain why phenylpyruvic acid is likely to be present in higher concentrations.

c) Describe the likely effects of this disease on the production of melanin.

13. An experiment was conducted in which the digestion of a short chain or amino acids (or polypeptide) by the enzyme trypsin was investigated. Six test tubes were placed in a water bath that was set at 35°C. Each test tube contained 5 mL of polypeptide solution and 1 mL of trypsin solution. The pH of the test tubes was altered as indicated below. The reaction was tested for the percentage breakdown of polypeptide into single amino acids at the end of 30 minutes. The results are displayed in the data table below.

pH of test tube contents	% breakdown of peptide
6	32
7	65
8	100
9	95
10	35
11	20



a) Use this data to plot a graph of the percentage (%) breakdown of polypeptide against the pH on the grid provided above.

b) Write a hypothesis that was possibly being tested by this experiment.

c) Name the independent and dependent variables.

d) Name two factors that should have been kept constant while conducting the experiment.

e) Explain why it is important to keep each of these constant.

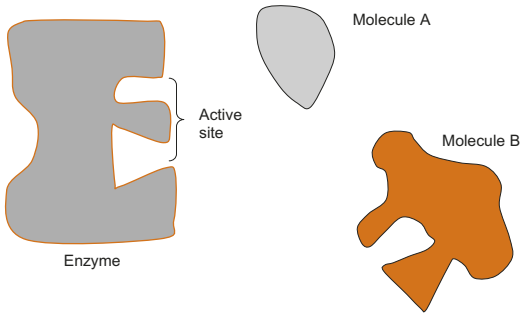
f) From this data, what is the optimum pH for the activity of the enzyme trypsin? Explain why.

14. When peeled apples are exposed to the air there quickly appears a 'browning' on the surface of the apple tissue. This is caused by the action of the enzyme phenol-oxidase.

a) Explain why placing the peeled apples in a refrigerator can slow the browning process.

b) Explain why, when the apples are boiled soon after the peeling, very little browning appears.

15. *Refer to the diagram below of an enzyme and two inhibitor molecules to answer the questions that follow.* Inhibitors are known to reduce the catalytic activity of enzymes.

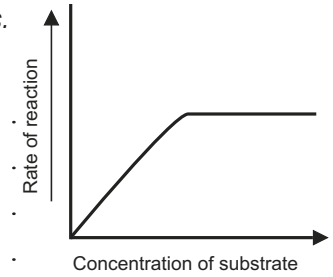


a) Explain how molecule B would reduce the enzyme's ability to break down its normal substrate.

b) Explain how molecule A may reduce enzyme-substrate binding.

16. *Use the graph on the right to assist you in answering the following questions.*

a) Explain the most likely reason for the plateau in the graph.

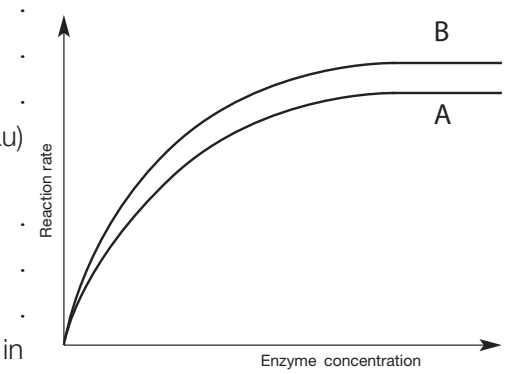


b) Draw on the graph the likely result if the enzyme concentration was halved.

17. *Refer to the graph below to answer the questions that follow.*

a) Describe the pattern of results comparing the different responses observed in A compared to B.

b) Explain the most likely reason for the flat section (plateau) observed in both graphs.



c) Suggest the most likely reason for the differences noted in graph A compared with graph B.

Chapter 1.5 Gene expression

Science Understanding

The phenotypic expression of genes depends on factors controlling transcription and translation. These include the products of other genes, such as transcription factors, and the environment

Cellular differentiation associated with tissue growth and development is controlled by gene expression.

- Recognise that changes in DNA methylation and histone modification can alter gene expression.

Epigenetic changes can lead to phenotypic differences between identical siblings, phenotypic differences between clones, and may cause human diseases.

- Explain how epigenetic modifications in genes that control cell division, such as changes in DNA methylation, can lead to cancer.

Chapter 1.2 presented information explaining how the base code in DNA can be transcribed and translated, allowing the formation of polypeptides and proteins that have vital roles in all organisms. Genes are segments of DNA that code for a particular polypeptide. All genes in eukaryotic cells consist of coding and non-coding segments. Both exons and introns are transcribed (or undergo transcription) to form RNA, but only information contained in exons is translated to form a polypeptide that subsequently folds into a specific protein.

This chapter examines factors involved in ensuring that cells exert careful and measured control over what genes are active and when and how this activity occurs. **Gene expression** is the process by which the genetic code in the DNA is used to direct protein synthesis. In some cells, certain genes are turned off, whilst in others they are expressed.

Phenotypic expression of genes

The gene pairs of homologous chromosomes control **phenotypic** characteristics (i.e. the **physical** factors expressed from genes). The genes of the corresponding pairs are called **alleles**, which are alternative forms of the same gene, such as different coloured eyes. Different alleles exist because genes are subject to mutations. Therefore, two organisms may appear to be similar, but they can have different **genotypes**. Similarly, two humans may have the same genotypes, but will appear to be different from each other if they have been exposed to different **environmental conditions** throughout their lives.

The relationship between phenotype and genotype can therefore be expressed:

P = G + E

P = phenotype

G = genotype

E = environment

Epigenetics

Epigenetics is the study of how the environment influences gene expression. As we develop, our DNA accumulates 'chemical tags' that are collectively called the **epigenome**. The epigenome is an additional level of coding on top of the DNA base sequence. These chemical tags do not affect the DNA base sequence, instead they change how our cells read the DNA and express it. The two main types of 'chemical tags' are **methylation** of cytosine bases and **acetylation** of histone proteins.

Epigenetic tags **can be inherited** from parents through the sperm and eggs. Once born, the epigenome of cells can be altered from environmental factors. The epigenome can be affected by both positive and negative experiences and can be temporary or permanent. The different experiences individuals have as they develop alter the number and location of these epigenetic tags. This is why **identical twins** can **exhibit different physical traits**, behave differently and have different health issues. Even though identical twins are genetically identical they are **epigenetically different**. This can also be applied to **clones**. All clones of one parent organism would be genetically identical, but they would all be exposed to different environmental factors, and therefore differ epigenetically.

Helpful online resources

MinuteEarth: Epigenetics: Why Inheritance Is Weirder Than We Thought
<https://www.youtube.com/watch?v=AvB0q3mg4sQ>

TED-Ed: What is epigenetics? - Carlos Guerrero-Bosagna
<https://www.youtube.com/watch?v=_aAhcNjmvhc>

Amoeba Sisters: Epigenetics
<https://www.youtube.com/watch?v=MD3Fc0XOjWk>

Factors controlling transcription

Gene expression is tightly regulated by a range of cellular processes that control gene expression. Genes can be 'switched on' causing transcription to take place, and 'switched off' preventing transcription. Some genes are expressed continuously whereas others are only switched on at particular times.

Transcription factors

Cells have many mechanisms for regulating the rate of transcription. One mechanism is the binding of transcription factors to specific base sequences upstream of the gene(s) to be transcribed.

A **promoter sequence** is a region on the DNA that is not transcribed but plays a role in controlling the transcription of a gene. This is where **RNA polymerase** binds to initiate transcription. Molecules called **transcription factors** can also bind to specific base sequences in these promoter regions and assist in the binding of RNA polymerase. Some transcription factors, called **activators** bind to DNA and **activate or increase** the rate of transcription, whereas others, called **repressors** bind to DNA and **slow or stop** transcription (see *Figure 151*).

Repressors and activator proteins can also bind to other base sequences upstream of the gene and promoter sequence. The binding of a repressor factor to one or more of these regions, silences transcription by **inhibiting RNA polymerase** from binding to the promoter region. In contrast, binding of activator proteins to their respective base sequence regions, stimulates gene expression. There are multiple mechanisms that the binding of activator proteins can initiate, but one example is **triggering RNA polymerase to release from the promoter** region and start moving along the gene.

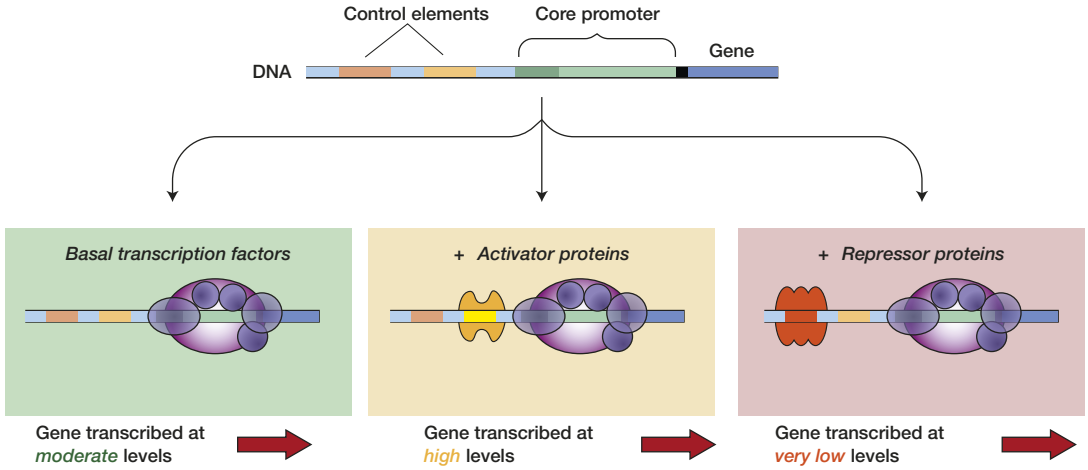


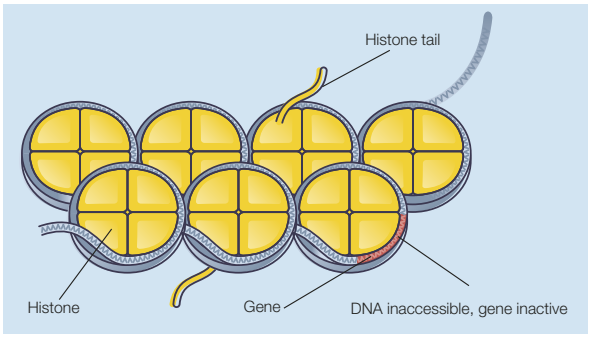
Figure 151 A section of DNA showing how the transcription of a gene can be increased or decreased by activator and repressor proteins binding to their respective control elements on the section of DNA

Methylation of cytosine bases

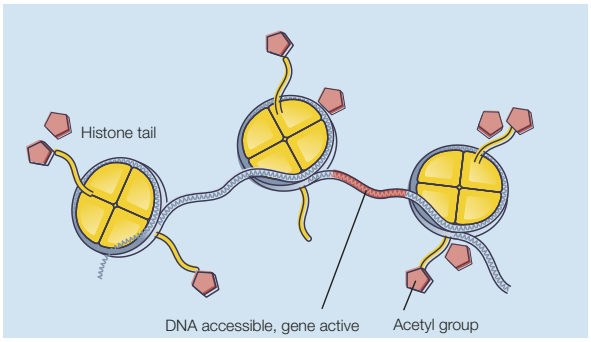
DNA **methylation** is a process in which a **methyl group (CH_3)** is added to the DNA strand. This usually occurs to a **cytosine base**. Methylation **does not alter the DNA sequence** but can influence gene expression. The methylation of cytosine bases **inhibits RNA polymerase** from binding to the promoter region(s), and hence transcription (see *Figure 153*). After methylation, genes usually retain their methyl groups when cell division occurs and thus the pattern of methylation can be passed on to the daughter cells.

Histone modification

DNA is packaged with **histone proteins** to form chromatin. The acetylation of histone proteins can change RNA polymerase **accessibility** to genes. **Acetylation** of histone proteins causes the chromatin to decondense resulting in **loose packing of the histone proteins**. This allows RNA polymerase to bind to the DNA and the gene(s) can be expressed. In contrast, **deacetylation** of histone proteins causes the chromatin to condense resulting in **more tightly packed** histone proteins. As a result, **RNA polymerase** is unable to bind to the DNA and transcription cannot occur (see *Figure 152*).The histone proteins can also be **methylated** and can result in an **increase or decrease in gene expression.** The consequence of methylation of histone proteins depends on the amino acid(s) within the histone protein being methylated, and the number of methyl groups added to that amino acid.



Deacetylation of histones causes nucleosomes to pack tightly together. Transcription factors cannot bind to DNA, and genes are not expressed.



Histone acetylation results in loose packing of nucleosomes. Transcription factors can bind to the DNA and genes are expressed.

Figure 152 The effect of acetylation and deacetylation on accessibility to the genetic code

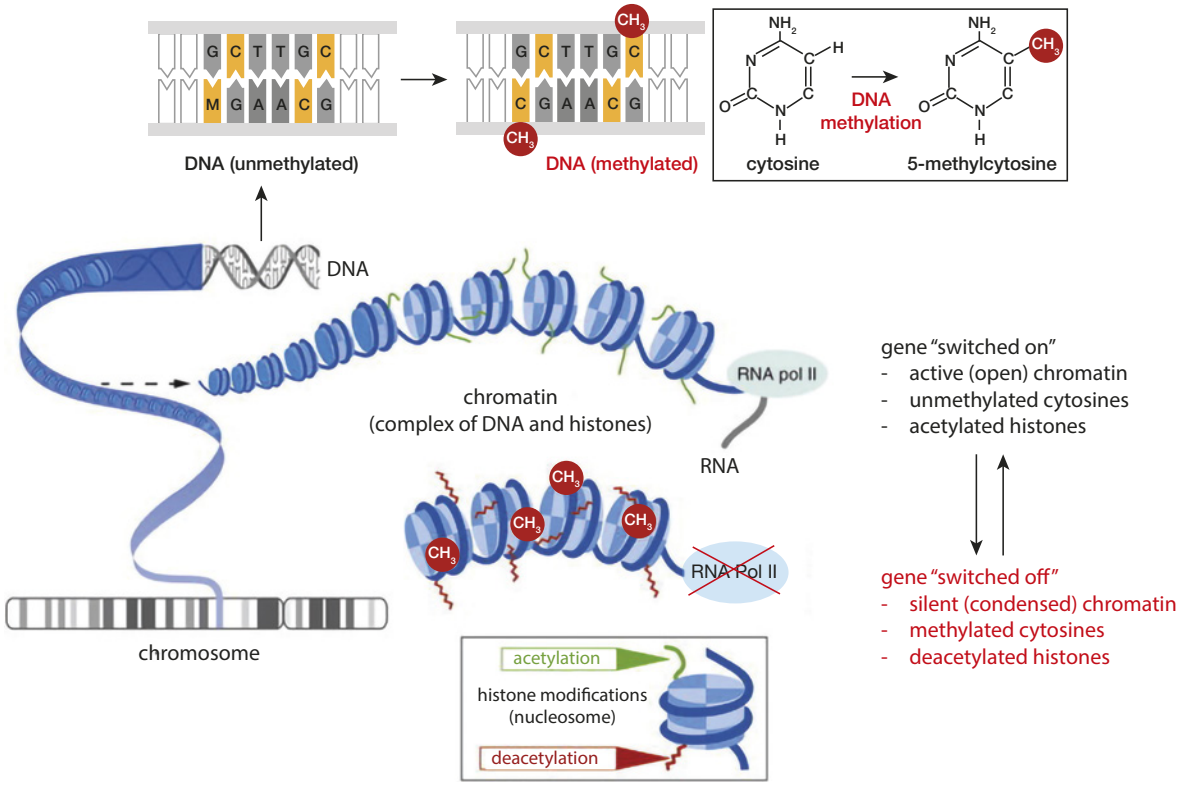


Figure 153 A summary of the effects of cytosine methylation and histone acetylation on gene expression

Factors controlling translation

Multicellular organisms such as humans, require many copies of the same protein; for example, many insulin proteins are required to communicate to multiple cells to take up glucose from the blood. As a result, mRNA is translated by multiple ribosomes to produce many copies of the polypeptide or protein. The ribosomes would continue to translate the mRNA unless there is a signal to stop. Cells require mechanisms to stop the process of translation, otherwise valuable resources such as energy and amino acids would be wasted. Furthermore, increases in some proteins can be detrimental for cells and contribute to certain disorders.

Translation factors therefore help coordinate the synthesis of polypeptides and proteins. They generally act on messenger RNA (mRNA) or micro RNA (miRNA), but there are also other mechanisms. These translation factors can increase or decrease the translation of the mature mRNA strand. There are multiple factors that control translation, but in this course, the focus will be on three of them: micro RNA (miRNA), small interfering RNA (siRNA) and long non-coding RNA (lncRNA). These three RNA molecules are all synthesised from non-coding DNA (i.e. introns) and are therefore categorised as non-coding RNAs (ncRNA).

Micro RNA (miRNA)

MicroRNA are a class of small non-coding RNA molecules consisting of approximately 22 nucleotides. As a translation factor they help **regulate gene expression after transcription** has occurred. They exert their regulatory action by binding in a complementary fashion to a small section of a specific mRNA molecule. This results in a small section of the mRNA strand being **double stranded** preventing the ribosome from accessing the full mRNA code and the expression of that gene (see process A in *Figure 154*).

Small interfering RNA (siRNA)

Small interfering RNA (siRNA) are also known as silencing RNA. They are another class of translation factors that act on mRNA preventing translation. They are similar in size to miRNA and generally consist of 21 nucleotides. siRNA binds to a specific mRNA molecule in a complementary fashion, and in doing so, promotes the **destruction of the mRNA strand**. The specific mRNA strand cannot be translated by ribosomes and gene expression is stopped.

Long non-coding RNA (lncRNA)

Long non-coding RNA (lncRNA) have many functions in the control of gene expression. The focus here though is its role as a **translation factor**. They are longer than miRNA and siRNA and consist of approximately 200 nucleotides. One function of lncRNA is to bind to a specific miRNA molecule in a complementary fashion. As lncRNA binds to miRNA and not mRNA, the miRNA cannot bind to mRNA and prevent translation. Therefore, lncRNA can **promote gene expression** by inhibiting a specific miRNA (see process B in *Figure 154*).

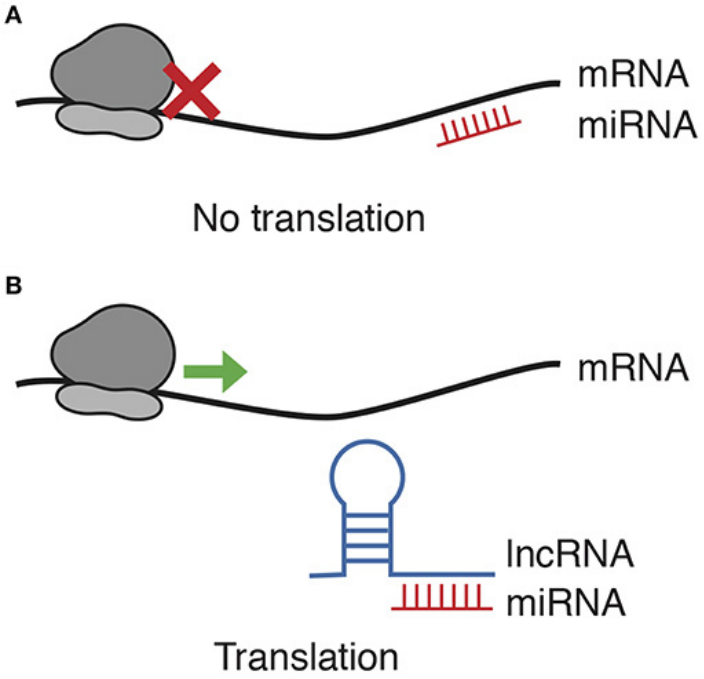


Figure 154 The complementary actions of miRNA (A) and lncRNA (B) in inhibiting and promoting gene expression

Factors influencing gene expression

As mentioned previously, the phenotype is affected by an individual's genotype and the environmental conditions the individual is exposed during its life. There are many factors that are known to influence the expression of genes. Some examples are:

Gender

Some genes are expressed differently in males and females such as baldness in males (see *Figure 155*). The gene associated with baldness is affected by the hormones testosterone and dihydro-testosterone. Usually, males have higher levels of these hormones compared to females. Similarly, these hormones act differently in males and females during puberty, resulting in different gene expression.

Figure 155 Baldness depends on age and gender

Chemicals

Many chemicals influence gene expression including illicit drugs, arsenic, methyl mercury, benzene, BPA and particulate matter. One specific example of chemicals in the environment influencing gene expression involves the tragic story of the drug thalidomide. It was used in the 1950s and early 1960s to combat morning sickness in pregnant women. Unfortunately, this drug was proved to interfere with gene expression involved with the proper development of arms and/or legs of the foetus and resulted in thousands of babies born worldwide with incompletely formed arms and/or legs.

Temperature

An example of temperature influencing gene expression is a gene in a rabbit from the Himalayas that is active in temperatures from 15-25°C. Air temperatures in this range lead to black colouration in the fur, whereas above these temperatures the gene is inactive and the fur is white. Refer to *Figure 156* of a pedigree Himalayan rabbit exhibiting the black colour in the extremities where the gene has been expressed. Similarly, ultraviolet light causes some skin cells in humans to produce the pigment melanin which we see as a 'suntan'.

Figure 156 A Himalayan rabbit

Diet and lifestyle

Our diet plays many roles in influencing gene expression. Some responses are immediate whereas others are longer lasting. An example of an immediate response would be increased production of the hormone insulin in response to consuming a lot of sugar. When blood sugar increases, insulin is released into the blood and mechanisms are activated to increase production of insulin.

Additionally, our diet and lifestyle influence the epigenome. One example of this is when an individual is following a low-fat diet. Because the individual is not consuming their regular amount of fat, the intestinal cells cannot absorb the body's requirements. This can result in the increased accessibility to genes associated with absorption of fats, and therefore increased synthesis of proteins involved in fat absorption. These proteins are inserted into the membranes of intestinal cells, increasing the number of receptors able to absorb fat. The low-fat diet will work when the individual is following it, however when the diet is broken, the individual is likely to put on more weight because their intestines can absorb more fat from their diet now.

Trauma

Trauma can also affect gene expression. Trauma can result in epigenetic changes to the genes regulating stress. Studies have shown that historical traumatic events have left epigenetic markers that have been inherited by children and grandchildren. One example is holocaust survivors that have passed on epigenetic markers to the genes controlling the release of stress hormones to their offspring.

Epigenetic changes and diseases

There are several common diseases, including cancer, cardiovascular disease and some auto-immune diseases that have been linked to epigenetic changes to DNA and histones. There are studies that have indicated that environmental factors, such as diet, stress, exposure to cigarette smoke, heavy metals or other chemicals may change patterns of DNA methylation in cells and therefore, healthy regulation of gene expression.

Cancer

Cancer is caused by **uncontrolled cell division**. Therefore, the genes associated with the control of cell division are highly regulated. Epigenetic factors can affect the expression of these genes that control cell division. If these changes lead to uncontrolled cell division, a tumour will start to grow, and it could become cancerous. Three types of genes associated with cell division and the effect of epigenetic changes are outlined below:

Type of gene	Effect of epigenetic changes
Proto-oncogenes	• Proto-oncogenes normally code for proteins involved in promoting cell division. • **Decreased methylation** to DNA can therefore promote cell division and if uncontrolled, lead to the formation of cancers
Tumour suppression genes	• Under normal circumstances, these genes code for proteins that suppress or inhibit cell division. This helps keep the number of new cells in a tissue 'in check' and suppresses tumour formation. • One example is the p53 gene that expresses the p53 protein. The p53 protein can stop the cell cycle and therefore, cell division. It can also activate proteins involved in DNA repair, and if the issue cannot be resolved, cell death. • **Increased DNA methylation** of tumour suppression genes switches them off and the proteins suppressing tumour formation can no longer be produced (or in much smaller amounts). As a result, uncontrolled division and a tumour could develop due to lack of normal cell division suppression.
DNA repair genes	• DNA repair genes can be activated to produce proteins involved in the repair of damaged DNA. • **Increased methylation** to DNA repair genes would result in them being turned off. Consequently, less damaged DNA would be repaired, and damaged DNA would accumulate. This increases the risk of uncontrolled cell division and cancer developing.

Cell differentiation

All organisms that reproduce sexually start life as a fertilised egg or zygote. This single cell begins to divide, and the organism grows to form a ball of cells called a blastocyst, then a mass of cells called the gastrula, and then different types of cells develop. This occurs very early in the life of an organism. In humans, this occurs in the first few weeks of pregnancy. Refer to *Figure 157* which represents the development of **specialised cells** in various layers and tissues from the original zygote.

Every somatic cell in an organism contains all the genetic information to carry out every function, but only a small portion of this material is activated in each cell. **Differentiation** is the process in which cells with identical chromosomes and genes become different and specialised in both their structure and function.

Specialised cells have specific **epigenetic tags** that help activate and silence specific genes. Once a cell becomes specialised, it cannot differentiate into another type of specialised cell. One reason for this is that epigenetic tags can be passed on from parent cells to their daughter cells though **mitosis**. The **inheritance of these tags** ensures that the daughter cells will also become the **same type of specialised cell** and will therefore be the correct type of cell for that specific tissue or organ. This is essential for the development of multicellular tissues and organs.

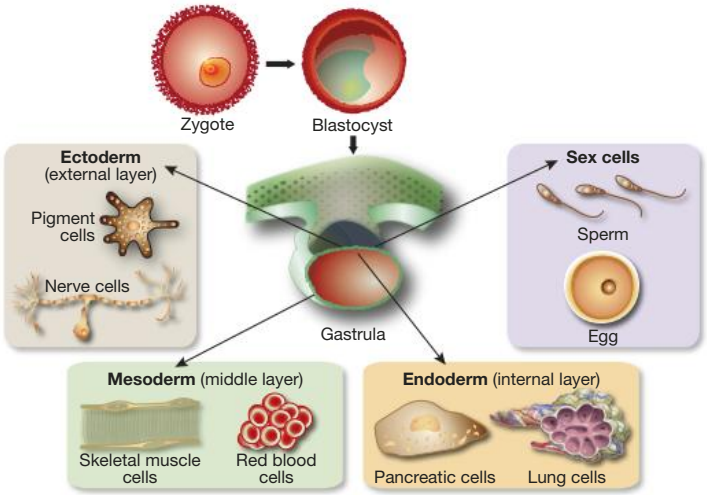


Figure 157 Some examples of differentiation

Stem cells

The adult human is made up of about 230 different types of specialised cells. Some examples include nerve cells, epithelial cells, muscle cells and sex cells. Even though these different cell types have different shapes and functions, they all originate from cells called stem cells.

Two types of stem cells are:

- pluripotent: stem cells that have the potential to develop into any human cell.
- multipotent: stem cells that can develop into some cell types only.

Therefore, **stem cells** are **unspecialised** and can differentiate into specialised cells making up the tissues and organs of the organism.

Essentially, cell differentiation results from the regulation of gene expression; in some cells particular genes are switched off and others are switched on. In virtually all cells, certain genes are nearly always switched on, often termed 'housekeeping genes' and are involved with general cellular maintenance and energy provision.

Scientists are beginning to understand the exact signals that seem to be involved in determining why cells in different regions or positions develop differently. These include:

- signal molecules released from one cell bind to surface cell receptors on target cells nearby and the signal molecules act to regulate genes in the nucleus.
- the interaction of membrane proteins on cells also initiates signal molecules. Signal molecules include transcription factors, discussed earlier in this chapter.
- cell signalling mechanisms in differentiation.

Refer to *Figure 158* which illustrates how this might occur.

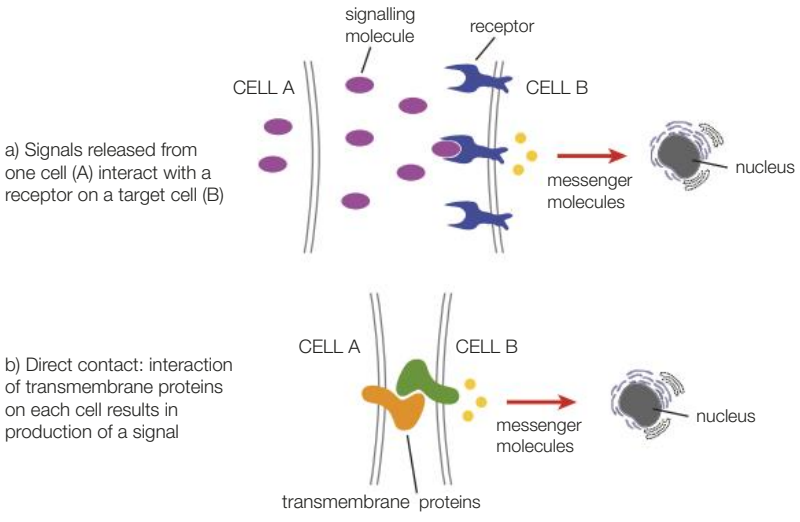


Figure 158 Cell signalling mechanisms in differentiation

Helpful online resources

TED-Ed: What are stem cells? - Craig A. Kohn
<https://www.youtube.com/watch?v=evH0I7Coc54&t=102s>

Amoeba Sisters: How Cells Become Specialized
<https://www.youtube.com/watch?v=t3g26p9Mh_k>

Cognito: GCSE Biology - Stem Cells in Medicine
<https://www.youtube.com/watch?v=5IN2NrGBOYY>

Cloning

A clone is a group of cells (or tissue) derived from a single cell or a group of genetically identical organisms. One of the most famous examples of a cloned organism was 'Dolly' the sheep who was cloned late in the 1990s using the nucleus in a cell from the udder of a Finn-Dorset ewe. The nucleus from the Finn-Dorset ewe contained the genetic information that was placed in the Scottish-Blackface ewe's egg cell. This surrogate mother gave birth to Dolly that was a clone of the original Finn-Dorset sheep (not blackface). *Refer to Figure 159.* It is important to note that **two clones will be genetically identical**; however, they would be be exposed to different environmental conditions throughout their life, and therefore they would be **epigenetically different**.

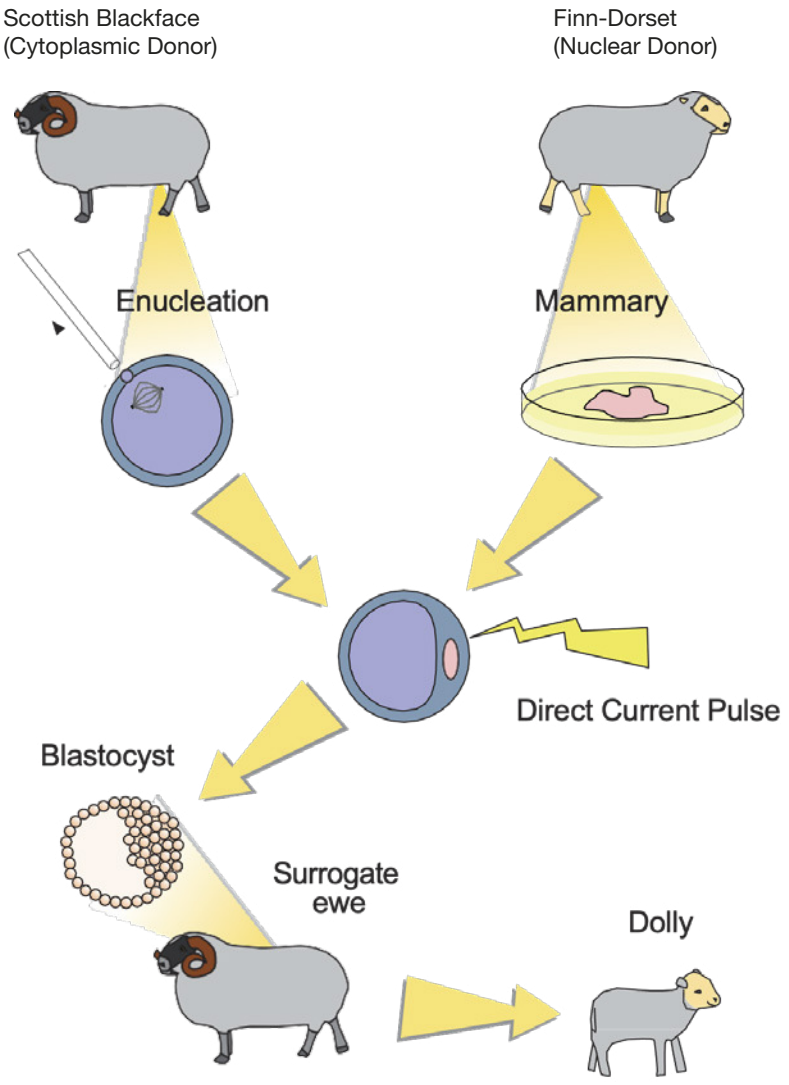


Figure 159 Cloning 'Dolly' the sheep

Helpful online resources

FuseSchool - Global Education: Modern Cloning Techniques | Genetics | Biology
<https://www.youtube.com/watch?v=FjBgLIE7514>

Therapeutic cloning

Therapeutic cloning is the use of **cloned stem cells** in medicine and therefore involves stem cell research. As stem cells are **unspecialised** cells, scientists can use different techniques to **control gene expression** and therefore control the type of cell they differentiate into. This research has great potential as it is possible to produce a wide range of tissues and enable diseased cells to be replaced with healthy ones. The acquirement of stem cells for research purposes is highly regulated due to many **ethical considerations,** such as creating new life just to extract stem cells, ending that potential life. Some possible methods of acquiring stem cells for research purposes are:

- by extraction from a leftover fertilised ovum from an IVF program (embryonic stem cells)
- by removal from tissue like bone marrow and the umbilical cord (adult stem cells)
- by 're-programming' ordinary somatic (or body) cells like skin cells in a way that induces (or encourages) them to become stem cells (induced pluripotent stem cells or IPS cells).

Once stem cells are obtained, they are either used to produce specific tissues in the lab that are then transplanted into patients to replace or repair damaged ones in the body or are injected directly into a specific region of the body to facilitate repair. The technology is not without limitations and is still in a relatively early stage of development. Producing tissue that is structurally correct is one thing, but whether it is properly functional can sometimes be another matter. Injecting stem cells into the body carries risks ranging from rejection, development of the wrong type of tissue and tumour formation.

1.5 Review questions

Multiple choice questions

1. Which of the four bases is usually methylated in eukaryotic cells?
   - J cytosine
   - K guanine
   - L adenine
   - M thymine
2. The cells lining the gut need to be continually replaced every few days. It is the role of specific stem cells to replace these cells lining the gut.

   These stem cells are said to be undifferentiated as they:
   - J have the genetic potential to divide and produce specialised gut cells.
   - K are the only cells that have the genes required to develop into gut cells.
   - L are the only cells that contain the full set of genes capable of giving rise to any type of cell.
   - M will develop into specialised gut cells as the old cells in the gut need replacing.
3. Cells are able to differentiate into a range of specialised cells. Stem cells found in the bone marrow of an organism usually differentiate into blood cells. It has been found that if these stem cells are injected into other tissues of the body, they sometimes differentiate into the cell types associated with that tissue.

   The most likely reason for the above observation is that:
   - J when placed in different environments different DNA molecules develop within the cell's nucleus.
   - K stem cells are undifferentiated and thus when provided with the appropriate stimulus can develop into a range of cell types.
   - L genes do not develop in a cell until stimulated by factors in the external environment.
   - M any cell can change into another cell type depending on its external environment.

4. Identical twins have the same genetic code.

   Why are small physical differences generally observed between identical twins?

   J Only a few of the approximately 230 different types of somatic cells differ in gene expression.

   K A small number of mutations occur to introns.

   L Because their stem cells are the same genetically, but their somatic cells differ in genetic code.

   M The environment affects the expression of genes.

5. *Refer to the diagram to the right to answer the following question.*

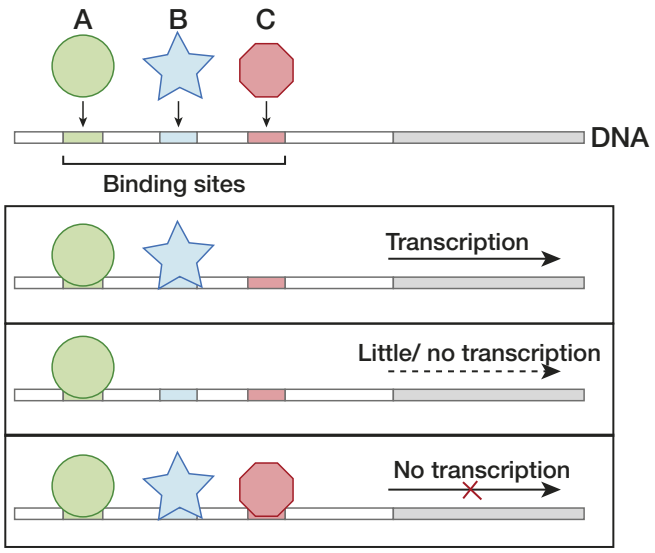
   Which of the following is correct with regards to gene expression?

   J A, B and C are all transcriptional activators.

   K B and C are repressor factors.

   L A is a repressor factor.

   M A and B are transcriptional activators.



6. The phenotypic expression of genes during translation is regulated by which of the following factors?

   J repressor

   K promoter

   L microRNA

   M activator

7. Consider the diagram below of a signalling molecule interacting within a target cell.

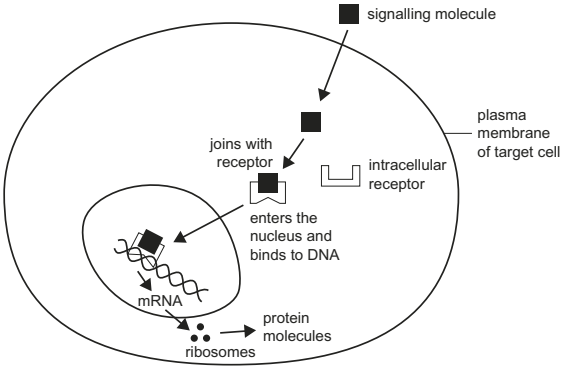
   Which of the following options is most correct with regards to the interaction between the signalling molecule and the target cell?

   J The signalling molecule and intracellular complex likely bonded to a DNA promotor region.

   K The signalling molecule and intracellular complex caused increased DNA methylation, activating gene expression.

   L The signalling molecule and intracellular receptor complex is a repressor factor.

   M The response of the target cell is DNA replication.



8. Which one of the following statements about methylation of DNA is incorrect?

   J The hypermethylation of DNA increases gene expression.

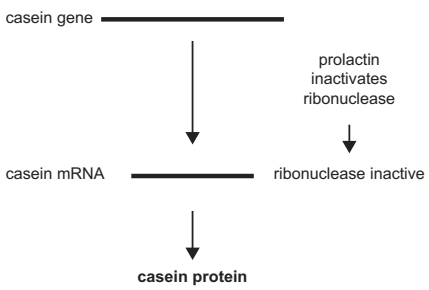
   K Sections of chromosomes are decondensed when they are unmethylated.

   L Increased methylation switches off genes.

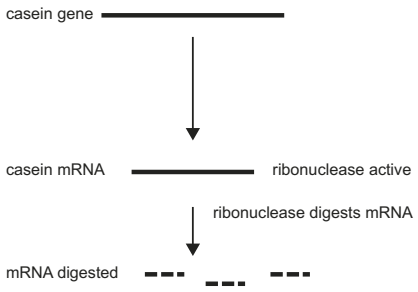
   M The methylation of DNA in somatic cells cannot be passed on to offspring.

9. Cow's milk consists of approximately 80% casein protein.

   The first diagram illustrates the pathway that occurs when cows are producing milk.



The second diagram illustrates the pathway that occurs when cows are not producing milk.



A correct conclusion made from the information above is:

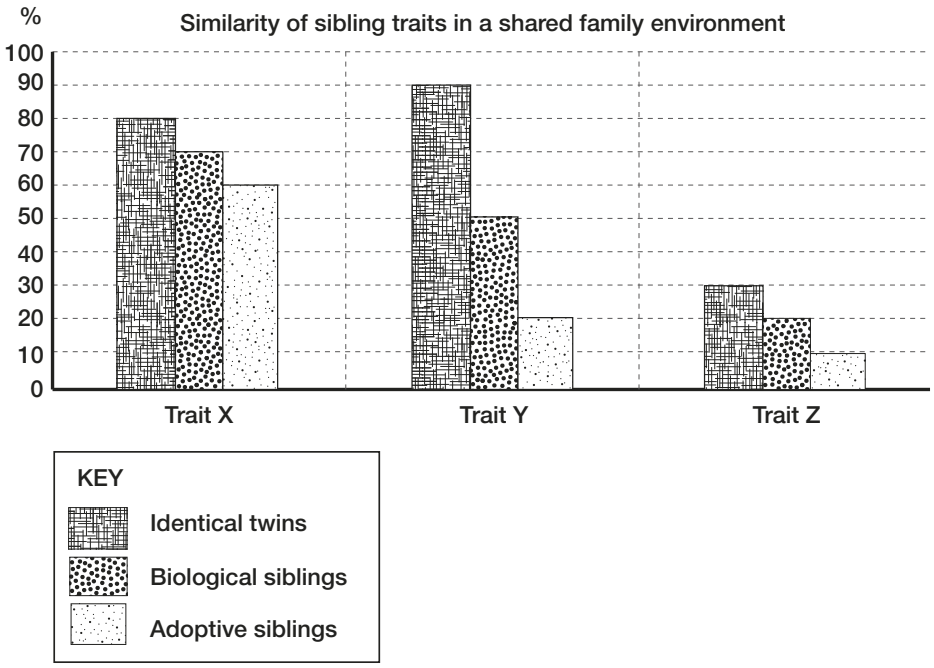
J The absence of prolactin hormone results in multiple miRNAs being produced.

K The presence of prolactin increases casein production.

L Prolactin only works in cows and no other mammals.

M Ribonuclease promotes casein production.

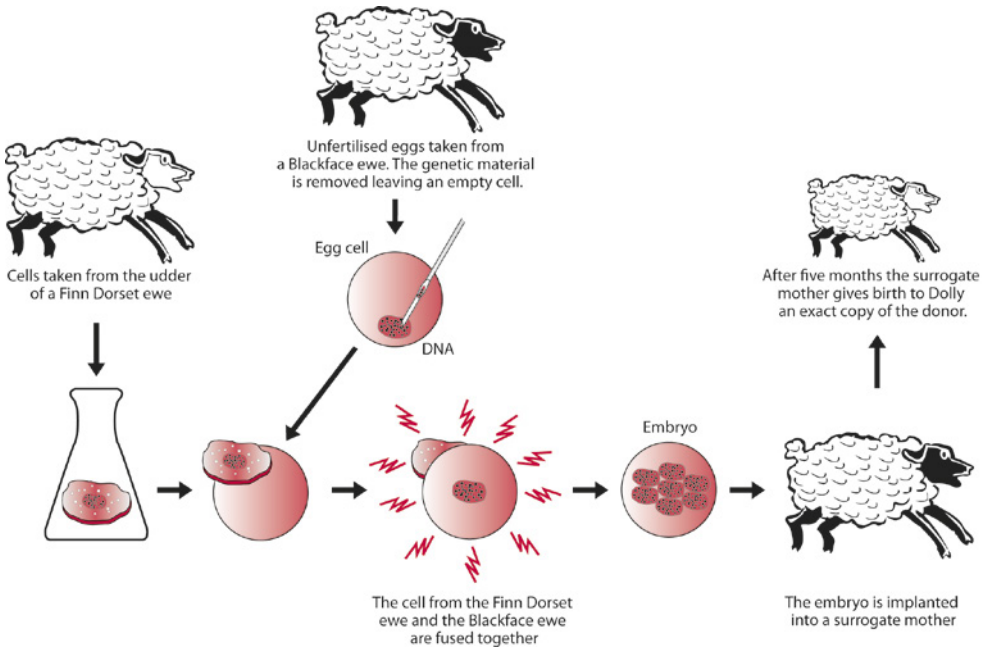
10. *Refer to the graphs below that show the impact of genes and environment on three different traits to answer the following question.*



Which of the following options correctly links the data with how genes and type of family environment affects the three traits?

	Trait X		Trait Y		Trait Z	
	Genes	*Environment*	*Genes*	*Environment*	*Genes*	*Environment*
J.	High	Low	Low	High	Low	Low
K.	High	Low	Low	High	High	High
L.	Low	High	High	Low	High	High
M.	Low	High	High	Low	Low	Low

11. *Refer to the diagram below to answer the question that follows.*



Which one of the following best describes Dolly's DNA make-up?

J Dolly will be both genetically and epigenetically identical to the Finn Dorsett ewe.

K All of DNA in Dolly's body cells is from the Finn Dorsett.

L The epigenome of all of Dolly's DNA will be influenced by the environmental factors experienced by the surrogate Scottish Blackface.

M The nuclear DNA is from the Finn Dorset and the mitochondrial DNA is from the Scottish Blackface.

12. A section of a mRNA molecule that codes for a specific protein has the following code:

…. A A G U C U C C A G U G …

The section of code on a specific lncRNA that acts on the miRNA corresponding to the sequence above is:

J …. A A G T C T C C A G T G …

K …. U U C A G A G G U C A C …

L …. A A G U C U C C A G U G …

M …. G U G A C C U C U G A A …

Free response questions

1. Describe why not all DNA in chromatin is easily expressed.

2. Some genes are expressed 'continuously'.

   a) Describe what this means.

   b) Give examples of such genes and state why it is necessary for them to be expressed in this way.

3. Nerve cells and muscle cells have exactly the same genetic makeup. Explain how it is possible for these cells to have the same DNA but very different structures and functions.

4. Once cells in an organism have fully differentiated, they are almost 'locked in' permanently to that cell type and the inactive DNA tends to remain permanently switched off.
   a) Explain how this is possible.

   b) Explain why stem cells are unlike specialised cells and retain their genetic potential.

5. Describe how baldness in males illustrates the effect of gender on gene expression.

6. Describe two instances where complementary binding of molecules to surface receptors is involved in directing the outcome of cell differentiation.

7. In an experiment, cold packs were attached to the back of a young developing Himalayan rabbit. It was noticed sometime later that the fur that grew was black in colour compared to white fur when a cold pack had not been attached. This colouration was noted as a permanent change.
   a) Predict the likely reasons for the change in fur colour.

   b) Explain how this supports the idea that environmental factors can influence gene expression.

8. The process of DNA methylation has been implicated in cancer.
   a) Compare the likely differences between methylation in a normal cell compared to a cell that is cancerous.

b) Predict the likely reasons that these changes in DNA methylation might lead to cancer.

9. Transcription factors are molecules that can affect the rate of transcription and hence, gene expression.
   a) Describe how an activator protein influences gene expression.

   b) Describe how repressor factors influence transcription of a specific gene.

10. 'Specialised cells have not arisen from differential expression of different sets of genes but varying levels of expression of the same group of genes'. Evaluate the above statement.

11. Studies have shown that young identical twins have nearly identical epigenomes but older identical twins exhibit much greater differences.
   a) Explain why identical twins can exhibit many physical and behavioural differences as they age.

   b) Describe how some epigenetic tags could negatively impact the identical twins.

12. In colon cancer, it is possible to detect high levels of methylation in the DNA (hyper-methylation) early on in the course of the disease.
   a) Name two types of genes where hyper-methylation could possibly lead to tumour formation.

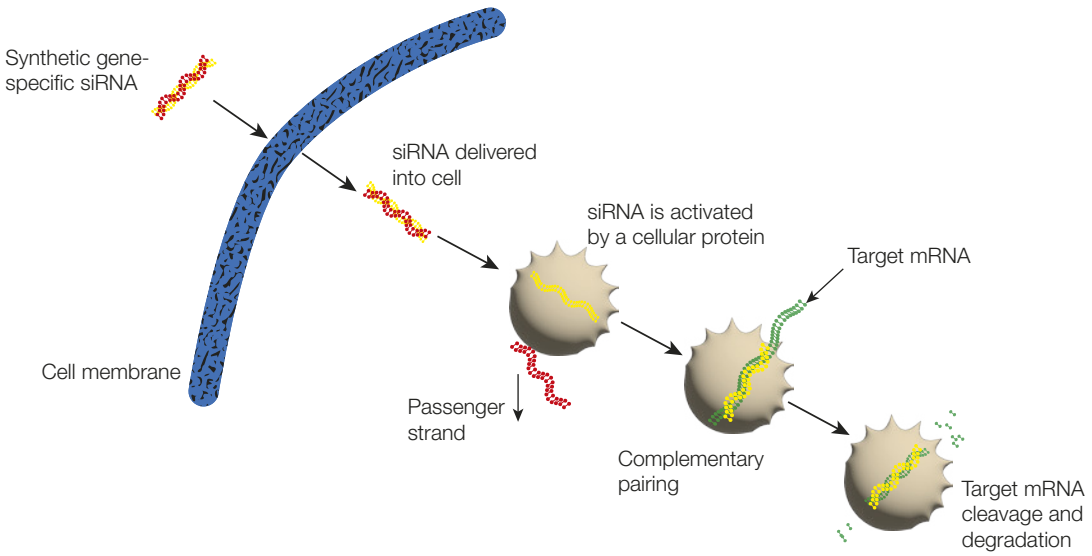
   b) Suggest how hyper-methylation might serve as a biomarker for colon cancer, allowing for early detection of the disease.

13. Post transcriptional factors act on RNA to influence gene expression.
   a) Provide another name for post-transcriptional factors.

   b) i) Describe how miRNA influences gene expression.

      ii) Describe how lncRNAs can affect the role miRNA plays in gene expression.

c) *Refer to the image below to answer the following questions.*



siRNA is another type of post-transcriptional factor. It is double stranded but is converted to a single strand to activate it. Scientists are researching the potential of synthetically made siRNAs to treat some disorders.

i) State if this treatment is better suited to disorders that originate from on overexpression or under expression of a specific protein.

ii) Explain one possible way that synthetic siRNA could be used to treat some types of cancers.

d) Using your knowledge of the interaction between science and society, discuss how research on possible cancer treatments like synthetic siRNAs is influenced by society.

e) Scientists are also researching possible treatments for other diseases affected by changes in gene expression.

Recently, scientists discovered that long term exposure to cold temperatures can cause epigenetic changes that convert energy storing white fat cells into energy burning brown fat cells. They also discovered the exact epigenetic tags to the DNA that caused this shift in gene expression.

Because brown fat cells use stored fats to create heat and keep the body warm, scientists are now researching ways to medically induce the same epigenetic changes to treat obesity.

i) Explain why scientists only change one variable when they are conducting their research.

Use your knowledge of the interaction between science and society to answer the following questions.

ii) Discuss one possible unexpected consequence to society of the researchers being successful at developing a drug to induce weight loss through epigenetic changes to white fat cells.

iii) Discuss one possible biological side effect that the researchers would have to determine prior to applying for their new medication to be approved for sale to treat obesity.

14. Some recent research has indicated that the types of foods a pregnant mother eats and the chemicals she is exposed to, can affect her offspring without causing mutations in DNA.

One example that has been studied concerned asthmatic children. It was found that children in New York City exposed in the uterus (womb) to high levels of polycyclic aromatic hydrocarbons (PAHs), common pollutants from traffic, were much more likely to have asthma than those who were not exposed to the chemical. The researcher found that a particular gene (ACSL3) was altered in asthmatic children and concluded that the changes in the DNA probably caused the asthma.

These changes to the ACSL3 gene appear to be occurring via epigenetic changes to the DNA.

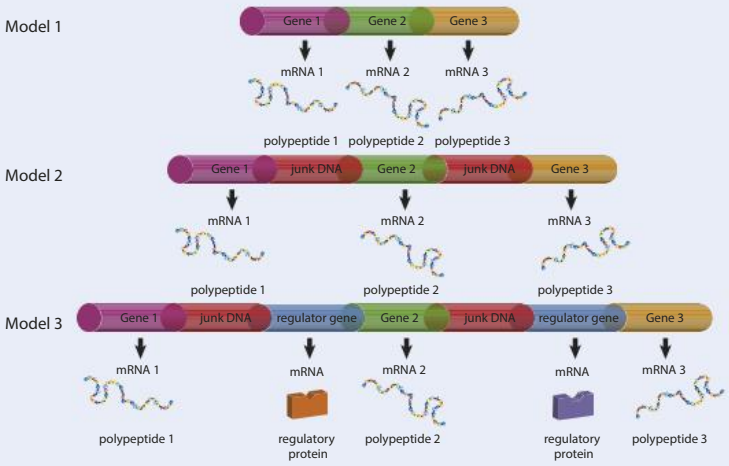
a) Describe some examples of normal cellular processes that control and regulate gene expression.

b) Explain how factors such as the diet and exposure to environmental chemicals may alter the way that genes are expressed. Link your understanding here to the higher incidence of asthma in New York City children.

Science as a Human Endeavour 1.5 - DNA is not mostly 'junk' after all

According to the Watson and Crick model, DNA consists of two strands of nucleotides that form a double helix structure. It was then discovered that one strand consists of segments of DNA base sequences (A, T, G and C) that code for protein. These 'coding DNA' pieces are called genes. In this 'DNA and genes' model (*see Model 1 below*), different genes code for different polypeptides and proteins.

The development of the first DNA sequencing technologies revealed however, that most of the bases in DNA actually do not code for proteins. This 'non-coding' DNA was thought to have no real function and so was called 'junk DNA'. According to this 'Junk DNA' model, DNA consisted of coding segments of DNA interspersed between vast amounts of junk (*see Model 2 below*).



Today, thanks to even better DNA sequencing and other technologies, it seems very likely that at least some of the once-called 'junk' DNA has a function. Just as coding DNA uses (coding) mRNA to make proteins, so non-coding DNA might be using (non-coding) RNA to regulate gene expression. This 'junk DNA regulates genes' model is currently the subject of intense scientific research (*see Model 3*).

1. Model 3 more closely represents current thinking of how genes are expressed. Describe two ways this differs from the original model (Model 1).

2. Discuss the impact that the original discovery of model 3 would have had on the scientists researching genetic diseases.

Chapter 1.6 Mutations

Science Understanding

Changes in the DNA sequence are called 'mutations'.

Mutations in genes and chromosomes can result from errors in DNA replication or cell division, or from damage by physical or chemical factors in the environment.

Mutation rate can be increased by:

- ionising radiation
- mutagenic chemicals
- viruses.

- Compare the different potential consequences of mutations in germ cells and somatic cells.
- Explain how inheritable mutations can lead to changes in the characteristics of the descendants.

In Chapter 1.5 it was noted that the code written in the DNA base sequence is not always expressed in a straight forward manner. Epigenetic changes can lead to changes in gene expression, often by a process called 'DNA methylation' and these changes can be passed on from one generation to the next if it occurs in the gametes.

In contrast, **mutations** are permanent changes to the actual sequence of DNA bases and these changes can lead to the alteration or absence of proteins and subsequent changes to the appearance of offspring (phenotype). Mutations to the gene structure generally occur during the phase of the cell cycle when DNA replication occurs or during cell division (either mitotic or meiotic division). This happens when the DNA strands unwind and the **bases are exposed** and vulnerable to damage, or incorrect bases are inserted in position.

The impacts of mutations include:

- **Genetic disease;** for example, as a result of a mutation either the polypeptide that is produced has the incorrect 3-D structure, or it is not produced at all. If this occurs to a protein that is required for the organism to function normally then a genetic disorder or disease may develop.
- **Cancer**; for example, if a mutation occurs in one of the genes that is used to produce a type of protein that is involved in the regulation of the cell cycle, then uncontrolled cell division may result, leading to the formation of tumours.

Each species on Earth is thought to have evolved from a common ancestor. DNA differs from one species to the next due to the accumulation of mutations in DNA over millions of years. **Mutations are random events** occurring spontaneously and, whilst environmental factors can cause or change rates of mutations, the environment does not direct the changes.

Types of Mutations

Point mutations occur to the genetic code of human cells every day, generally through mistakes in DNA replication. These point mutations mostly occur in the non-coding DNA and have little to no effect; however, on the rare occasion it occurs to coding DNA, consequences to the cell and organism could arise. A point mutation results from a single base being substituted, inserted, or deleted. The effect this has will depend on whether the point mutation is a silent, missense, nonsense or frameshift mutation.

Base substitutions

A base substitution is where one nucleotide, with a base attached, is **substituted** for a different one (see *Figure 161*); for example, a guanine could be replaced with an adenine during DNA replication.

Base insertions and deletions

A **single base insertion or deletion** generally results in a **frameshift mutation**. This type of mutation will alter all the genetic code significantly and therefore the primary structure (amino acid sequence) of the resultant polypeptide as well. As mRNA is read in sequences of three bases called codons, a single base insertion or deletion will alter the 'frame' of the reading, from the site of the mutation onwards. Examples of these types of mutations are illustrated in *Figures 161* and 162.

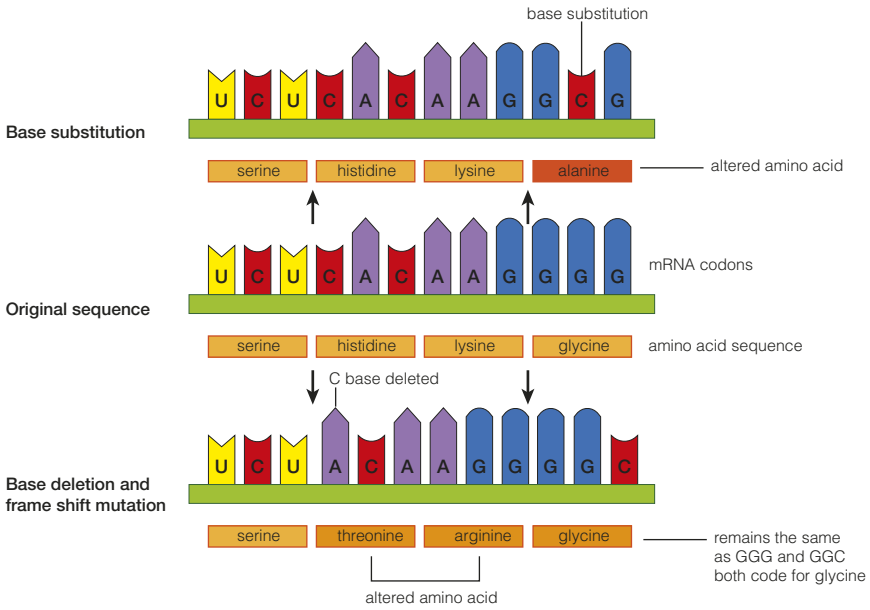


Figure 161 An example of a single base substitution and single base deletion

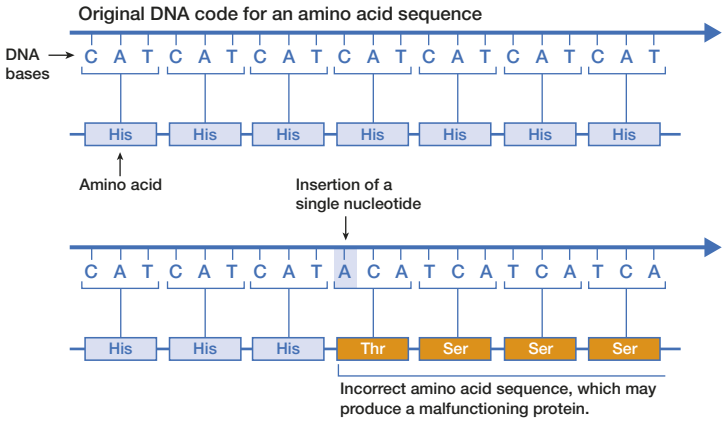


Figure 162 Insertion mutations change the frame of reading of the genetic code

Silent mutations

A **silent mutation** occurs when a base substitution results in the altered codon corresponding to the **same amino acid** (see *Figure 163*). This can occur because there are 64 codons that code for the 20 amino acids, meaning some amino acids are coded for by multiple codons. This type of mutation would not have an effect on the resultant polypeptide or protein.

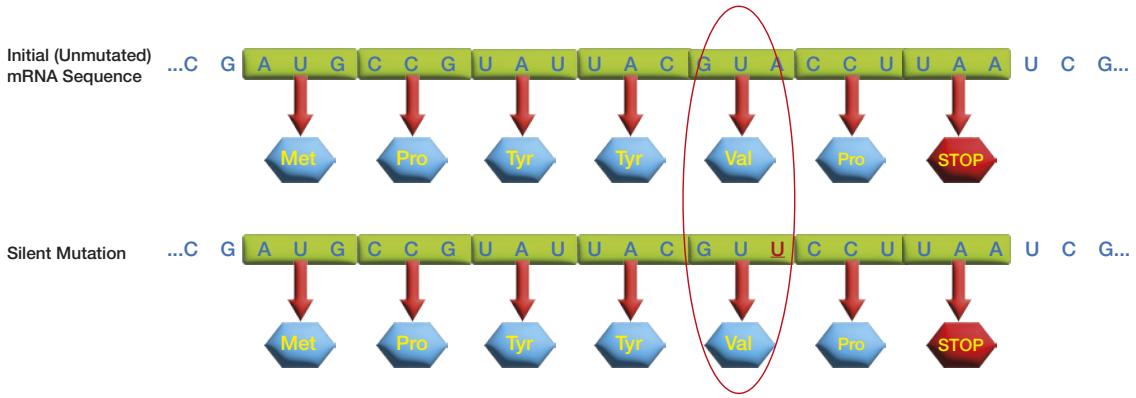


Figure 163 An example of a silent mutation resulting in the same valine amino acid

Missense mutations

A **missense mutation** occurs when a base substitution results in the altered codon coding for a **different amino acid** (see *Figure 164*). This will alter the amino acid sequence in the polypeptide or protein and hence it's function.

Nonsense mutations

A **nonsense mutation** occurs when a base substitution results in the altered codon coding for a **stop codon** instead of an amino acid (see *Figure 164*). This will lead to a **shortened polypeptide** as translation will stop prematurely.

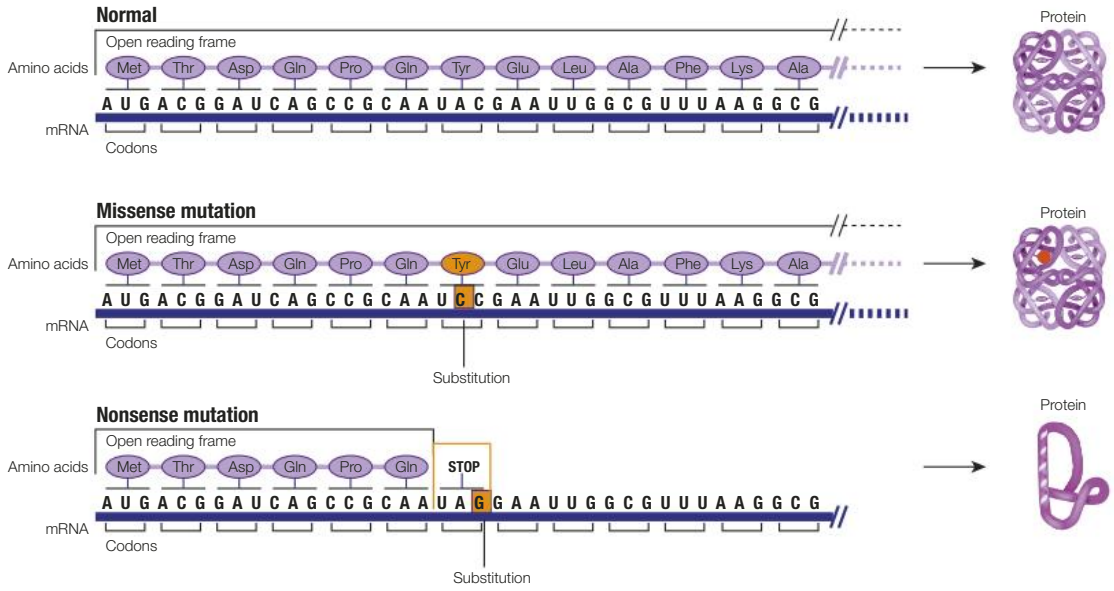


Figure 164 An example of a missense and a nonsense mutation and the effects on the resultant protein

Helpful online resources

Cognito: GCSE Biology - What are DNA Mutations?

<https://www.youtube.com/watch?v=3jwDI7nYBPM>

Khanacademymedicine: The different types of mutations | Biomolecules | MCAT | Khan Academy

<https://www.youtube.com/watch?v=xYOK-yzUWSI>

Large scale mutations

Another type of mutation involves large-scale changes to the structure or number of chromosomes in a cell. These changes often occur during meiotic division (the cell division that gives rise to gametes) as this is when chromosomes pair and then separate into gametes.

Examples of these mutations include:

Deletion: genetic material breaks off from a section of the chromosome and is lost.

Duplication: genetic material is duplicated and extra copies of genes are found on the chromosome.

Translocation: a section of one chromosome detaches and moves to a new chromosome.

Inversion: a section of broken chromosome is inserted back but the segment is reversed during the process.

Insertion: a secton of DNA from one chromosome may be removed and added to another chromosome.

Aneuploidy: a chromosome mutation that leads to individuals with an abnormal number of chromosomes. Examples will be discussed later in this chapter.

Refer to *Figure 165* which illustrates these types of changes to chromosome structure.

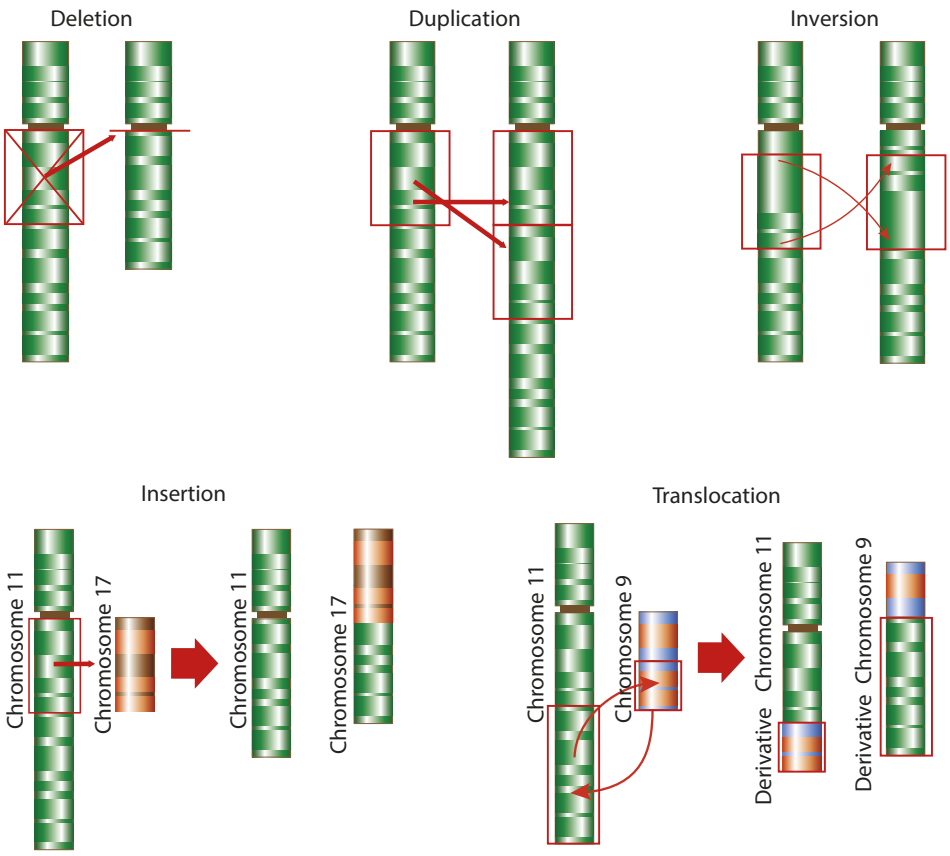


Figure 165 Different types of chromosomal changes

Factors that increase the rate of mutation

Mutations occur spontaneously in organisms but the natural rate is quite low. Rates of mutation can be increased by physical, chemical or biological factors called **mutagens** (see *Figure 166*).

Ionising radiation

The most common **physical agents** are high-energy radiation like X-rays or ultraviolet light (UV). Humans can be exposed to both naturally occurring and other forms of radiation that increase mutation rates. UV radiation from the sun can create bonds between DNA bases that would not normally exist, leading to disruptions to transcription and translation. **Ionising radiation** e.g. X-rays may create ions which break sugar-phosphate backbones or base pairs in the DNA.

Mutagenic chemicals

Certain chemicals in the environment can also increase mutation rates. Generally, these chemicals either:

- cause chemical changes to particular bases
- mimic the shape of normal bases and thus disrupt the DNA replication process
- disrupt cell division leading to chromosomal errors
- cause direct damage to chromosomes which may lead to breaks

Some examples of chemical mutagens include:

- cigarette smoke (contains multiple mutagens including benzopyrene)
- asbestos (a fibrous silicate material that had many uses in the past)
- benzene (found in petrol)
- vinyl chloride (found in plastics)
- etoposide (a chemotherapy drug)

Viruses

Viruses are infective particles that do not have independent existence but rely on the host cell to survive and reproduce. A typical mode of action of the virus is to inject their DNA or RNA into the host cell and it then incorporates with the host genetic material. **Viruses are biological agents** that may induce the usual substitution, insertion and deletion mutations.

It has also been estabished that some long-lasting virus particles, such as hepatitis B, induce the host to secrete chemicals that, over time, can lead to mutations.

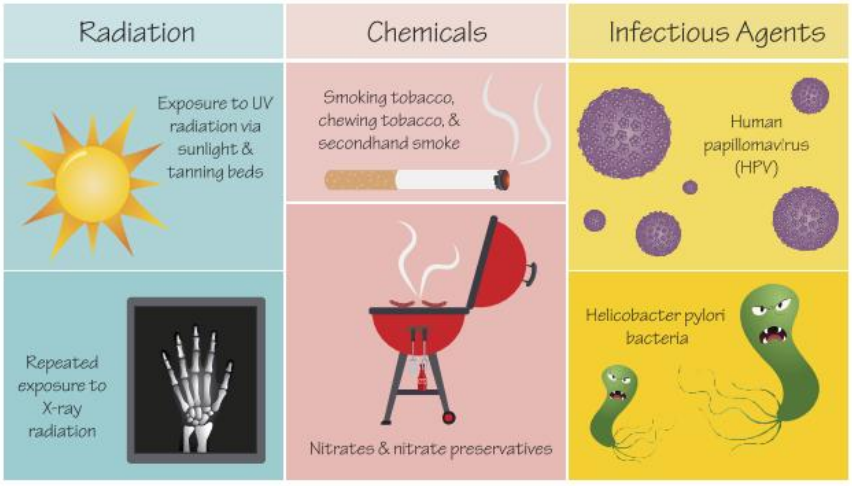


Figure 166 Some examples of physical, chemical and biological mutagens

Helpful online resources

Khanacademymedicine: Mutagens and carcinogens | Biomolecules | MCAT | Khan Academy
<https://www.youtube.com/watch?v=4mrp5ul9anE>

Kurzgesagt - In a Nutshell: Could Your Phone Hurt You? Electromagnetic Pollution
<https://www.youtube.com/watch?v=FfgT6zx4k3Q>

Consequences of mutations

Mutations in genes can lead to changes in the characteristics of the descendants. It is important to distinguish two types of cells in which mutations can occur.

Germline cells

Germline cells are any cells in the testes and ovaries that give rise to gametes (sex cells). There are two types of gametes, sperm cells in males and egg cells (ova) in females. **Germline cell mutations** can be passed on (inherited) in the cells of future generations. When the DNA replicates as the new embryo grows, the mutated or faulty gene is also replicated and appears in all new cells.

Somatic cells

Somatic cells (body cells) refer to every cell in the body, excluding gametes. **Somatic cell mutations** can cause serious disease but it will not be passed on (non-inheritable) to the future generations.

Examples of human diseases resulting from mutations

Two examples of human diseases that can be caused by mutations the DNA are sickle-cell anaemia and cystic fibrosis.

Sickle cell anaemia

This disease is a blood condition that is often fatal. A gene, located on chromosome 11, coding for the haemoglobin protein has a base substitution which gives rise to a **single amino acid change** (missense mutation). The haemoglobin formed is abnormal and gives rise to sickle-shaped red blood cells that do not carry oxygen as efficiently. A molecule of haemoglobin has two pairs of polypeptide chains; one with

141 amino acids and the other with 146 amino acids. In people suffering from sickle-cell anaemia, in one of the chains the amino acid glutamic acid is replaced by the amino acid valine.

Interestingly, the reason that this faulty gene has not been eliminated from the human population during evolution is that in countries where malaria is prevalent, having one copy of this faulty gene actually assists in the survival of the person if they are infected with the malarial parasite.

Refer to *Figure 167* showing the sickle-shaped red blood cells caused by this mutation.

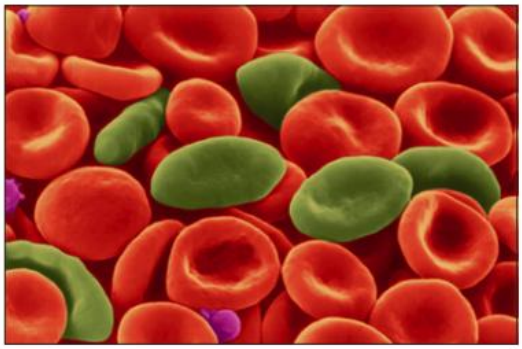


Figure 167 Normal red blood cells and sickle cells (green)

Helpful online resources

TED-Ed: How this disease changes the shape of your cells - Amber M. Yates
<https://www.youtube.com/watch?v=hRnrIpUMyZQ&t=53s>

Cystic Fibrosis (CF)

This is another inherited disease whereby sufferers experience a range of debilitating symptoms. Humans have a gene ('CFTR', on chromosome 7) that makes a protein which controls the movement of salt and water across the membranes of all cells. People who suffer from CF have inherited a mutation in the CFTR gene causing production of a faulty protein that leads to the production of thick sticky mucus and salty sweat in the respiratory and digestive organs. This makes breathing and digesting food difficult, inefficient and sometimes painful. To suffer from the condition, people must have inherited two faulty copies of the gene, one from each parent.

Refer to *Figure 168* which indicates the impact of this disease on a range of organs in the human body.

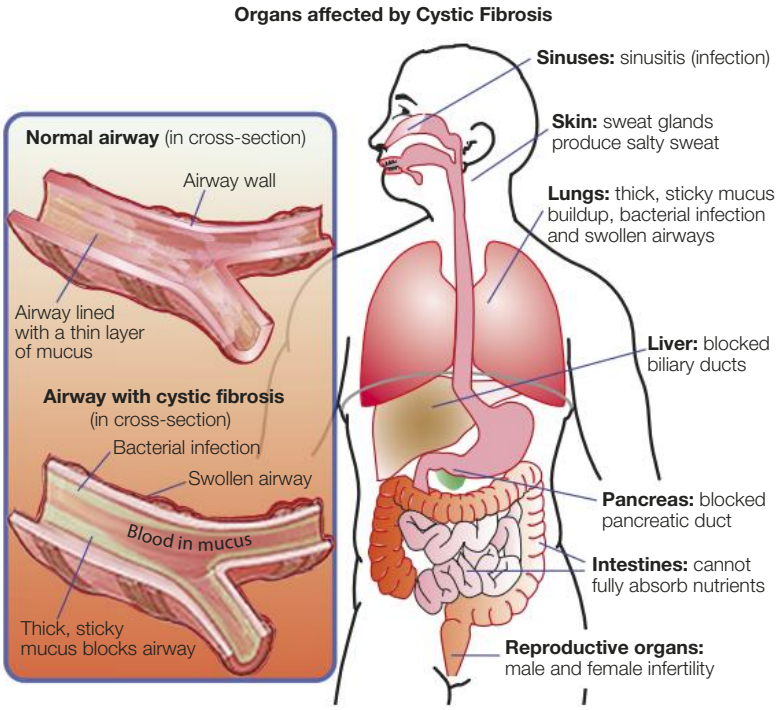


Figure 168 The main symptoms of Cystic Fibrosis

Helpful online resources

SciShow: New Cystic Fibrosis Treatment a “Game-Changer” | SciShow News
<https://www.youtube.com/watch?v=8uqvfIKjmEY>

Mutations are also a source of variation

Although mutations in somatic cells will not be passed on to future generations, these changes can cause significant disease. Many cancers are caused by somatic cell mutations. Most mutations discussed have been harmful. This is to be expected as any random change to the DNA which has been evolving over millions of years is unlikely to bring about a positive change. However, as will be discussed later in the book, mutations are the source of new genes and changes in phenotype which provide a source of variation on which natural selection can act.

One example of a contemporary mutation which has been beneficial for some humans is a mutation in the ‘CCR 5-Delta 32’ gene which results in a smaller cell membrane receptor. It has been noted that individuals with this mutation are less likely to suffer from HIV infection as the virus cannot use this receptor to enter human cells and then replicate.

Refer to *Figure 169* indicating how the HIV virus penetrates a white blood cell. At first the virus attaches to a CD4 receptor(blue) and then subsequently a CD5 receptor (green).

In the case of the favourable mutation the virus is unable to bind to the second receptor and then unable to inject its DNA into the cell.

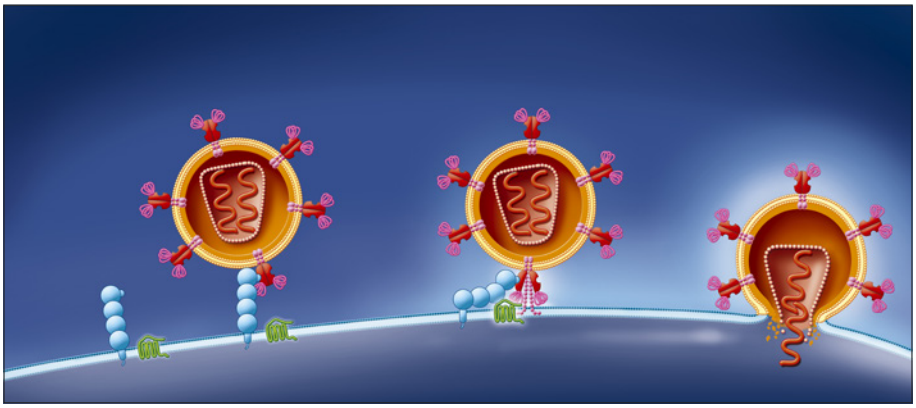


Figure 169 How the HIV virus penetrates a white blood cell

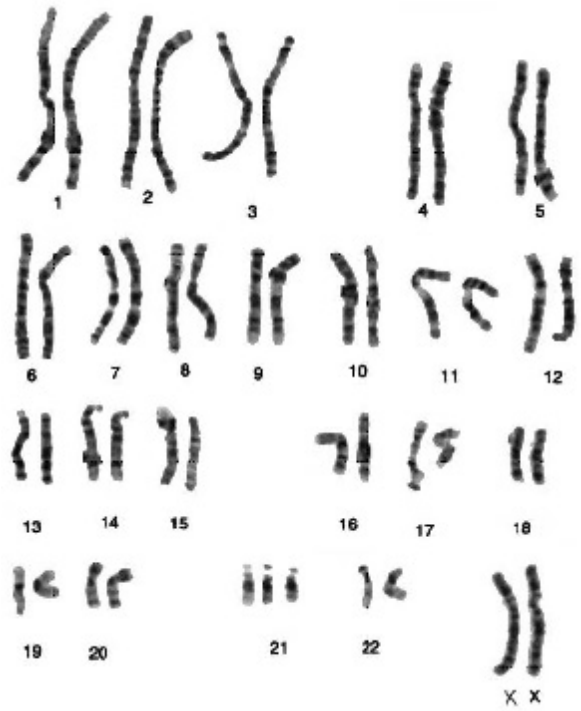
Consequences of abnormal chromosome numbers

Two disorders that can be observed in offspring as a result of an abnormal number of chromosomes are *Klinefelter syndrome* and *Down syndrome*. Both of these conditions are caused by what is termed **non-disjunction** which is a failure of chromosomes to separate properly during meiosis when gametes are being formed. In *Klinefelter syndrome* this results in males that have an extra X sex chromosome. Non-disjunction of chromosome 21 causes *Down syndrome* that results in either males or females having an extra chromosome 21, as shown in the **karyotype** in *Figure 1610(b)*.

Klinefelter syndrome is the most common chromosome disorder in men – approximately 1 in 650 male babies are born with it. Children grow up with very low levels of testosterone (the male sex hormone) which results in reduced muscle development, little to no body hair, and sterility.

Down syndrome occurs in both males and females - somewhere between 1 in 700-900 babies world wide are born with Down syndrome each year. People with Down syndrome are short in statue and have a distinct facial appearance, intellectual disability, and often abnormalities to the function of organs like the heart and thyroid gland. See *Figure 1610*(a).

Refer also to *Figure 1610*(b) which shows the extra chromosome 21 found in individuals with *Down syndrome.*



Figures 1610 (a) A boy with Down syndrome and 169 (b) Karyotype of a female with Down syndrome

1.6 Review questions

Multiple choice questions

1. Mutations are most likely to occur during the process of:
   - J transcription
   - K translation
   - L fertilisation
   - M replication

2. *Refer to the following diagram showing the result of a mutation in a short sequence of template DNA from a gene coding for a particular polypeptide.*

Original sequence

Mutated sequence

Which of the following options, best describes the impact this type of mutation would have on a polypeptide synthesised from this mutated gene?

- J A significantly altered polypeptide will be formed from the mutated DNA.
- K A polypeptide will be produced that differs by one amino acid.
- L There would be no change in the polypeptide formed.
- M Two amino acids in the polypeptide sequence would change.

3. *Refer to the sections of original and mutated template DNA sequences below to answer the question that follows.*

Original template DNA sequence: 3' –TAG CGC GCG ATT – 5'
Mutated template DNA sequence: 3' –TAG CCC GCG ATT – 5'

Based only on the information provided in this question, the mutation would be classified as a:

J Missense mutation.

K Silent mutation.

L Nonsense mutation.

M Point mutation.

4. An example of a chemical mutagen is:

J UV radiation.

K Asbestos.

L Methylation.

M A virus

5. X-rays are an example of:

J a chemical mutagen that decreases the mutation rate.

K a chemical mutagen that increases the mutation rate.

L a physical mutagen that increases the mutation rate.

M a physical mutagen that decreases the mutation rate.

6. Which of the following statements with regards to mutations is most correct?

J A frameshift mutation results from a DNA base substitution.

K A nonsense mutation in a sperm cell cannot be inherited by a descendant.

L A missense mutation in a somatic cell will be passed on to offspring.

M A silent mutation in an egg cell will have no effect on the characteristics of a resulting descendant.

7. Resistance to insecticides has been observed in populations of fruit flies. The resistance developed through mutation.

Insecticide resistant fruit flies have the sequence UCU at a specific section of the mRNA sequence, whereas the 'normal' fruit flies that are susceptible to the insecticide exhibit the sequence GCU.

This mutation is a:

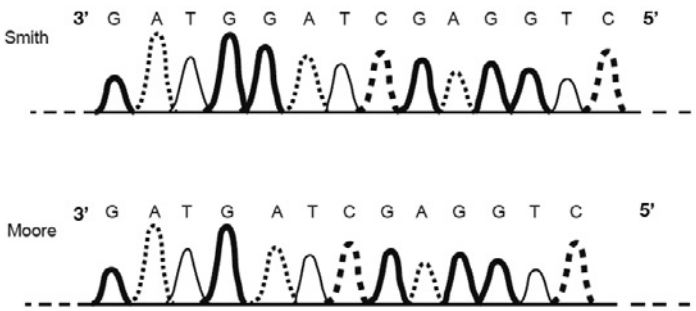
J base substitution that occurred during mitosis of a body cell.

K chromosomal deletion that occurred during mitosis of a body cell.

L base substitution that occurred during meiosis of a sperm cell.

M chromosomal deletion that occurred during meiosis of an egg cell.

8. The following electropherogram shows a small section of corresponding template strand DNA for two individuals. This section of DNA controls the expression of a specific gene. Moore suffers a genetic disease that has been linked to this section of DNA; however, Smith does not have this genetic disease.



With reference to the electropherogram on the previous page, it is reasonable to conclude that:

J A deletion of a nucleotide could be the cause of Moore's genetic disorder.

K The complementary coding strand sequence for this section of template DNA would be:

5' C T A C C T A G C T C C A G 3'

L The mRNA transcribed from the template DNA sequence for Smith would be:

5' G A U G G A U C G A G G U C 3'

M The sequences for both Smith and Moore code for five amino acids.

Refer to the table below showing mRNA codons and their corresponding amino acids, to answer questions 9 and 10.

UUU	phe	UCU	ser	UAU	tyr	UGU	cys
UUC	phe	UCC	ser	UAC	tyr	UGC	cys
UUA	leu	UCA	ser	UAA	stop	UGA	stop
UUG	leu	UCG	ser	UAG	stop	UGG	trp
CUU	leu	CCU	pro	CAU	his	CGU	arg
CUC	leu	CCC	pro	CAC	his	CGC	arg
CUA	leu	CCA	pro	CAA	gln	CGA	arg
CUG	leu	CCG	pro	CAG	gln	CGG	arg
AUU	ile	ACU	thr	AAU	asn	AGU	ser
AUC	ile	ACC	thr	AAC	asn	AGC	ser
AUA	ile	ACA	thr	AAA	lys	AGA	arg
AUG	start/met	ACG	thr	AAG	lys	AGG	arg
GUU	val	GCU	ala	GAU	asp	GGU	gly
GUC	val	GCC	ala	GAC	asp	GGC	gly
GUA	val	GCA	ala	GAA	glu	GGA	gly
GUG	val	GCG	ala	GAG	glu	GGG	gly

9. An individual was exposed to a mutagenic chemical. A section of the template DNA sequence before and after the exposure is shown below:

Original template DNA sequence: 3' GCC TAG GTC CCC GGC GAT ATC 5'

Mutated template DNA sequence: 3' GCC TAA GTT CCC GGC AAT ATC 5'

This chemical exposure:

J resulted in the introduction of a stop codon and a shorter mRNA molecule than the original code.

K has caused two missense mutations that would impact the structure of the translated protein.

L has caused three silent mutations that would impact the structure of the translated protein.

M has had no effect on the protein coded for by this DNA sequence.

10. Another individual was also exposed to the chemical mutagen. The changes to a section of the individual's template DNA sequence are show below:

Original template DNA sequence: 3' TAC TAG ATG GCA CGC ACA ATA 5'

Mutated template DNA sequence: 3' TAC AAG ATT GGA CGC ACA ATA 5'

Which of the following statements is most correct?

J The mutated DNA sequence would produce a polypeptide that differs by three amino acids to a polypeptide produced from the original DNA sequence.

K A thymine base was inserted at the ninth position of the mutated DNA sequence.

L The polypeptide translated from the mutated sequence would be two amino acids in length.

M The exposure resulted in one missense mutation and one nonsense mutation.

Free response questions

1. Name one chemical, physical and biological factor that can act as a mutagen.

   Biological: .

   Physical: .

   Chemical: .

2. Name four types of large scale chromosome mutations that occur and lead to an alteration in chromosome number or structure.

3. State, giving reasons, during what cellular processes the following are likely to occur:

   a) point mutations .

   b) large scale chromosome mutations..

4. Describe how ionising radiation is likely to increase the rate of mutation.

5. Using your knowledge of the complementary base pairing of DNA, suggest likely ways that chemical mutagens might alter the normal sequence of DNA.

Refer to the following table showing mRNA codons and their corresponding amino acids to answer questions 6 and 8

UUU	phe	UCU	ser	UAU	tyr	UGU	cys
UUC	phe	UCC	ser	UAC	tyr	UGC	cys
UUA	leu	UCA	ser	UAA	stop	UGA	stop
UUG	leu	UCG	ser	UAG	stop	UGG	trp
CUU	leu	CCU	pro	CAU	his	CGU	arg
CUC	leu	CCC	pro	CAC	his	CGC	arg
CUA	leu	CCA	pro	CAA	gln	CGA	arg
CUG	leu	CCG	pro	CAG	gln	CGG	arg
AUU	ile	ACU	thr	AAU	asn	AGU	ser
AUC	ile	ACC	thr	AAC	asn	AGC	ser
AUA	ile	ACA	thr	AAA	lys	AGA	arg
AUG	start/met	ACG	thr	AAG	lys	AGG	arg
GUU	val	GCU	ala	GAU	asp	GGU	gly
GUC	val	GCC	ala	GAC	asp	GGC	gly
GUA	val	GCA	ala	GAA	glu	GGA	gly
GUG	val	GCG	ala	GAG	glu	GGG	gly

6. Consider the sequence of template DNA with the following anticodons.

DNA anticodon	CGA	CAC	GGT	ATA
mRNA codon	GCU	GUG	CCA	UAU
Amino acid code	ala	val	pro	tyr

Use the table above and the mRNA codon table to help you answer the following questions:

a) Complete the following table showing a single point mutation:

Original DNA	CGA	CAC	GGT	ATA
Altered DNA	CGA	GAC	GGT	ATA
mRNA codon				
Amino acid code				

b) Which base was substituted in the altered DNA? . . . . . .

c) Describe the effect that this has had on the amino acid sequence formed. . . . . .

. . . . . .

d) Complete the following table showing a **different** single point mutation:

Original DNA	CGA	CAC	GGT	ATA
Altered DNA	CGA	ACG	GTA	TAT
mRNA				
Amino acid code				

e) State the type of point mutation that has occurred to this sequence? . .....

f) With reference to the table above, explain the effect this type of mutation will have on the polypeptide chain/protein that forms from this altered sequence.

7. Compare and contrast mutations and epigenetic changes in DNA.

8. Below is a short section of the template DNA bases that code for the production of the haemoglobin protein.

3' TGA GGA CTC CTC 5'

The mutation that gives rise to sickle cell anaemia has the altered template DNA sequence:

3' TGA GGA CAC CTC 5'

a) Identify the alteration to the base sequence? .

b) State if this is an example of a single base substitution, insertion or deletion? .

c) Using the table showing mRNA codons and their corresponding amino acids on page 88, determine if this single base change is a silent, missense or nonsense mutation and justify your answer.

d) Explain the effect of this type of mutation on the haemoglobin protein and its role in an organism.

9. Benzopyrene is a chemical mutagen found in cigarette smoke.

a) Explain how benzopyrene could contribute to lung cancer associated with cigarette smoking.

b) Explain why lung cancer associated with cigarette smoking would not be an inheritable disease.

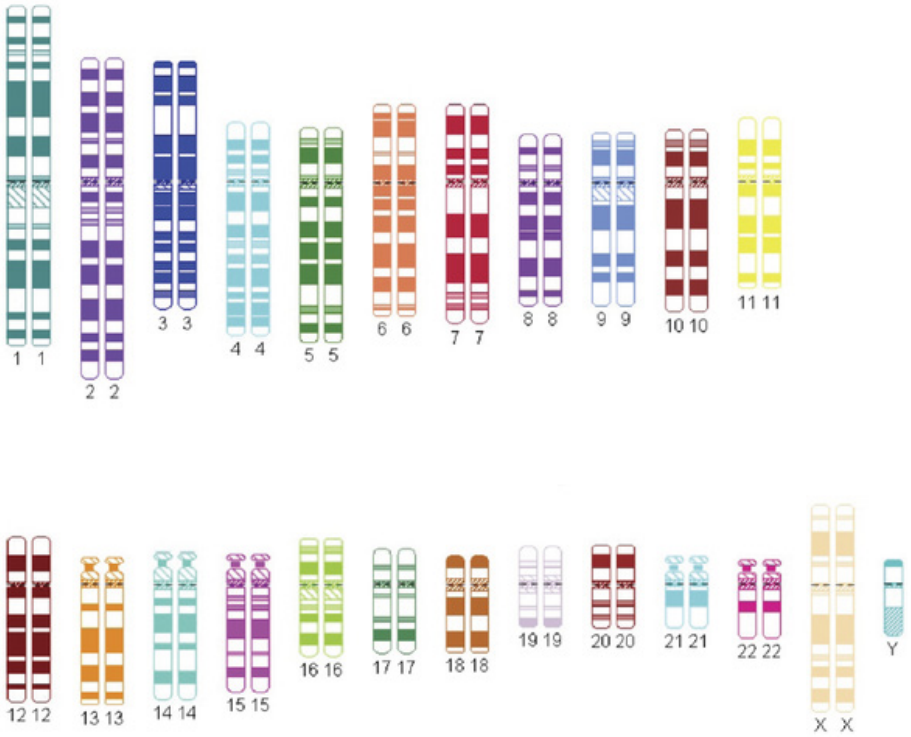
10. Explain how an accumulation of mutations in DNA over millions of years has contributed to the variety of species on Earth today.

11. Mutations can occur in either gamete (germline) or somatic cell types.

Using examples, explain the different effects of mutations to these two types of cells and the individual.

12. Explain how it is possible that a single base substitution mutation in the gene coding for a specific polypeptide may have no effect on the actual polypeptide produced.

13. Refer to the diagram below of the karyotype of a person suffering from *Klinefelter* syndrome.



a) State the chromosomal disorder seen in the karyotype.

b) During what cellular process is this likely to occur?

c) Explain why the symptoms associated with the disease are likely to be severe.

14. The drug etoposide can be used as a powerful chemotherapy drug in the treatment of cancer. Using your knowledge of its impact on chromosomes, infer how it might help in destroying cancerous cells.

Science as a Human Endeavour 1.6 - Gene therapy clinical trials

Science is a major global process that seeks to develop solutions to problems that are based on evidence. It is dependent on a huge number of teams of scientists across the world who work with existing scientific knowledge to discover new ways of understanding the world around us and to make new products and technologies that improve the quality of life for all. To sustain this scientists and scientific institutions require trained staff and adequate funding and rely on clear processes of communication, internationally understood and acknowledged conventions, and regular and open reviews of results.

Biological sciences operate in the same way. One example is the field of gene therapy. The first gene therapy to be approved was undertaken in 1990 to attempt to treat an immune deficiency disease called SCID (or severe combined immune-deficiency). By the mid-1990s gene therapy looked set to revolutionise medicine but within a few years the technology was plagued by side-effects and support fell away. Since then, however, gene therapy technologies have improved a great deal. With hundreds of clinical trials now going on, expectations that gene therapy will deliver effective treatments are high.

You may need to refer to the online resources below to answer the questions that follow.

1. The use of clinical trials in gene therapy is an example of an international convention used by all scientists and doctors prior to the widespread use of any therapy or drug to treat human patients. In December 2016 Phase 3 clinical trials were announced for a gene therapy to treat a motor neuron disease called SMA (or spinal muscular atrophy) that affects about 1 in 11,000 Australian babies.

   Describe what a Phase 3 clinical trial like this is designed to determine and discuss the communication involved in coordinating a Phase 3 trial.

2. In the United States, review of results gathered by clinical trials of SCID treatments that used gene therapy took place ten years after the treatment had been approved for use. Explain why review of results of clinical trials is essential to the scientific process and why the public is dependent on this occurring even if it is well after the procedure is being used to treat patients.

Helpful online resources

Demystifying Medicine McMaster: Clinical Trials: It's not just a phase!

<https://www.youtube.com/watch?v=wcXbP-F_4K4>

Chapter 1.7 Biotechnology: tools and techniques

Science Understanding

DNA can be extracted from cells.

Modern techniques can be used to analyse even small amounts of DNA.

Segments of DNA can be multiplied using the polymerase chain reaction (PCR).

- Describe PCR, including the roles of
  - heating and cooling
  - primers
  - free nucleotides
  - heat-resistant enzymes.

The base sequence of DNA can be determined by electrophoresis.

- Describe electrophoresis.

The results of electrophoresis may be displayed in an electropherogram.

- Interpret electropherograms that illustrate DNA sequences.

DNA sequencing enables mapping of species' genomes.

The results of electrophoresis can be used to construct DNA profiles. They may be displayed in an electropherogram or in a table of data.

- DNA profiling identifies the unique genetic makeup of individuals.
- Interpret electropherograms and tables of data that illustrate DNA profiles.
- Explain how differences in DNA fragments, identified by DNA profiling, can be used; for example, in forensic science.
- Discuss the ethical, economic, and cultural issues related to the collection of genetic information.

Biotechnology

The use or application of science to provide solutions to problems is called technology. **Biotechnology** refers to forms of technology that are based around biology. It is not new, because humans have been using biological techniques and processes for thousands of years to make bread, wine, cheese and other products. In the last few decades, with the advancement of scientific discoveries, new and continually developing ranges of tools, processes and technologies are emerging that enhance human wellbeing and potentially help the planet and its ecosystems.

This chapter will present and discuss a range of the most commonly used **tools and techniques** used in biotechnology and the following chapter will examine a range of applications.

Extracting DNA from cells

Genetic material can be manipulated. In other words, it can be deliberately altered by scientists who can transfer DNA from one species to the DNA of another species. It is possible to move DNA between species as the **genetic code is universal**. This means that the same mRNA codon codes for the same amino acid in every organism. This makes it possible to introduce a human gene that can code for insulin to a bacterium which can then make the human protein insulin. Prior to transferring DNA, it must be **extracted from cells**. A simple method to extract DNA is:

1. Obtain cell/tissue sample.
2. Centrifuge (spins) the cells at high speeds to separate the nucleus from the other smaller organelles.
3. Add detergents to physically break down the nuclear membrane, exposing the chromosomes.
4. The DNA then has to be isolated from the histone proteins.

As has already been discussed, the human genome has 46 chromosomes and around 21,000 protein-coding genes. Given that the average size of a gene is many thousand bases on the template strand, it is not hard to appreciate how difficult it is to locate or select a particular gene that scientists wish to work with.

Helpful online resources

Genetic Science Learning Centre: DNA Extraction:
<http://learn.genetics.utah.edu/content/labs/extraction/>

Gene probes

Gene probes are single-stranded DNA or RNA segments that have been constructed in the laboratory. They can be used to select particular genes because they have **radioactive or fluorescent markers** that enable them to be readily located. The probes work by binding in a complementary manner to the 'gene of interest'. When it binds to the probe, the gene of interest is said to have been **hybridised** with the radioactive probe. Refer to *Figure 171*.

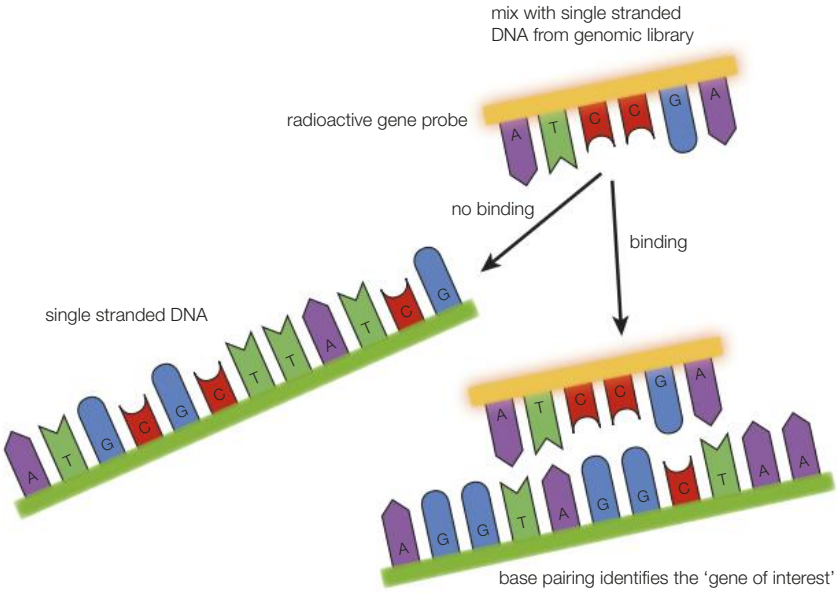


Figure 171 The use of gene probes

Figure 172 reveals a grid of DNA fragments making up the human chromosome 17. Scientists have isolated this to be the site of a defective gene responsible for many cases of inherited breast cancer. The grid represents pieces of DNA which have been spotted onto filter paper and following this, an X-ray plate has been superimposed showing fragments tagged with a radioactive marker. These tagged fragments, some of which correspond to genes, have been hybridised to help researchers map genes on a chromosome.

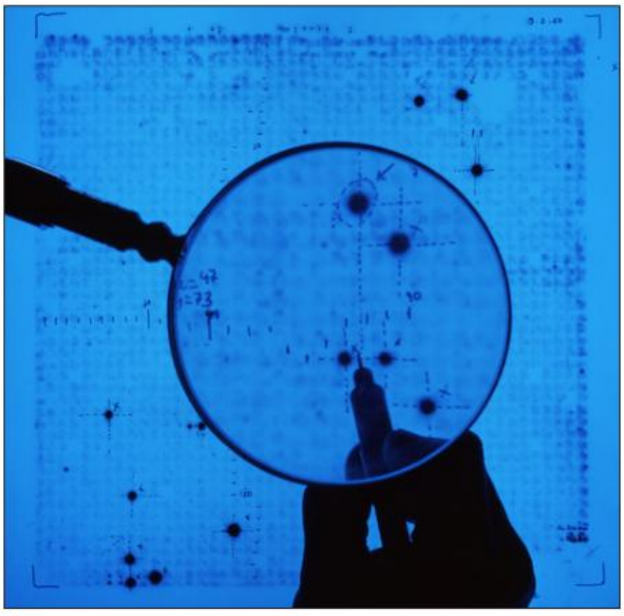


Figure 172 Using hybridisation to locate the gene for breast cancer

Restriction enzymes

Bacteria produce **restriction enzymes** (endonucleases) which **cut DNA** naturally and thus act as a defence mechanism against viral DNA that may invade the bacteria. These enzymes were discovered in 1970 and not long after they were used in a type of biotechnology called **genetic engineering** to cut DNA at specific sites and thus help remove or **isolate genes**. Most restriction enzymes recognise short nucleotide sequences; around 4 to 8 and these sites are called restriction sites. They work by making an incision or cut through the sugar phosphate backbone of the DNA. The enzyme named EcoR1 was extracted from the bacteria E Coli and cuts DNA in a staggered fashion as can be seen in *Figure 173*.

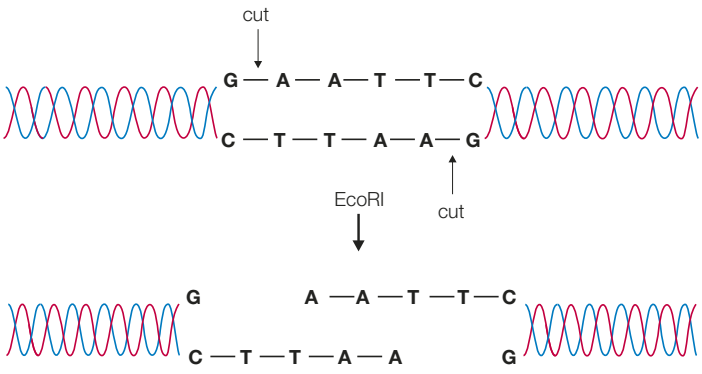


Figure 173 The action of a restriction enzyme 'EcoR1'

As seen in *Figure 173*, the enzyme cuts between the G and A bases and the effect is that the DNA is cut leaving overlapping ends. When preparing to transfer DNA, **the same restriction enzyme** is used for the host and the donor so that the cuts are made in the same way. When this occurs, the overlapping sections are referred to as '**sticky ends**' and the sticky ends enable complementary binding between host DNA and donor DNA. An enzyme, **DNA ligase**, is used to join the host and donor DNA. The incorporation of DNA into bacteria like this is called **bacterial transformation**.

Refer to *Figure 174* which shows the joining of bacterial plasmid DNA (host) and human DNA (donor) using a restriction enzyme to cut the DNA and a ligase enzyme to join the two pieces together; the resulting DNA is termed **recombinant DNA**. Techniques that permit or produce recombinant DNA are called recombinant DNA technology.

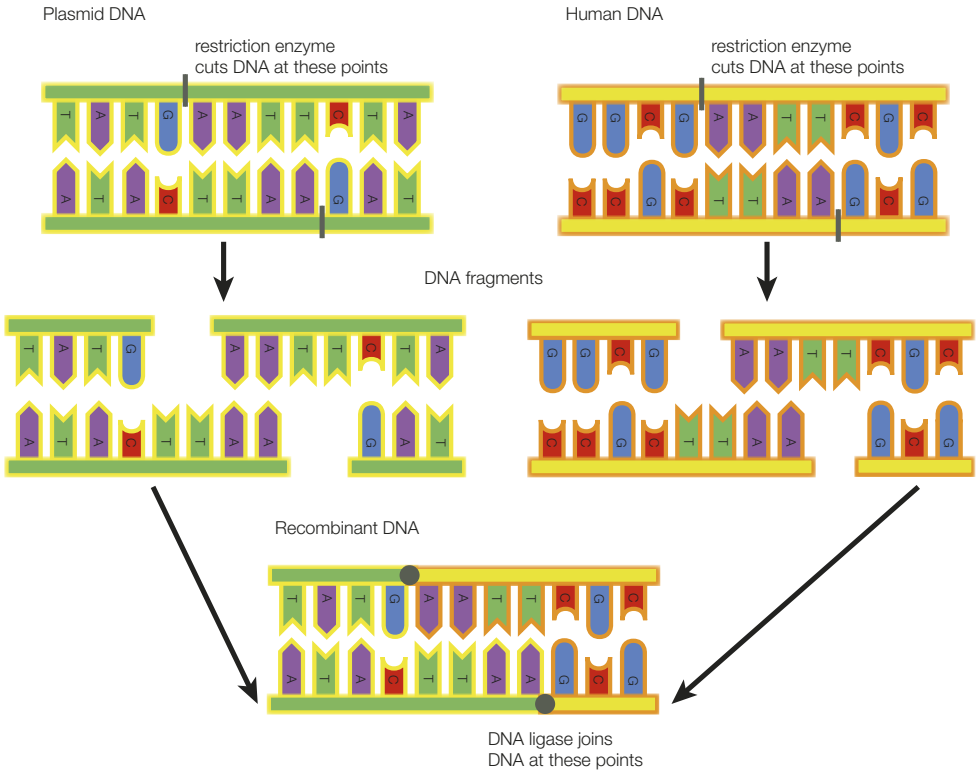


Figure 174 The production of recombinant DNA

Helpful online resources

Khanacademymedicine: Restriction Enzyme
<https://www.youtube.com/watch?v=U2cKywEn6KY>

Polymerase Chain Reaction (PCR)

The sample of DNA that scientists have to work with is from the nucleus of cells (nuclear DNA) and they are often provided with small samples; for example, a hair found at the scene of a crime. To solve this problem, a process called the **polymerase chain reaction (PCR)** was developed that can be used to create many more copies of the same DNA prior to analysis or for another application. DNA that has been put through the PCR process is said to have been multiplied, or **amplified**. PCR is carried out in a thermal cycler shown in *Figure 175*.

Figure 175 A thermal cycler

To carry out this process, the following ingredients are required:

- The target **DNA template** that needs to be copied.
- **DNA primers** which are short sections of DNA that bind to either side of the template (target) DNA to prevent the double strands of the target DNA reforming and to act as a binding site for Taq DNA polymerase to bind to.
- **Free DNA nucleotides**, which are required to assemble the new DNA copies.
- **Taq DNA polymerase** enzyme from bacteria that can tolerate higher temperatures than human DNA polymerase.
- Buffer solutions to provide a suitable chemical environment for the process.

The three stages of polymerase chain reaction (PCR)	
Step 1: Denaturing	The template DNA is heated to about 95°C so that the hydrogen bonds holding the double helix together are broken and this exposes the bases.
Step 2: Annealing	The mixture is cooled to around 60°C and this enables the primers to bind to the complementary bases that are exposed on the template DNA.
Step 3: Extension	The temperature is raised to approximately 72°C to enable the nucleotides to bind with the exposed DNA bases and the Taq DNA polymerase will then join them into a DNA strand. Each of the original strands has formed a new complementary strand at the end of the process.

The above process is then repeated. New DNA is made into many copies in an exponential fashion. Refer to *Figure 176* which represents three cycles of PCR.

Note that sometimes mitochondrial DNA (mtDNA) is collected and analysed. This may decrease the need for the PCR process because each cell has many mitochondria, so many copies of the mtDNA already exist.

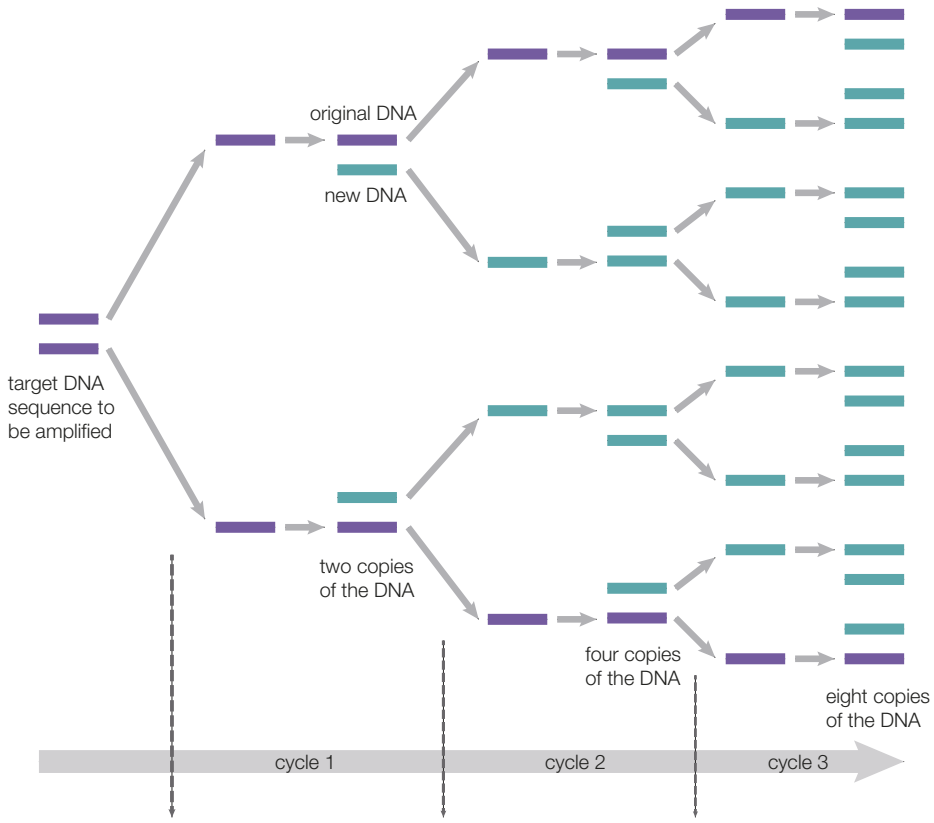


Figure 176 The process of PCR

Helpful online resources

Amoeba Sisters: PCR (Polymerase Chain Reaction)
<https://www.youtube.com/watch?v=a5jmdh9AnS4>

Electrophoresis

There are two types of electrophoresis, gel, and capillary. Both types of electrophoresis separate molecules, specifically different length fragments of DNA, based on their **size and charge**.

Gel electrophoresis

Gel electrophoresis is a technique used to separate proteins or fragments of DNA according to their size and charge. A gel is prepared in a thin layer and placed in a container as shown in *Figures 177*.

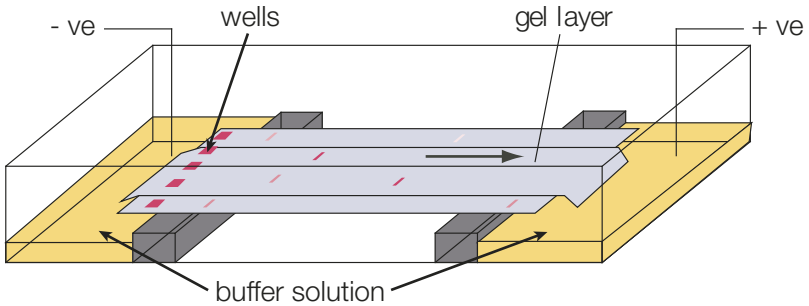


Figure 177 The principle of gel electrophoresis

DNA is slightly **negatively charged** due to the negatively charged phosphate groups that comprise its backbone. Therefore, if samples of DNA fragments are loaded into the wells and the electrophoresis tank is connected to a power supply to generate an electric field, the DNA fragments will be **repelled** away from the loading wells (which are also negatively charged) towards the positively charged terminal. The smaller the DNA fragment is (less DNA base pairs), the further the fragment moves because it has less resistance to the agarose gel.

Capillary electrophoresis

Capillary electrophoresis has multiple applications including DNA sequencing and DNA profiling. It has mostly replaced the use of gel electrophoresis because it is more easily automated and faster.

The general principles of electrophoresis still apply:

- DNA fragments move from the negative electrode to the positive electrode.
- Shorter DNA fragments move faster and further through the tube than longer ones.

Frederick Sanger, a British biochemist developed a technique called the chain termination method which allows DNA fragments to be **fluorescently tagged**. The fluorescent tag is located at **the last nucleotide** of the DNA sequence. Each of the 4 DNA bases has a different fluorescent tag (see *Figure 178*).

The DNA fragments to be separated are loaded into capillaries containing a polymer, such as polyacrylamide gel, and an electric field is applied. The smaller DNA fragments travel faster than the larger ones through the capillary and exit the capillary tube from smallest to largest. The DNA fragments are struck by a laser as they exit the capillary that **excites the fluorescent dye** of the last nucleotide. An image of the fluorescence is captured by a digital camera, also called a **detector** (see *Figure 178*). The fluorescent images of all the DNA fragments in the sample are converted into a graphical representation called an **electropherogram**.

The electropherogram produced will differ depending on the purpose for using capillary electrophoresis. If the goal is to sequence DNA, an electropherogram revealing an order of DNA nucleotides will be produced (see *Figure 179*). However, if the goal is to create a DNA profile, the electropherogram will illustrate peaks at specific base lengths, respective of the alleles the subject carries (see *Figure 1721*).

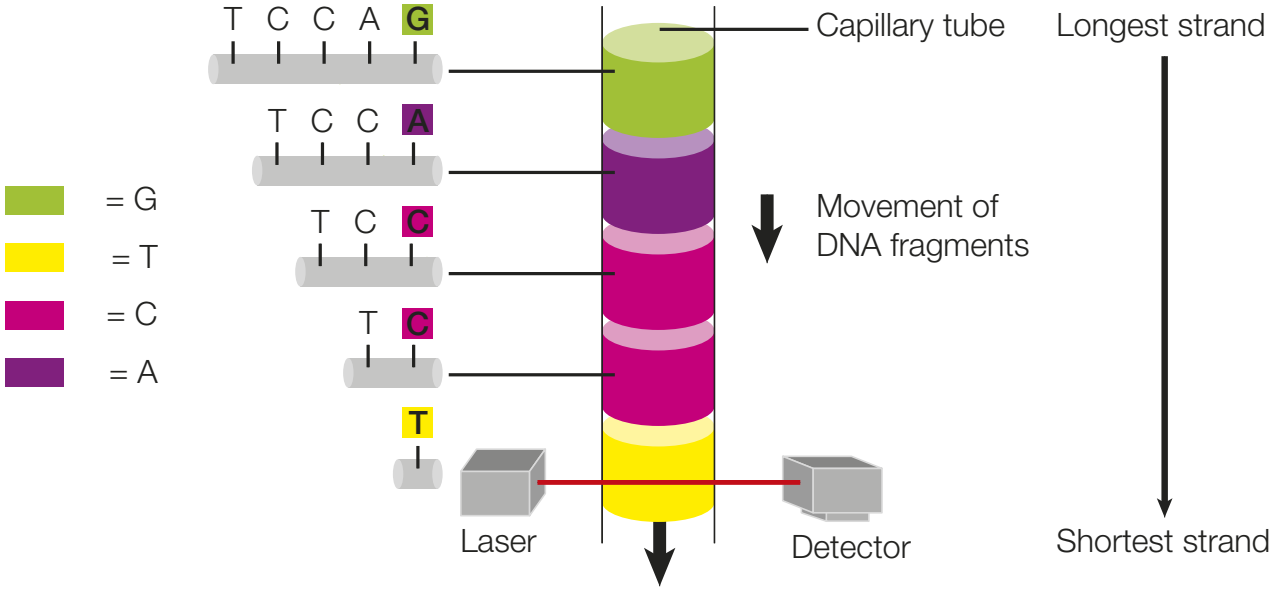


Figure 178 The principle of capillary electrophoresis

Helpful online resources

Promega Corporation: What Is Capillary Electrophoresis?
<https://www.youtube.com/watch?v=x7PUqNA0eOA>

DNA sequencing

DNA sequencing involves techniques that are used to determine the **actual sequence of DNA bases** (A, T, G, C) in a **specific gene segment of DNA** or **the entire genome** of an organism (often called genome sequencing). The process was first developed with small, simple organisms such as bacteria. The first sequence of the entire human genome was published in 2003, as a result of the Human Genome Project (HGP).

The process of DNA sequencing involves **PCR and capillary electrophoresis**. A simplified explanation of the method is:

1. The DNA template to be sequenced is obtained.
2. The DNA template is mixed with Taq DNA polymerase, free floating DNA nucleotides, sequencing primers and terminator nucleotides (which are fluorescently tagged and terminate DNA synthesis).
3. The reaction mixture runs through many PCR cycles amplifying DNA; however, when a fluorescently tagged terminator nucleotide is added by Taq polymerase, DNA synthesis is stopped.
4. This results in an array of DNA fragments of a single base difference as they have been terminated at a different place along the DNA template (see *Figure 178*).
5. The array of newly synthesized DNA fragments undergoes capillary electrophoresis identifying the terminator nucleotide of each DNA fragment and a **DNA sequence electropherogram** is produced (see *Figure 179*).
6. The sequence of the DNA template can then be determined.

DNA sequencing techniques are used in laboratories around the globe as scientists continue to **map the genomes of different species**. Collating and analysing this information continues to advance our understanding of genetics, gene control and evolutionary relationships between organisms. It also enhances our ability to use biotechnology and genetic techniques to enhance the well-being of humans and other species.

It is useful to note that research and development into DNA sequencing technology continues to advance and there have been significant developments since the first generation sequencing technique detailed above. Third generation DNA sequencing technology, such as nanopore sequencing is noted later in this Chapter (see SHE 1.7 on page 124).

Figure 179 An example of an electropherogram illustrating a section of DNA sequence

Helpful online resources

TED-Ed: How to sequence the human genome – Mark J. Kiel
<https://www.youtube.com/watch?v=MvuYATh7Y74>

TED-Ed: The race to sequence the human genome – Tien Nguyen
<https://www.youtube.com/watch?v=AhsIF-cmoQQ>

DNA profiling

Introduction

Human cells contain approximately 3 billion base pairs and on average about 99.9% of these base pairs are shared across all humans. **Identical twins** are an exception however, as they share 100% of their DNA. Even though humans are genetically similar, there is still enough **genetic variation** to accurately distinguish between individuals. This is because the 0.1% unique DNA to an individual equates to approximately 3 million different DNA base pairs.

The variation of DNA between individuals' genomes occurs at particular locations, called **loci**. It is these variations that are analysed through the process of **DNA profiling**. Everyone has a unique DNA profile based on their **unique DNA variations** in their genome, so the DNA profile can be used to **compare and identify** an individual for a variety of applications. DNA profiling is often used to compare DNA from different sources **without mapping the entire genome** (which involves the process of DNA sequencing). DNA profiling was originally called DNA fingerprinting, but this term has been revised to avoid confusion with skin fingerprinting.

Applications of DNA profiling

DNA profiling can be used for a variety of applications. Some examples are summarised in the table below.

Application	Details
Forensic science	Used as evidence to convict criminals (see *Figure 1710*), to eliminate suspects, solve cold cases and reduce chance of wrongful convictions.
Innocence Project	Exonerating wrongfully convicted criminals.
Profile archiving	Development of state and national databases to record DNA profiles of citizens and use to match repeat offenders who may have evaded conviction in the past.
Paternity testing	To confirm the biological father of a child.
Genetic genealogy	Tracing paternal ancestry using DNA on Y chromosome.
Identifying remains	Victims of war, natural disasters, accidents, etc. can have their identify confirmed to give families closure.
Medical uses	Many uses including diagnosing diseases, identifying hereditary diseases in family lines and matching donated organs to transplant recipients to minimise chance of rejection.
Food industry	Detecting food fraud.
Veterinary science	Confirming pedigree of animals.
Agriculture	Identification of seed stocks.
Building industry	To verify if imported wood has been harvested legally and to track stolen timber.

Figure 1710 An example of the use of DNA profiling is for forensic purposes where DNA left at the scene of a crime (e.g. blood, skin, hair, saliva, semen) can be used to identify a suspect

Use of introns in DNA profiling

DNA profiling **relies on variations** in the **non-coding introns** of individuals' genomes. The introns contain different categories of repeating sequences, and the number of repeats is unique to the individual. The two main categories of repeating sequences are **Variable Number Tandem Repeats (VNTR)**, and **Short Tandem Repeats (STR)**.

Because humans are a sexually reproducing species, every person inherits 23 chromosomes from their mother and 23 from their father (total of 46). This means that every person inherits two copies of each gene, known as **two alleles**. There can be many different alleles present in a population, but individuals can only carry a maximum of two alleles.

This is the same for the inheritance of an individual's non-coding repeating sequences (VNTRs and STRs). Every individual will inherit two alleles for specific VNTRs and STRs, one from the paternal chromosome and the other from the maternal chromosome. If the individual has two chromosomes with the same number of repeats, he or she is **homozygous** for that STR/VNTR locus (see the mother in *Figure 1711*). If the subject has inherited different numbers of repeating sequences, they are **heterozygous** for that STR/VNTR locus (see the father and daughter of *Figure 1711*).

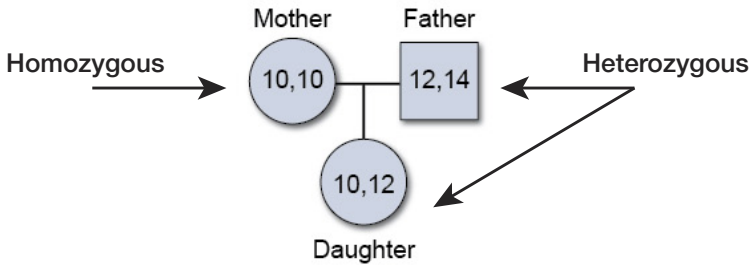


Figure 1711 A simple model of STR inheritance

Variable Number Tandem Repeats (VNTR)

VNTRs are repeated sequences of DNA bases ranging from approximately 10 to 80 bases in length and can repeat up to 30 times. An example of a VNTR is:

Allele 1

AGTCGGTAAG	AGTCGGTAAG	AGTCGGTAAG	AGTCGGTAAG	AGTCGGTAAG

Allele 2

AGTCGGTAAG	AGTCGGTAAG	AGTCGGTAAG	AGTCGGTAAG	AGTCGGTAAG	AGTCGGTAAG	AGTCGGTAAG

This VNTR has a ten-letter code (AGTCGGTAAG) repeating 5 times for allele 1, and 7 times for allele 2. There are many possible alleles (number of repeats of this VNTR) in a population. This VNTR is found at a **specific location (locus)** on a chromosome (see *Figure 1712*).

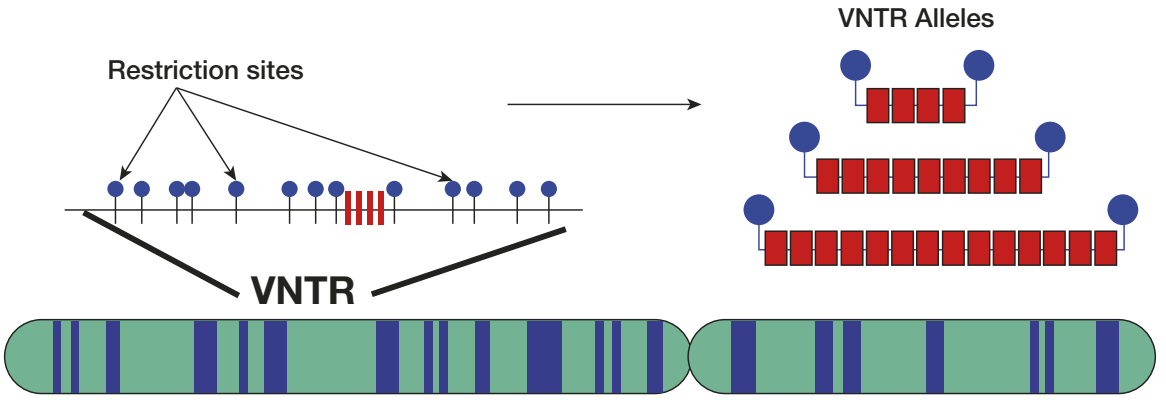


Figure 1712 A single chromosome showing the VNTR locus with four repeating units (red) is illustrated on the left, and some possible VNTR alleles (4, 9 and 14 repeats) are shown on the right

Short Tandem Repeats (STR)

Recently, DNA profiling using VNTRs has been superseded by using STRs. STRs are generally 2 to 6 base pairs in length, that repeat multiple times and are **highly variable** within the human population (see *Figure 1713*). STRs are found at different loci in the genome. The variation in the number of repeats results in variation in lengths of DNA for alleles, and therefore electrophoresis can be used to determine how many repeats an individuals' alleles have.

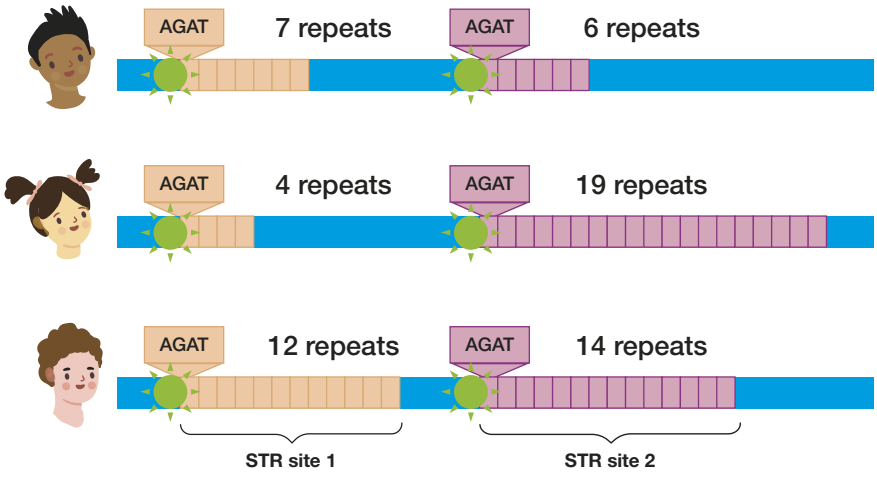


Figure 1713 An example of variation of STR repeats at two loci

DNA profiling using gel electrophoresis

The DNA to be tested is amplified using PCR. Then VNTRs are cut out using restriction enzymes (see *Figure 1712*) and the resultant DNA fragments are separated using gel electrophoresis. A Southern blotting technique (see *Figure 1714*) is then required to view the colourless VNTR DNA. This requires the DNA fragments to be transferred to a membrane and the addition of a **fluorescent probe** that is **complementary to the VNTR**. The example VNTR sequence used earlier was AGTCGGTAAG, therefore the probe required to **hybridise** to this VNTR would be TCAGCCATTC. The use of multiple fluorescent probes to target multiple VNTRs produces a DNA profile **pattern that is unique** to a specific individual (see *Figure 1715*). Finally, the membrane with DNA fragments and fluorescent probes is x-rayed to view the unique pattern of DNA fragments (see *Figure 1714*).

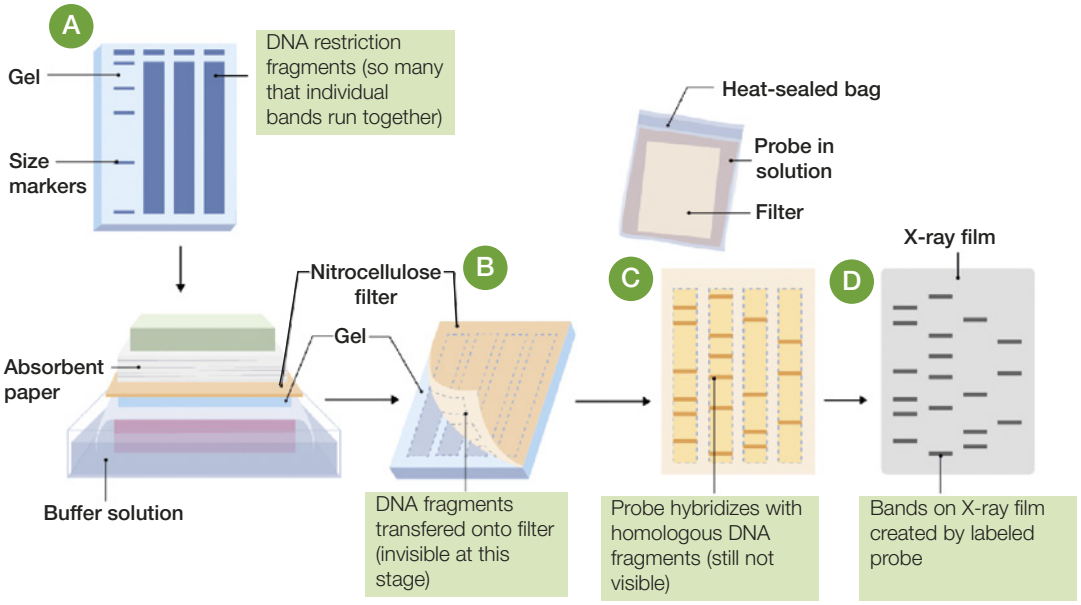


Figure 1714 A summary of the Southern blotting technique used to create a DNA profile using VNTR DNA

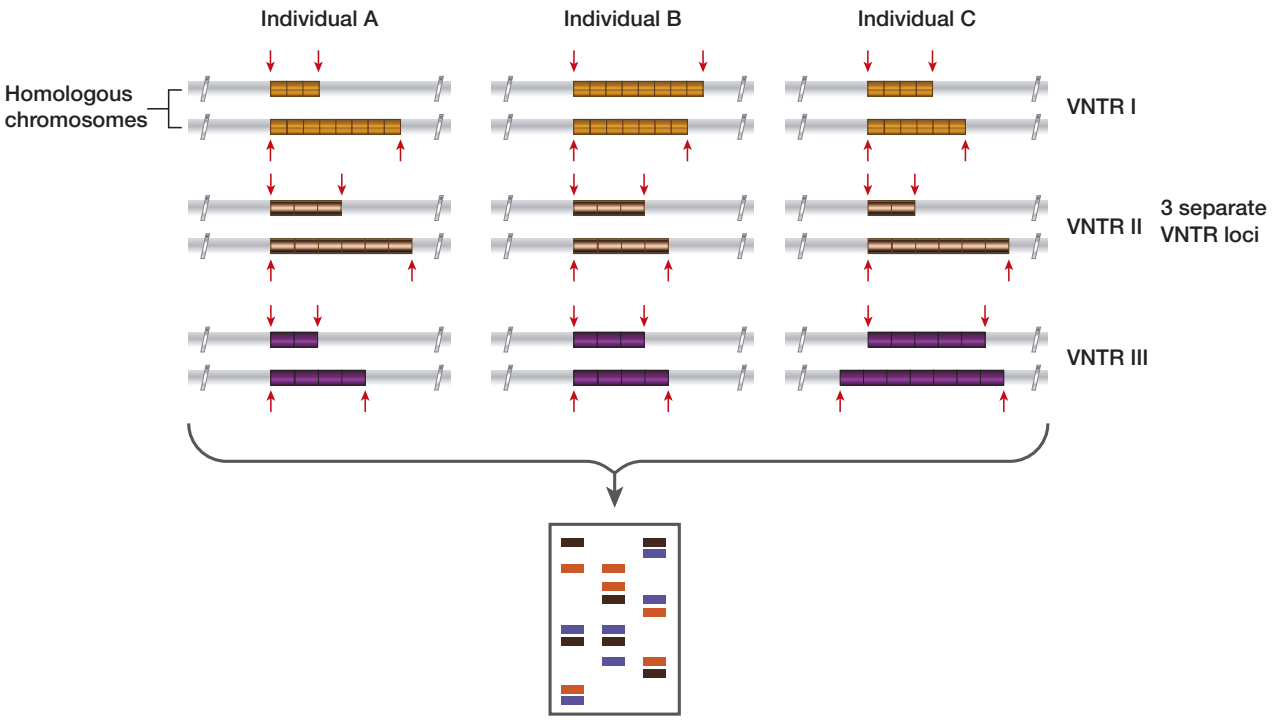


Figure 1715 The use of multiple fluorescent probes for multiple VNTRs allows production of unique DNA profiles

Helpful online resources

Oxford Mastering Biology: Animation E4, 1.6 DNA fingerprinting
<https://www.youtube.com/watch?v=P9pqCJ42wHM>

Interpreting DNA profiles produced by gel electrophoresis

The interpretation of DNA profiles using gel electrophoresis depends on the type of investigation occurring. If a pure sample of the perpetrators DNA is left at the scene of a crime, then all the DNA fragments need to align to identify the perpetrator (see *Figure 1716*). However, if the genetic sample is a mixture of the perpetrators and the victim's DNA, then some of the bands in the sample will belong to the perpetrator and others to the victim. This is similar in paternity tests. Not all bands from the child's DNA sample will match up exactly with the father. Half the DNA fragments were inherited from the father and the other half from the mother (see *Figure 1717*).

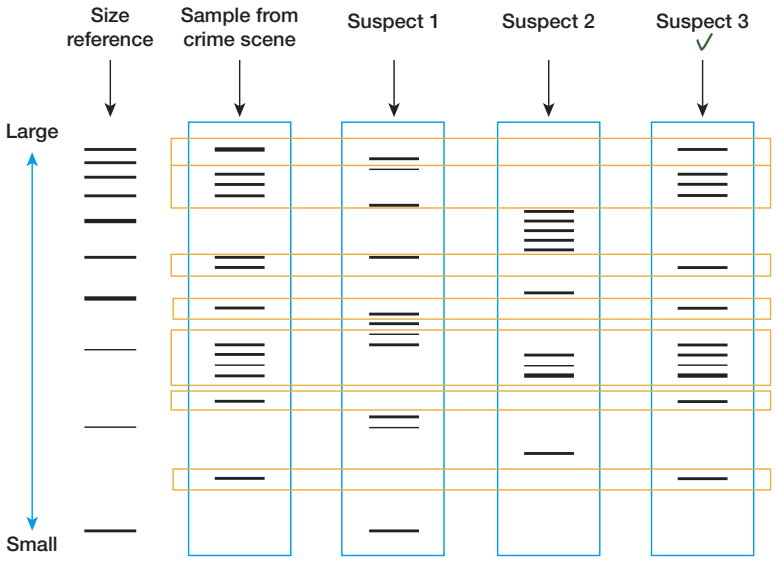


Figure 1716 An example of how to analyse a DNA profile to match a suspect to DNA left at the scene of a crime

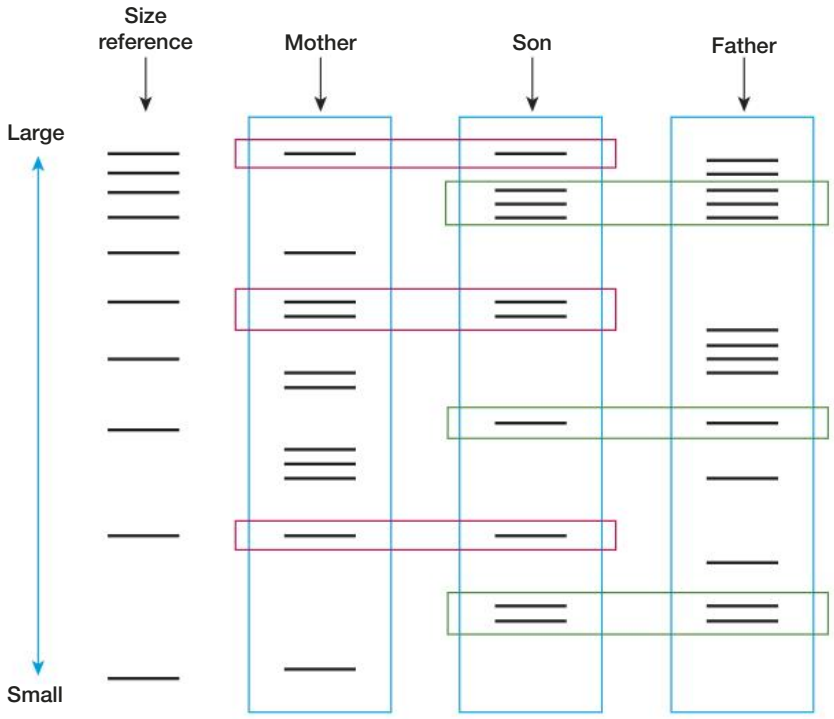


Figure 1717 An example of how to analyse a DNA profile to solve a paternity dispute

STRs can also be used in gel electrophoresis to create an individual's DNA profile. The exact same process used to create VNTR based DNA profiles is used except the fluorescent probe(s) used must be complementary to the STR repeating unit. The number of STR repeats can be identified based on how far the DNA fragments travel through the gel and hence their lengths (see *Figure 1718*).

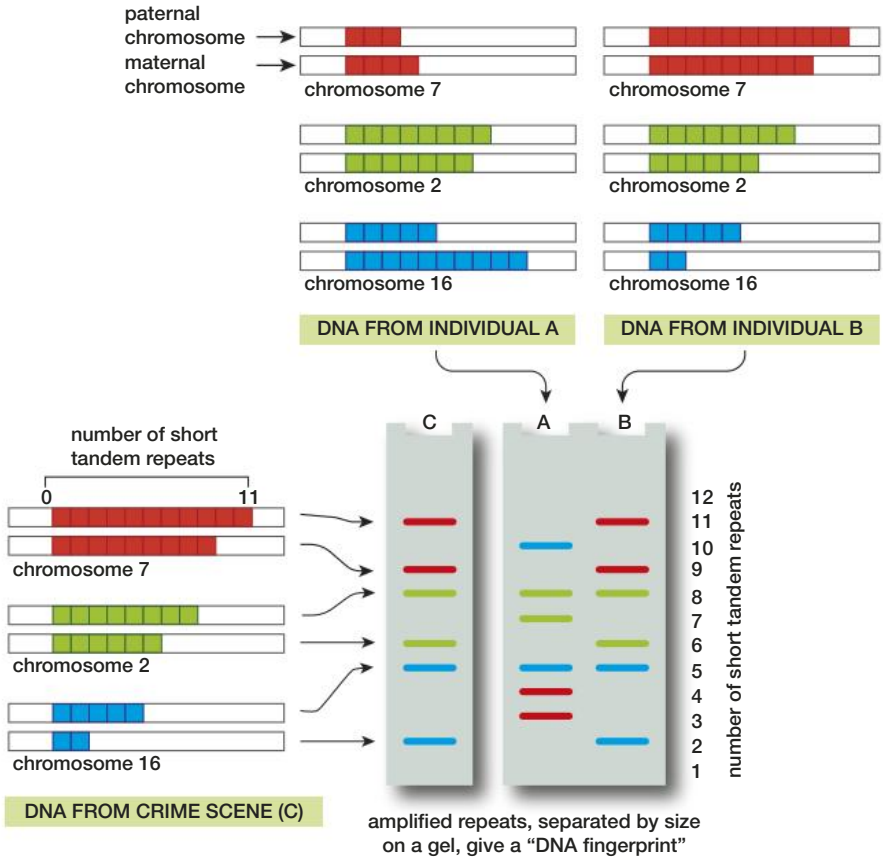


Figure 1718 An example of gel electrophoresis using STRs that illustrates Individual B's DNA matches the DNA from the crime scene (C)

Helpful online resources

FuseSchool–Global Education: DNA Fingerprinting | Genetics | Biology | FuseSchool
<https://www.youtube.com/watch?v=7onjVBsQwQ8>

DNA profiling using capillary electrophoresis

Capillary electrophoresis can be used to identify the number of repeating STRs at multiple loci quickly. A simplified explanation of the method is:

1. DNA template is extracted.
2. The STRs are tagged using different fluorescent markers and amplified using PCR.
3. DNA sample is run through capillary electrophoresis (see *Figure 1719*).
4. The results are processed by computer software to determine the size of the DNA fragment and hence STR repeats.
5. Data can be illustrated as an electropherogram (see *Figure 1719*) or DNA profile table.

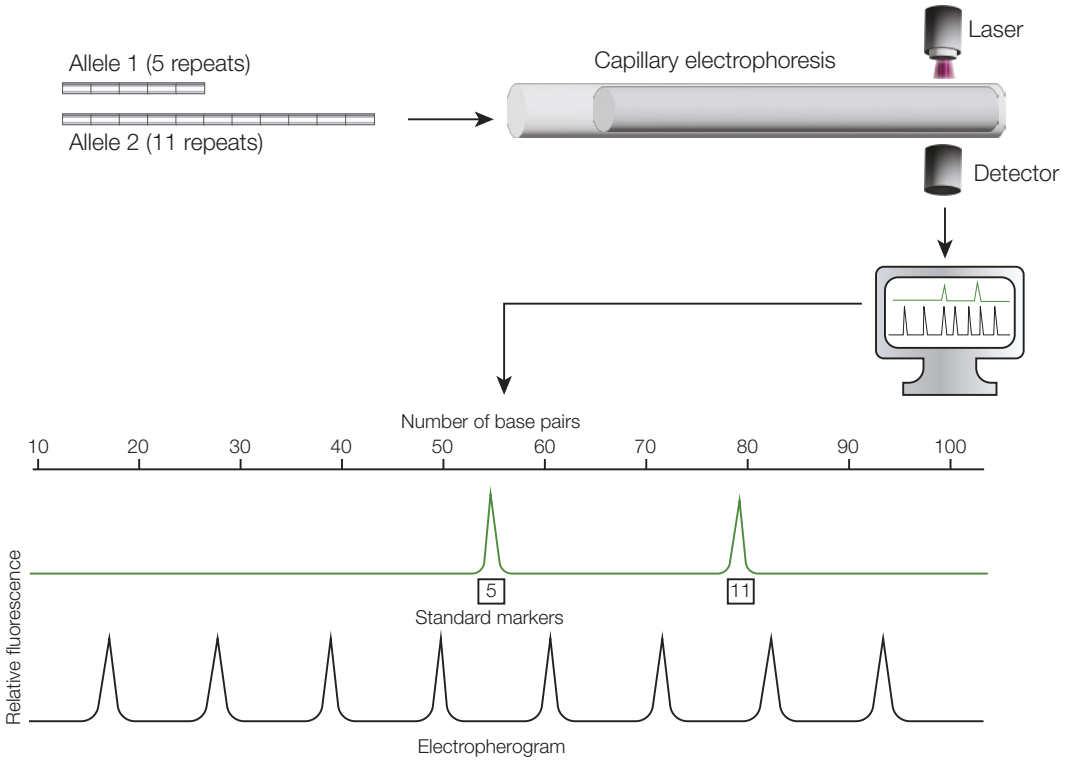


Figure 1719 A simplified example of how an electropherogram is produced using one STR locus (5 and 11 repeats)

Interpreting DNA profiles produced by capillary electrophoresis

STRs are highly variable between people, and this enables forensic scientists to establish which DNA belongs to which person. The length of an STR varies between individuals and are signified by a number as previously discussed. Identifying the number of repeats at one STR locus is not sufficient evidence to create a unique profile. Generally, **13 STR loci are analysed**. This is the number used in the United States of America's (USA) combined DNA index system (CODIS). The CODIS system ensures consistency across all laboratories in the USA so that DNA profiles processed and stored can all be compared fairly against the same set of STR loci (see *Figure 1720*). The use of 13 different STR loci also makes it **statistically impossible** for the resulting DNA profile to belong to two different people (**excluding identical twins**). There is an estimated one in ten trillion chance that two people would have the same DNA profile using 13 STR loci, whilst there are less than 8 billion humans on Earth.

In 2017 however, the CODIS system was updated to include an additional 7 STR loci to be analysed ongoing. These loci were added to facilitate more effective **international sharing of DNA profiles** with Europe who were using different STR loci for their analyses (see *Figure 1720*).

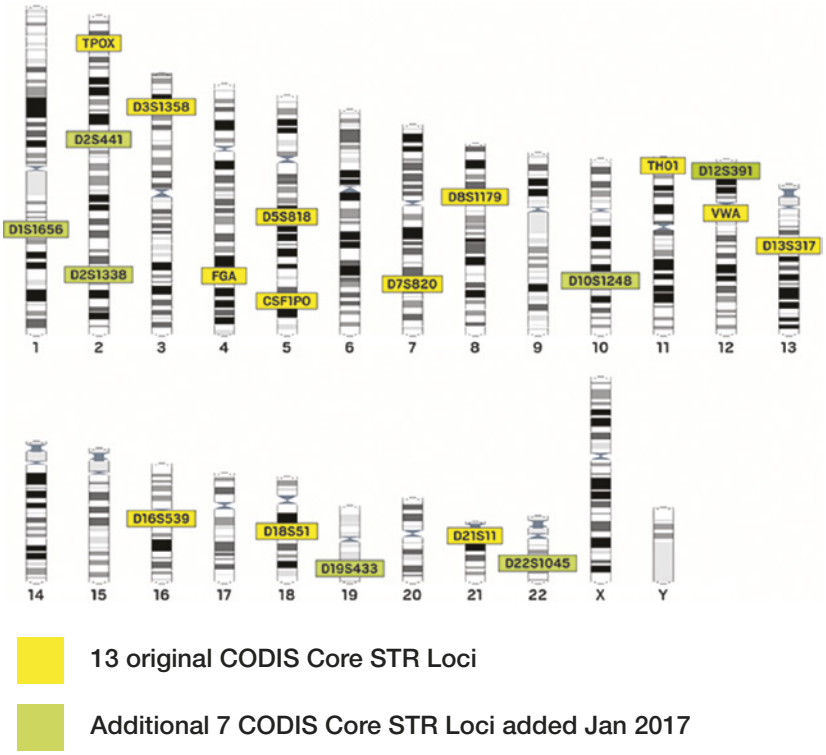


Figure 1720 The 13 original and 7 additional STR loci of the CODIS system

Following capillary electrophoresis, a graph called an electropherogram is produced. Refer to *Figure 1721*(a) for an example of a **DNA profile electropherogram**. In this example, three gene loci are analysed. It is evident that there are three alleles at two STR loci (D8S1179) and D7S820). This indicates that the sample of genetic information is from multiple sources because an individual can only have two alleles (e.g. 11 and 14), one from each parent. The numbers running along the top of the graph represent the number of base pairs in the DNA fragment containing the STR repeats (the more STR repeats, the more base pairs present). The length is required to calculate the number of STR repeats in the fragments. This is generally done automatically using software. The number of STR repeats for the multiple STR loci can then be presented as a **DNA profile table** for analysis (see *Figure 1721*(b)).

DNA profiles produced using STRs and capillary electrophoresis are interpreted in a similar manner to those produced by gel electrophoresis. If identifying DNA left at a crime, the number of repeats at the 13 STR loci should all match up exactly if the sample is from the perpetrator only; however, if the DNA profile is a mixture from a victim and a perpetrator (such as in *Figure 1721*) the STR repeats will not match exactly to the perpetrator, as they are from two individuals.

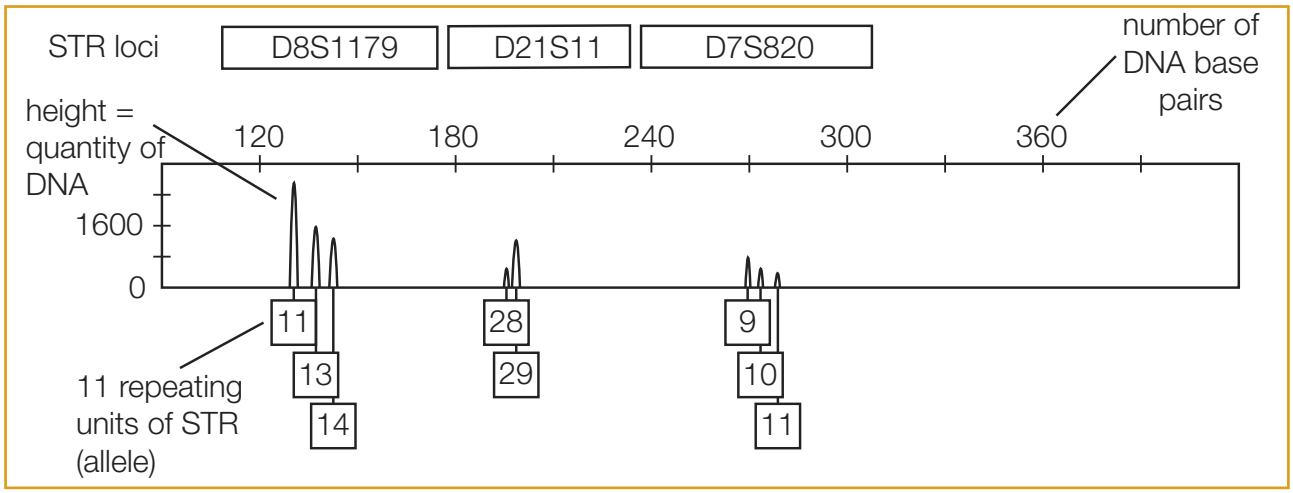


Figure 1721 (a) An example of a DNA profile electropherogram for three STR loci showing multiple alleles

STR locus	DNA evidence at crime scene				Suspects DNA		Victims DNA	
D8S1179	11	13	14	-	11	14	11	13
D21S11	28	29	-	-	29	-	28	29
D7S820	9	10	11	-	9	-	10	11

Figure 1721 (b) The data from an electropherogram can be converted into a table form

Helpful online resources

The best review of STRs (Short Tandem Repeat) mutation | applied to the forensic
<https://www.youtube.com/watch?v=9bEAJYnVVBA>

Collecting and storing genetic information

There are potential issues that can arise from the collection and storage of genetic information from individuals. With recent advances in DNA sequencing and whole genomic analysis, the scope to discover and store vast quantities of biological information about individuals is ever expanding. The use of ICT and computer software, like complex DNA databases by government-funded agencies, to assist with the storage, analysis and communication of biological data is called **bioinformatics**. The leading bioinformatics agency in the United States is called the National Centre for Biotechnology Information (NCBI). One software program that it maintains and makes available to researchers is a DNA sequence search engine called 'BLAST'.

Governments around the world have legislated and organised committees to set guidelines about what is and what is not acceptable in the area of bioinformatics. In Australia, the committee is called the Human Genetics Advisory Committee (HGAC). Questions that concern the HGAC include:

- Whose data is stored on the human genetic database?
- Who has access to this data?
- How is this data used?

Rules and regulations regarding the collection of genetic information is not straight forward. Governments often store genetic information of convicted criminals, but there are also private companies offering services that require a consumers' genetic information. The main example is direct to consumer genetic tests for heath or ancestry purposes. Recently, there have been companies offering paid DNA tests to help people lose weight, such as developing exercise plans and nutrition guides based on an individuals' DNA. As consumers willingly provide their DNA for these types of tests, it is hard for blanket rules governing the collection and storage of genetic information. In addition, there is the possibility of governments enforcing citizens to provide DNA samples, with the aim of creating a centralised genetic database to proactively deter crime. This idea would likely help reduce crime, but it is a breach of an individuals' right to personal privacy and international human rights law. Refer to the table below for a summary of some additional issues surrounding the collection of genetic information.

Type of Issue	Details
Ethical	Are laws surrounding the technology up to date to help protect the genetic information?
Ethical	Direct to consumer genetic testing has limited regulation, which is a concern for the privacy of consumers' genetic information.
Ethical	Some companies allow the genetic testing of multiple samples without consent of the individuals. Surreptitious DNA testing (testing without the individual knowing) is another ethical threat to the privacy of genetic information.
Ethical	What if the business/governments servers are hacked and personal genetic information is released?
Ethical	What if laws are passed in the future to allow genetic information to employers and insurance companies and individuals are exposed to prejudice based on their genetic profile?
Economic	The costs associated with the collection of genetic profiles from all citizens for a mandated national database is very expensive initially.
Economic	Will this act as a deterrence and decrease crime rate? This could reduce costs to society significantly. This could also reduce the burden on the legal system where cases are backed up for years (less crime = less cases).
Economic	The creation of new jobs to collect, process, monitor and protect genetic information. New field of genetic testing counsellors creates more job opportunities.
Cultural	Cultural profiling concerns. What if the genetic information was misused to ethnically profile a particular group of people? For example, during World War II the Nazi Party used census data to identify Jewish individuals.
Cultural	The potential of having a greater understanding of race/ethnicities risk of developing specific genetic diseases.
Cultural	Culturally based hesitation of genetic testing has led to the current underrepresentation of certain race/ethnicities in genetic databases of variants.

Helpful online resources

MinuteEarth: Is It Safe To Get Your DNA Tested?
<https://www.youtube.com/watch?v=uyRgk8Cqmzg>

SciShow: How DNA Analysis Led Police to the Golden State Killer
<https://www.youtube.com/watch?v=lAFJ3WfXhOY>

Life Noggin: Who Owns Your DNA? (YOU DON'T)
<https://www.youtube.com/watch?v=e30ZgPwFyCI>

1.7 Review questions

Multiple choice questions

1. DNA fingerprinting involves the technique of gel electrophoresis. What is separated by this technique?
   - J DNA segments of different length
   - K Telomeres
   - L Individual genes
   - M Chromosomes of different lengths
2. Which one of the following is an example of genetic testing?
   - J Testing genes for the presence of plasmids.
   - K Determining the presence of a particular allele.
   - L Curing a genetic disease through gene therapy.
   - M Using a DNA probe to locate a specific allele.
3. Which of the following options would **not** be an ethical consideration for the proposition of a national genetic database?
   - J The inability of infants to consent to their genetic profile being taken.
   - K The misuse of information by insurance companies.
   - L The possibility of solving and preventing crime.
   - M The possibility of data entry errors in the genetic database.
4. Primers are used in polymerase chain reaction because:
   - J their only function is to act as a site for taq DNA polymerase to bind to.
   - K they prevent taq DNA polymerase from denaturing at high temperatures.
   - L taq DNA polymerase binds them to the exposed bases creating two identical copies of the DNA.
   - M they act as a site for taq DNA polymerase to bind to and to prevent the re-joining of the two DNA strands.
5. A probe:
   - J is always synthesised using DNA nucleotides.
   - K is complementary to all of the gene of interest.
   - L is manmade in a laboratory.
   - M can identify a gene of interest by recognising its sticky ends.
6. Which one of the following statements about DNA sequencing is most correct?

   DNA sequencing:
   - J enables mapping of species' genomes.
   - K is conducted using polymerase chain reaction.
   - L is commonly used to resolve paternity issues.
   - M compares short tandem repeats to identify species.

Refer to the information and table below to answer Questions 7 and 8.
*Restriction enzymes cut DNA into smaller fragments. A few restriction enzymes and the recognition sequences they cut at (represented with the symbol *), are displayed in the table below.*

Restriction enzyme	Recognition sequence
HindIII	A* A G C T T T T C G A *A
EcoRI	G* A A T T C C T T A A *G
HaeIII	G G* C C C C* G G
AluI	A G* C T T C* G A

7. Which of the following options is correct if the restriction enzyme EcoRI digested one copy of the section of double stranded DNA shown below?

   T T A A G G A A T T C A A

   A A T T C C T T A A G T T

   J Four single stranded DNA sections with blunt ends will be produced.

   K Two double stranded DNA sections with blunt ends will be produced.

   L Four single stranded DNA sections with sticky ends will be produced.

   M Two double stranded DNA sections with sticky ends will be produced.

8. The restriction enzymes that can cut the following section of DNA are:

   C T T A A G C T T C C A A A T T A C C G A

   G A A T T C G A A G G T T T A A T G G C T

   J EcoRI and HaeIII.

   K EcoRI and HindIII.

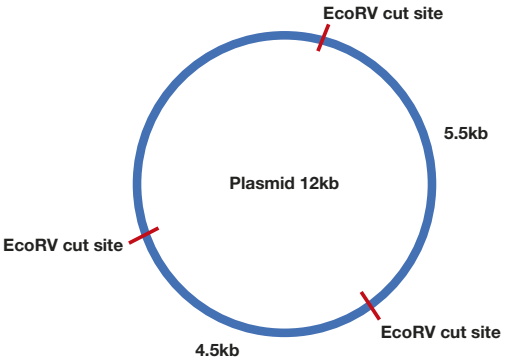
   L AluI and HaeIII.

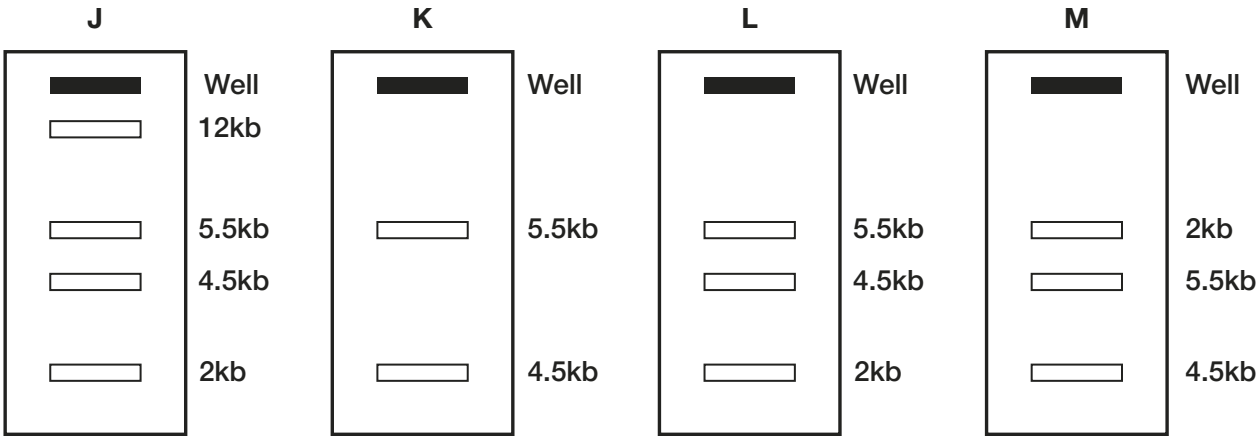
   M AluI and HindIII.

9. A 'kilobase' is a term used in molecular biology for 1000 base pairs. A 12kb plasmid was cut with the restriction enzyme EcoRV.

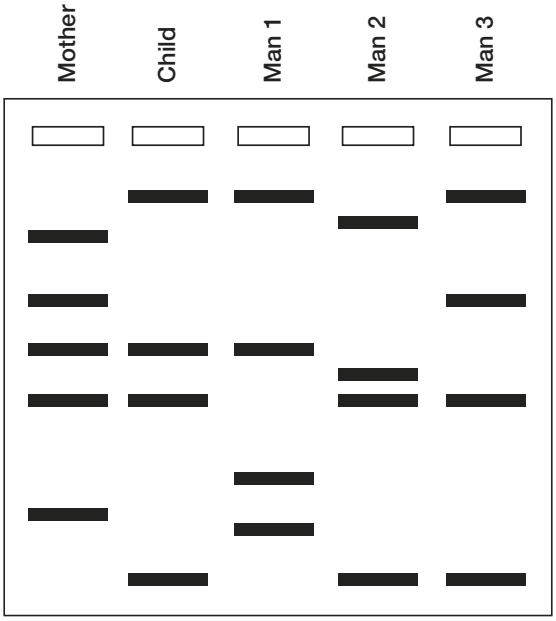
   Refer to the diagram to the right to answer the question that follows.

   Which diagram best illustrates the gel resulting from electrophoresis of the plasmid after the addition of EcoRV enzymes.





10. A paternity test was conducted to determine the father of a child. There were three possible fathers. The results of the DNA fingerprints from the mother, child and three possible fathers are shown below.



The likely father of this child is:

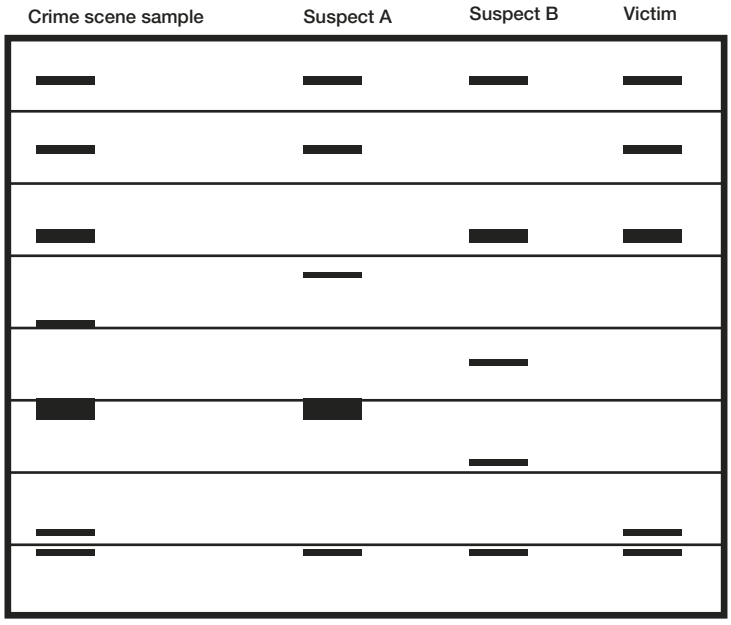
J Man 1

K Man 2

L Man 3

M Another man who has not been identified.

11. A victim was robbed from behind at gunpoint in a shopping centre carpark. A struggle broke out and both the victim and attacker were injured. The attacker ended up running away. The results of DNA fingerprints from the crime scene sample, two suspects and the victim are shown below:



Which one of the following is a true statement?

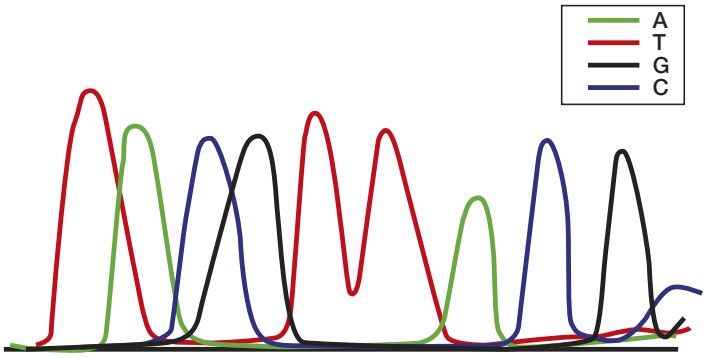
J Suspect A is the attacker.

K Neither suspect A or B was the attacker.

L Both suspect A and B could be the attacker.

M Suspect B is the attacker.

12. *Refer to the electropherogram below showing a section of DNA to answer the following question.*



Which of the following statements is most correct regarding the above electropherogram?

J A base substitution has occurred at the fifth base from the left and now has a T instead of an A.

K The mRNA sequence transcribed from this section of DNA would be: UACGUUACG

L It's possible that three different tRNA could bring three different amino acids to the mRNA molecule synthesised from this section of DNA.

M The miRNA sequence required to bind to this section of an mRNA molecule transcribed from the section of DNA illustrated would be: AUGCAAUGC

13. Genetic relationships can be determined using the short tandem repeats in DNA to create DNA profiles that can then be compared.

Five individuals had their DNA profile of four STRs produced. The results are shown in the DNA profile table below as well as their respective genders.

STR Locus	Individual 1	Individual 2	Individual 3	Individual 4	Individual 5
CSF1PO	7,14	7,11	8,13	7,14	7,14
TPOX	6,10	10,12	6,9	10,12	10,10
D21S11	27,30	29,32	27,27	29,30	27,28
D8S1179	9,11	12,13	17,17	11,12	9,11

	Individual 1	Individual 2	Individual 3	Individual 4	Individual 5
Gender identifier	male	female	female	male	male

Which of the following relationships is a likely possibility based on the results of the DNA profiles above?

J Individuals 1 and 2 could be the parents of individual 4.

K Individual 2 is the mother of individual 3.

L Individuals 1 and 4 could be the parents of individual 5.

M Individual 5 is the child of individual 4.

14. *Refer to the table below showing a DNA profile table of 8 STR alleles for three suspects and a sample from the scene of the crime.*

STR Locus	Evidence Sample	Suspect 1	Suspect 2	Suspect 3
D3S1358	15, 17	15, 17	17, 17	15, 17
vWA	15, 16	15, 16	18, 19	15, 16
FGA	23, 27	23, 27	21, 23	23, 27
D8S1179	12, 13	12, 12	15, 14	12, 13
D21S11	28, 30	28, 30	27, 30	28, 30
D18S51	12, 18	12, 18	14, 18	12, 18
D5S818	12, 13	12, 13	12, 9	12, 13
D13S317	12, 12	12, 13	12, 22	12, 12

What conclusion can be drawn from the data obtained?

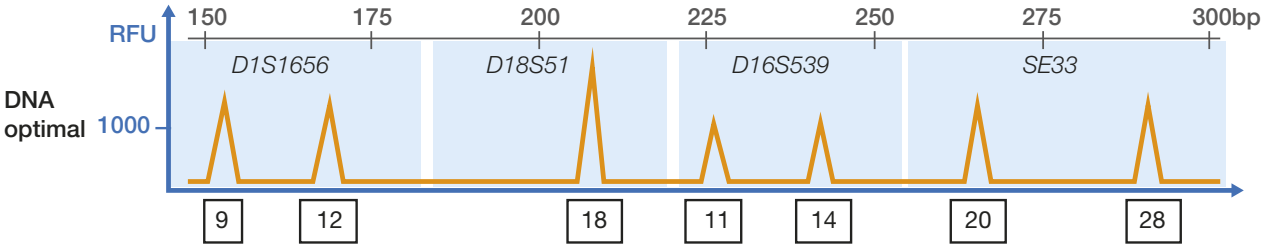
J Suspect 1 committed the crime.

K Suspect 2 committed the crime.

L Suspect 3 committed the crime.

M None of the 3 suspects committed the crime.

15. *Refer to the electropherogram below to answer the following question.*



Which one of the following statements is correct?

J Seven STR loci are shown in this electropherogram.

K The individual having the DNA profile only has one allele for D18S51.

L The greatest number of STR repeats is seen at D18S51.

M The amount of STR loci shown in the electropherogram would be not enough to convict a criminal of an offence.

Free response questions

1. Name three potential concerns or issues associated with the collection and storage of human genetic data.

2. State two characteristics of molecules that are able to act as gene probes.

3. Often, during PCR, the DNA, enzyme and nucleotide mixture is heated to temperatures well in excess of 60-70°C.

   a) State why it is necessary to heat the DNA in this manner.

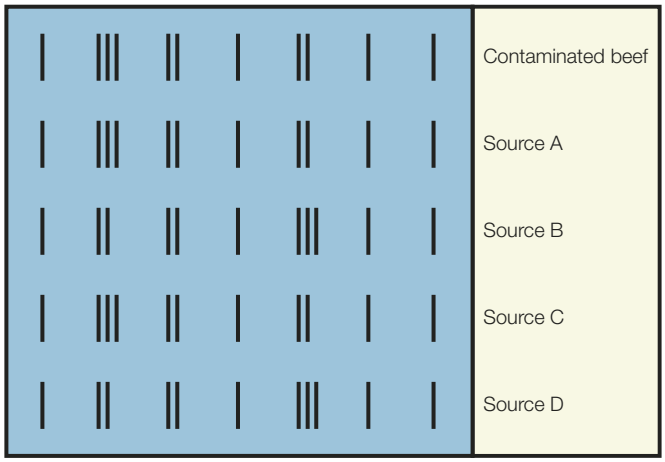
   b) Explain why this heating would prevent the use of human DNA polymerase to catalyse a reaction.

4. Explain why the same restriction enzyme is used to cut the DNA of multiple suspects to prepare DNA profiles.

5. In DNA profiling, bands or segments of DNA appear at different spots in the electrophoretic gel. Explain why segments appear at different spots after electrophoresis.

6. PCR is carried out 'in cycles' in a thermal cycler machine. As a result of each cycle the amount of DNA is doubled; in other words, after one cycle, there are 2 copies of the sample of DNA to be amplified, after two cycles there are 4 copies, and so on. How many copies of the original sample of DNA will have been produced after 10 PCR cycles? Show your working.

7. A cattle industry carried out a study using DNA profiling to determine if beef from various sources was contaminated. *Refer to the DNA profile below from the study.*



   a) How many sources of beef were contaminated?

   b) What percentage of the total number of sources used in the DNA profile above were contaminated? *Show your working.*

8. State and briefly give reasons regarding which technique would most likely be used in the following situations:

   a) Multiplying or amplifying the DNA of a suspected criminal's hair follicle cells found at a crime scene.

   b) Comparing human DNA with chimpanzee DNA, looking for differences in coding for a particular protein.

   c) Analysing DNA in an embryo, looking for susceptibility to a particular genetic abnormality.

9. A sample of DNA was found at a crime scene and was sent to the lab for analysis. As part of the DNA profiling process, scientists had to prepare multiple primers for specific VNTRs. One known VNTR on the coding DNA strand for analysis is:

   5' - AGTTCGCGTGA - 3'

   a) Determine the sequence of the VNTR code on the template DNA strand including 5' and 3' labels.

   b) Determine the sequence of the primer synthesised by scientists to bind to the VNTR on the DNA template strand including 5' and 3' labels.

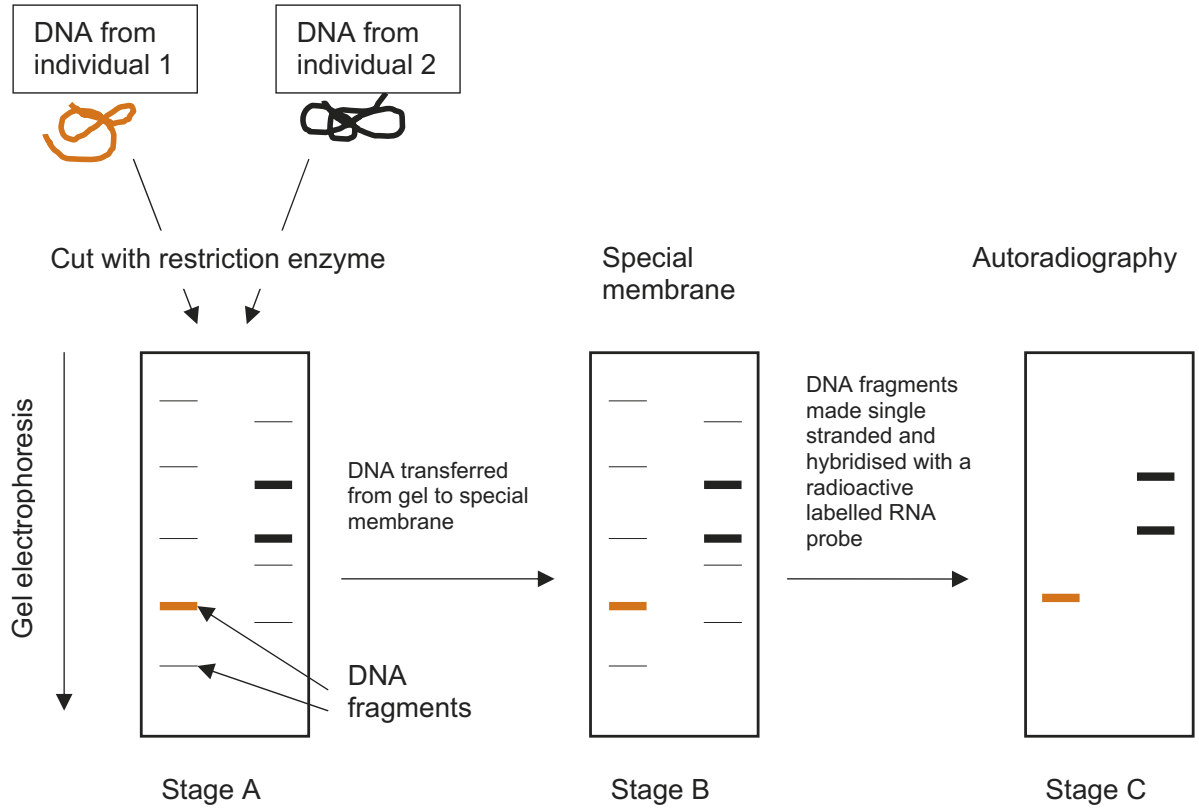
10. A high percentage of criminals are recidivists or repeat offenders. In many countries the DNA profile of these individuals is kept and stored in a genetic database.

    a) This has enabled some suspects to be convicted of crimes committed over a decade ago. Explain how this is possible.

    b) Discuss how might this enable detectives to track criminals internationally?

11. When a restriction enzyme cuts a DNA molecule, the cuts are not even and leave single-stranded ends. Suggest why this is an advantage in recombinant DNA technology.

12. *Refer to the diagram below showing a procedure that can be used to compare DNA and answer the questions below.*



a) Explain why this procedure could be used to identify a suspect at the scene of the crime.

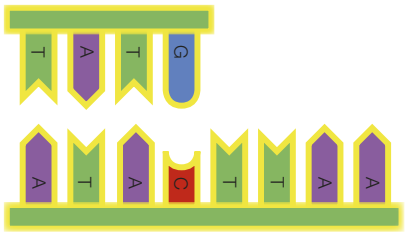
b) In Stage C the DNA of the gel has been hybridized with a radioactive probe. Describe the purpose of this step in the procedure.

13. Short tandem repeats (STR's), found in segments of DNA, have been found to be very useful in discriminating between individuals in the process of DNA profiling. The segments have very low mutation rates. Explain why these low mutation rates are also an advantage in DNA profiling.

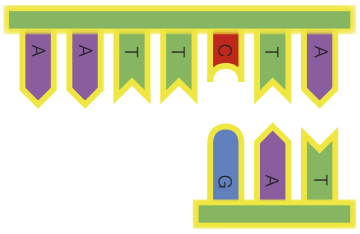
14. Compare the techniques and applications of DNA sequencing and profiling.

15. These two segments of DNA were produced by the action of a specific restriction enzyme.

Segment 1



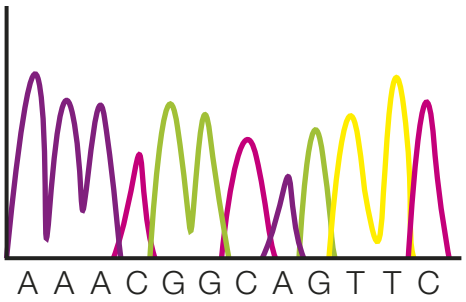
Segment 2



a) On the left side (segment 1), draw a diagram of the single DNA segment prior to the action of the enzyme.

b) Indicate on the diagram the specific recognition site for this enzyme and where the cuts occur.

16. Using capillary electrophoresis, DNA fragments can be separated by their molecular weight (size). A DNA sequence can be worked out using this technique and a laser to detect bases marked with fluorescent dyes.



a) State 2 factors that may affect the rate at which molecules move through the capillary.

b) Compare the DNA sequences shown below in the two electropherograms:

i) State the change which has occurred from sequence 1 (left) compared with sequence 2 (right).

ii) Using your knowledge from earlier in this Topic, suggest what possible impact this might have on the polypeptide produced when this sequence is transcribed and translated.

17. The results of electropherograms are used to construct DNA profiles and thus are key in forensic science. Refer to the DNA profile table below to answer the questions that follow.

STR locus	DNA evidence at crime scene				Suspects DNA		Victims DNA	
D8S1179	11	13	14	-	11	14	11	13
D21S11	28	29	-	-	29	-	28	29
D7S820	9	10	11	-	9	-	10	11

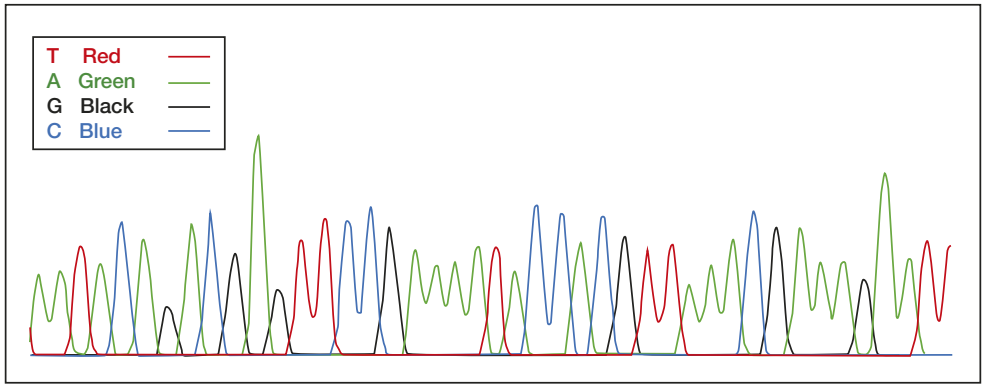
a) State the importance of STR's in the production of a DNA profile of an individual.

b) Explain why each individual has two alleles for each marker shown.

c) Explain, giving reasons which marker does not provide strong support as to whether the suspect might be guilty.

d) Explain how the other two markers do provide evidence to support the fact that the suspect may have been at the scene of the crime

18. *Refer to the electropherogram of a sequence of DNA below to answer the following questions.*



a) State the sequence of the DNA for the section of DNA represented by the electropherogram.

b) State the transcribed sequence of this section of DNA.

c) A miRNA that binds to the transcribed mRNA from the section of DNA shown, is 22 bases long. State the miRNA sequence if it binds to the first 22 bases of this section of code.

d) In 2015, Kuwait mandated nationwide compulsory genetic testing for all citizens, residents and visitors in response to a suicide bombing of a Mosque that killed 27 people.

Using your understanding of science as a human endeavour:

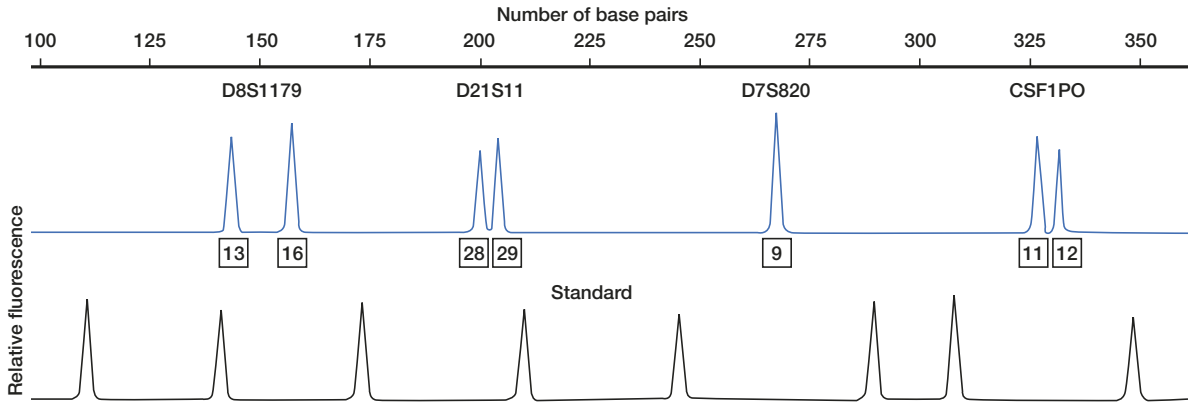
i) Discuss two ethical issues associated with this mandated collection of genetic information.

ii) Discuss one impact of the mandated genetic database that could have affected Kuwait's economy negatively, other than the initial costs of the tests.

In 2017, Kuwaiti lawyers legally challenged this law and it was overturned by the constitutional court, It is no longer applicable.

iii) Discuss how society influenced this law to be overturned.

19. *Refer to the electropherogram below of an individual showing the alleles at four STR loci.*

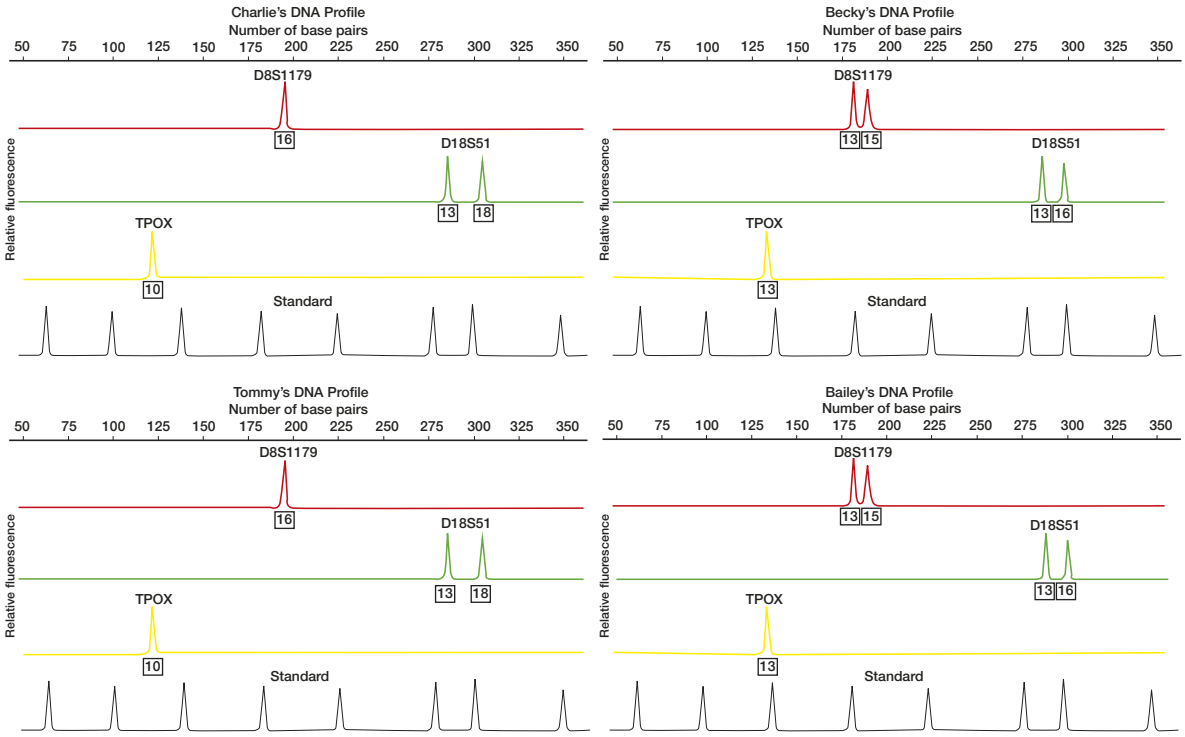


a) With reference to the electropherogram above, complete the table below:

STR Locus	Evidence Sample's STR Repeats

b) Explain why the D7S820 locus is only showing one STR value.

c) *Refer to the four electropherograms below showing the alleles of three STR loci for four different individuals.*



i) With reference to the electropherograms above, complete the DNA profile table below:

STR Locus	Charlie	Becky	Tommy	Bailey

ii) Identify the two individuals that could be identical twins and justify your decision.

iii) Explain why concluding two individuals are identical twins based on the data provided is limited.

20. Forensic scientists have determined a DNA profile from a sample recovered from a crime scene. The police have narrowed their investigation down to two different suspects they believe could have committed the crime. The suspects mouths were swabbed to collect cheek cells and the samples were sent for DNA profiling.

The results of the forensic analysis are shown in the DNA profile table below.

STR Locus	Crime Scene Sample	Victim	Suspect 1	Suspect 2
D3S1358	8, 12, 15	8, 15	12	12, 15
vWA	23, 24	24	18, 24	23, 24
FGA	15, 21, 27	15, 27	15, 21	15, 21
TH01	12, 13, 20, 24	20, 24	9, 12	12, 13
TPOX	7, 14, 18	7, 18	14, 20	14
CSF1PO	16, 22, 26, 30	22, 26	22, 32	16, 30
D5S818	13, 16	13	10, 11	13, 16
D13S317	10, 12, 19, 27	19, 27	10, 18	10, 12
D7S820	22, 26, 30	26, 30	21, 25	22
D8S1179	9, 12, 18, 22	18, 22	11, 18	9, 12
D21S11	10, 11, 16, 19	10, 19	16, 20	11, 16
D18S51	17, 30, 31	31	27, 32	17, 30
D16S539	23, 17, 27, 33	27,33	23, 27	23, 17

a) Identify the suspect that committed the crime and justify your reasoning.

b) Explain why there are only four STR alleles represented in the ‘Crime Scene Sample.”

c) Explain if you would be confident presenting your results to the court for the trial of suspect 2.

21. A suspect was identified in a robbery case. Her DNA was collected, and data for four STR loci (D5S818, CSF1PO, D7S820, D8S1179) were obtained. The suspect's DNA profile data is shown below:

D5S818

Allele 1

–CAATCATAGCCACAAGATAGATAGATAGATAGATAGATAGATACCAAAGAG–

Allele 2

–CAATCATAGCCACAAGATAGATAGATAGATAGATAGATAGATAGATACCAAAGAG–

CSF1PO

Allele 1

–GGCCATCTTCAGATAGATAGATAGATAGATAGATAGATAGATAGATAGATAGATAGATAGATGCTAGTCC–

Allele 2

–GGCCATCTTCGATAAGATAGATAGATAGATAGATAGATAGATAGATAGATAGATAGATAGATAGATGCTAGTCC–

D7S820

Allele 1

–CCTCATTGACGATAGATAGATAGATAGATAGATAGATAGATAGATACATAGTCAG–

Allele 2

–CCTCATTGACGATAGATAGATAGATAGATAGATAGATAGATAGATAGATAGATAGATAGATACATAGTCAG–

D8S1179

Allele 1

–GTTCATTTTCATCTATCTATCTATCTATCTATCTATCTATCTACGAATGTACA–

Allele 2

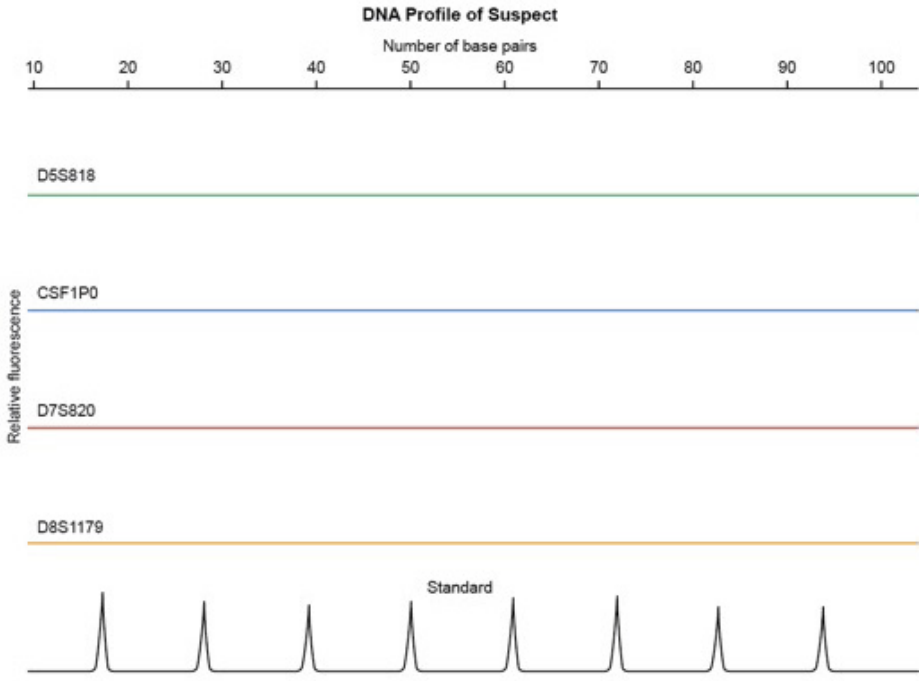
–GTTCATTTTCATCTATCTATCTATCTATCTATCTATCTATCTACGAATGTACA–

a) Analyse each STR locus by locating and counting the number of STR repeats and determine whether the suspect is homozygous or heterozygous at each locus to complete the table below.

STR locus	Number of base pairs	STR repeat	Number of repeats for allele 1	Number of repeats for allele 2	Heterozygous or homozygous
STR D5S818 on Chromosome 5					
STR CSF1PO on Chromosome 5					
STR D7S820 on Chromosome 7					
STR D8S1179 on Chromosome 8					

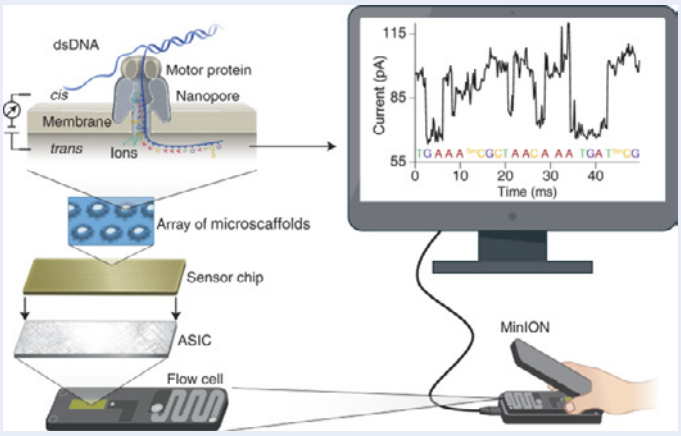
b) State and explain which DNA fragment would travel the shortest distance if all 8 were analysed using gel electrophoresis?

c) Use the data from the table above to draw the suspect's electropherogram on the chart below.



Science as a Human Endeavour 1.7 – Nanopore sequencing

Nanopore sequencing is a third-generation type of sequencing technology that can be conducted without the need to complete PCR first; therefore, it enables real-time analysis of genetic information providing immediate results. Furthermore, portable versions of the technology can be purchased facilitating many possible applications, across multiple industries. Nanopore sequencing works by passing a DNA or RNA molecule through a protein nanopore and monitoring the changes to electrical current as each nucleotide passes through the pore. This technology became commercially available in 2015.



Refer to the 'Helpful online resource' below to watch a short video on nanopore sequencing.

1. Discuss two applications of nanopore sequencing that are an improvement to the Sanger sequencing method (using terminator nucleotides, PCR and capillary electrophoresis).

2. Discuss one unexpected consequence that could arise from the misuse of portable nanopore sequencing and its impact on those affected.

Helpful online resources

National DNA Database: Nanopore DNA sequencing

<https://www.youtube.com/watch?v=E9-Rm5AoZGw>

Chapter 1.8 Biotechnology: applications

Science Understanding

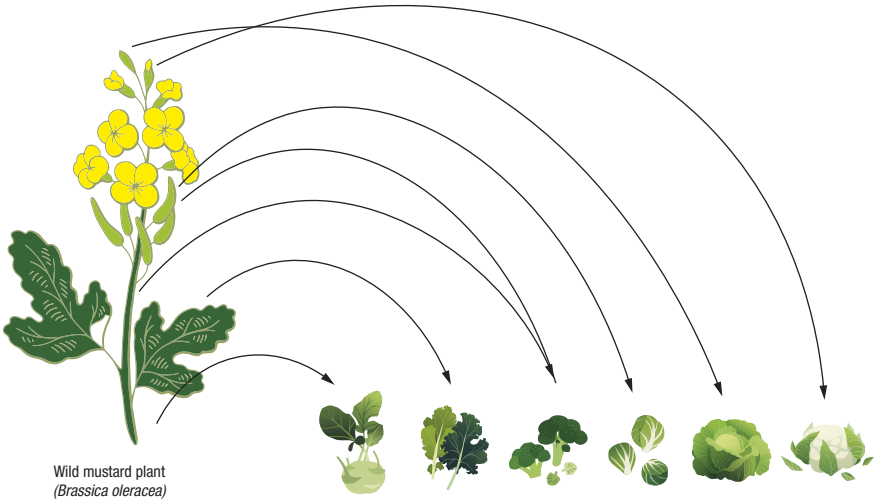
Biotechnology can involve the use of plasmids and viruses as vectors, bacterial enzymes, and yeasts.

Techniques include bacterial transformations, electroporation, and microinjection.

- Describe how particular genes can be selected using probes and removed using restriction enzymes.
- Describe how selected genes can be transferred between species.
- Describe how CRISPR, such as CRISPR-Cas9, can be used to edit and/or transfer genes.
- Discuss the design of new proteins and their uses.

Genetic Engineering (GE)

Humans have been altering the genomes of plants and animals for many years. We have selectively bred species for desired traits such as bigger and juicier fruits, seedless watermelons and leaner animals. One could argue that none of the produce we eat is 'organic' and 'natural' due to humans' interference. A prime example of this is the selective breeding of the wild mustard plant. Many of the leafy greens we eat today were created by selectively breeding the wild mustard plant for different traits. This gave rise to vegetables such as broccoli, cauliflower, cabbage and kale (see *Figure 181*). It is because of humans that these new varieties exist.



Strain	Kohlrabi	Kale	Broccoli	Brussels sprouts	Cabbage	Cauliflower
Modified trait	Stem	Leaves	Flower buds and stem	Lateral leaf buds	Terminal leaf bud	Flower buds

Figure 181 Some common vegetables that resulted from the selective breeding of the wild mustard plant by humans.

Genetic engineering (GE) refers to the techniques and processes used to directly manipulate the genomics of organisms. Genetic engineering allows greater precision and control over the genetic changes to organisms in comparison to selective breeding. Genetic engineering allows scientists to **transfer specific genes from one species to another**, providing the target organism with the **new desired trait(s)**. The products of genetic engineering are generally called genetically modified organisms (GMOs). Very specific trait(s) can be transferred, and it is possible because **DNA is universal** across all organisms. It is also possible to 'knockout' (remove) unwanted genes, removing the limiting effect, or undesired trait, of that gene on an organism. Some examples of genetically modified organisms are discussed in more detail later in the chapter.

Genetic engineering can also be used to produce proteins using organisms such as bacteria and yeast. This is often referred to as **protein engineering**, and it is a reliable process to help manufacture large quantities of proteins like insulin for diabetics and antigens for use in some vaccines.

DNA cloning

The cloning of genes requires the **extraction of DNA** from cells prior to being manipulated. It also requires the application of **restriction and DNA ligase enzymes**, and **fluorescently labelled probes**. Please review your understanding of these concepts by referring to Chapter 1.7.

Genetic and protein engineering both require the extraction of the gene(s) of interest from the target DNA. The gene(s) of interest are multiplied by inserting them into bacteria and culturing them. As the bacteria divide by binary fission, they replicate their DNA including the inserted gene(s) of interest, **cloning the gene**. This method is **quicker** and cheaper than the artificial synthesis of DNA, known as gene synthesis. Many copies of the gene of interest are required in genetic engineering to increase the chance of the gene of interest being **incorporated into the genome** of the desired organism.

It is important to note that bacterial plasmids play a large role in genetic and protein engineering. Plasmids allow the insertion of a gene of interest forming a recombinant plasmid (see *Figure 182*). When the recombinant plasmid is inserted back into bacteria (known as bacterial transformation), the plasmid can replicate independently making more copies of the gene of interest. Bacterial ribosomes can also synthesise the protein that the gene of interest codes for. This is a form of protein engineering, and the desired protein can then be harvested and processed for human use.

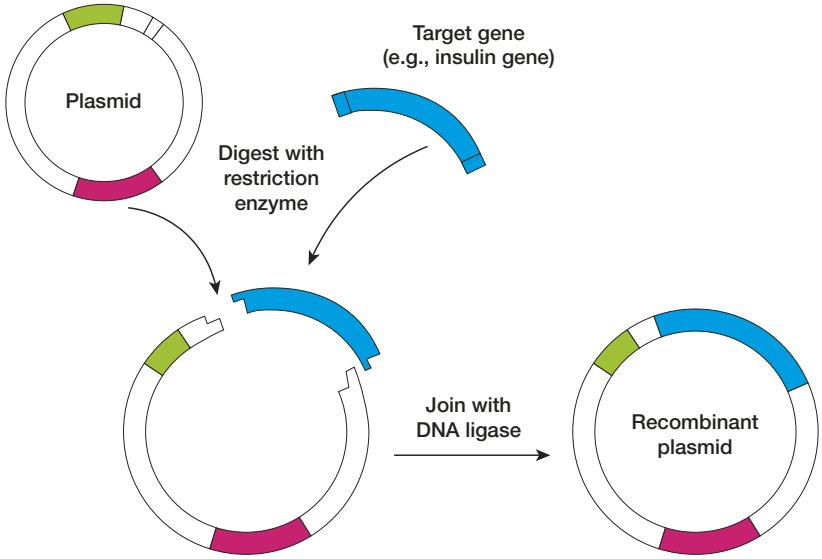


Figure 182 The formation of a recombinant plasmid containing a gene of interest

Steps of DNA cloning process

1. Extract DNA from target cell containing the gene of interest.
2. Cut the target DNA using a **specific restriction enzyme** (this produces multiple DNA fragments with sticky ends containing unpaired bases).
3. Remove plasmids from bacteria.
4. Cut the plasmids with the **same restriction enzyme** (this produces complementary sticky ends).
5. The DNA fragments are inserted into the bacterial plasmids and annealed using **DNA ligase** (forming **recombinant plasmids**, one of which contains the gene of interest).
6. Bacterial cells take up recombinant plasmids in a process called **transformation**. This involves shocking them using **electricity (electroporation)** or high temperatures.
7. All transgenic bacteria are then **cultured** (DNA replication and binary fission occurs leads to many copies of modified bacteria quickly).
8. This exponential growth of bacteria results in multiple copies of the gene of interest being produced (i.e. **DNA cloning**).
9. The **transformed** bacterial colony containing the gene of interest is identified using a specific **fluorescent DNA probe** that is complementary to a section of the gene of interest.

10. The **fluorescent colony** that the probe binds to is isolated from the other colonies and is cultured separately (see *Figure 183*).
11. If the goal is to produce and harvest a human protein (e.g. insulin) the protein is harvested and processed for human use.
12. However, if the goal is to transfer the gene of interest into another organism, the multiple copies may need to be isolated for transfer (depending on the method). This is applicable to both **transgenesis** and **gene therapy**.

Refer to *Figure 184* for a visual summary of the DNA cloning process.

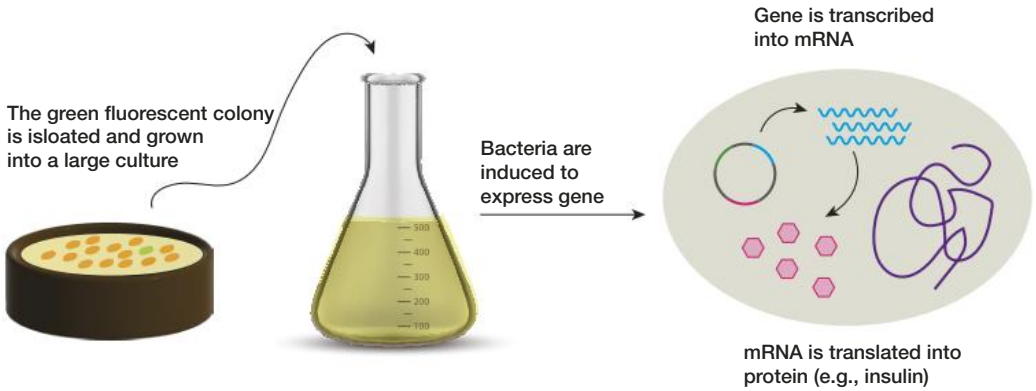


Figure 183 A probe is used to identify the bacterial colony with the gene of interest so that it can be grown into a large culture

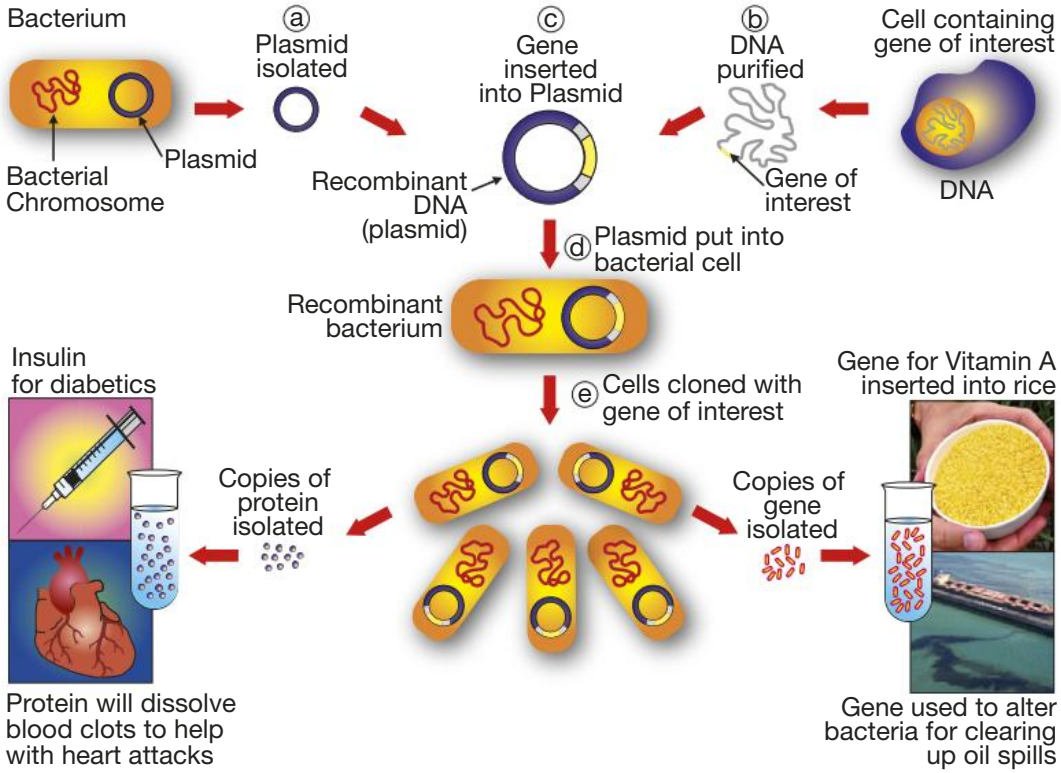


Figure 184 The technique of making and using transgenic bacteria

Helpful online resources

FuseSchool: Genetic engineering | Genetics | Biology | FuseSchool
<https://www.youtube.com/watch?v=DIM38NlkWEo>

Aldevron: Plasmid DNA Technology
<https://www.youtube.com/watch?v=Vn2OtIFkmBQ>

Amoeba Sisters: Genetic Engineering
<https://www.youtube.com/watch?v=CDw4WPng2iE&t=231s>

The use of yeasts in protein engineering

Yeasts have been used by humans for centuries in processes such as baking, brewing and winemaking. They have also been applied to the biopharmaceutical industry more recently and used as 'protein factories' that **manufacture specific proteins**. Yeast are often used in the production of some **antibiotics** and antigen proteins for **vaccines** against various diseases. Some vaccines that include recombinant proteins produced by yeast include:

- Hepatitis B
- Malaria
- Dengue
- HIV Type 1
- Epstein-Barr virus, and
- SARS-CoV-2.

Using yeast instead has some **advantages** such as:

- Yeast are generally safe, inexpensive and easy to observe.
- The genomes of the commonly used yeast have been sequenced and genes have been mapped making it a useful tool for biopharmaceutical industry.
- Yeast can synthesise more complex eukaryotic proteins.
- The yeast can make the required modifications to the proteins after being translated.
- They grow and reproduce quickly, therefore produce large quantities of the protein quickly too.

However, using yeast also has some **limitations** such as:

- Yeast can produce methanol which is flammable.
- Glycosylation (addition of carbohydrates) of proteins is different in yeasts compared to in human cells, which can lead to less effective vaccines.

Transgenesis (transferring genes between species)

Gene transfer involves techniques in which genetic material is transferred from one organism to another. The process is called **transgenesis** and organisms formed in this manner are called **transgenic organisms**. Prior to transgenesis, the **gene(s) of interest are cloned**. They are then isolated using restriction enzymes and can be transferred into the cells of desired species. They must be transferred into the **'first' cell** of the transgenic organism, so that the recombinant DNA is **present in all cells** in the organism. Multiple copies of genes are needed to increase the chance of the gene of interest **incorporating into the new organism's genome** and being expressed in the correct cells. Gene transfer can be achieved chemically, physically or by using **vectors**, such as viruses or bacterial plasmids. These methods are explained in more detail below.

Microinjection

Microinjection is a physical method of gene transfer that is often used to transfer genes to **animal cells**. Many copies of the desired gene are injected directly into the nucleus of a **fertilised egg cell**, through a very thin micropipette (see *Figure 185*). It is then transferred into the recipient mother, where it can grow and be born. This technique is highly flexible but is slow and requires highly skilled technicians. This method is also used in vitro fertilisation to improve the chance of fertilisation of an ovum with a sperm (the technique is called intra-cytoplasmic sperm injection).

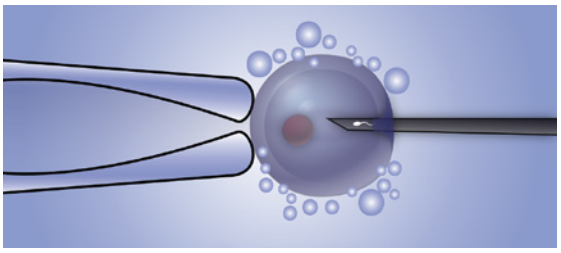


Figure 185 A micropipette (left) entering a single cell in process of microinjection

Viral Vectors

Viruses naturally infect plant and animal cells and transfer their DNA into the nucleus of the cells they are invading. If the viral DNA is modified to contain a 'desired' gene this can also be transferred into a host or target cell nucleus. These are called viral vectors.

Helpful online resources

Oxford Mastering Biology: Animation E4, 1.3 Production of GM animals
<https://www.youtube.com/watch?v=LciR8T3oca4>

Electroporation

Electroporation can be used to transfer genes into some bacterial, plant and animal cells. Electroporation uses an electric shock to puncture small holes in the cell membrane allowing the gene to get into the cell.

Ti Plasmid

Agrobacterium tumefaciens is a type of bacteria that naturally **infects plants** by copying its Ti (tumour inducing) plasmid and transferring one copy to the plant cell. The plasmid then incorporates its DNA with the plants DNA and promotes cell division, resulting in a tumour. However, scientists have managed to remove the tumour inducing genes and are able to replace them with another desirable gene. The bacteria transfer this gene instead of tumour inducing genes and results in the new trait being incorporated into the plant genome (see *Figure 186*).

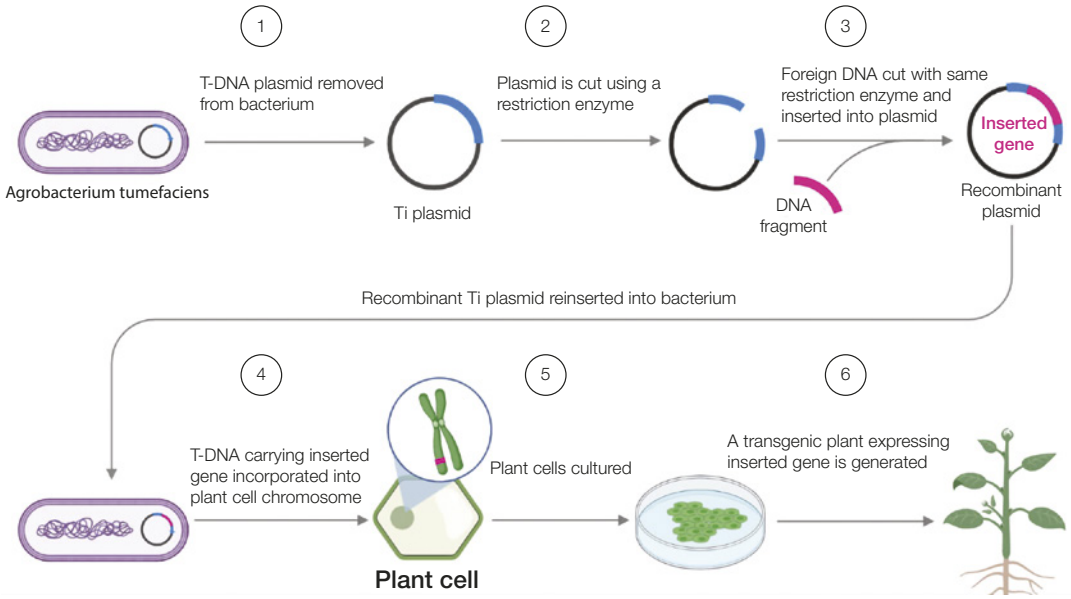


Figure 186 The process of Agrobacterium-mediated transformation and gene transfer to plant cells

Helpful online resources

Oxford Mastering Biology: Animation E4, 1.2 Production of GM plants
<https://www.youtube.com/watch?v=7UZxS1o4geQ>

Examples of genetically modified organisms (GMOs)

There are many different current and potential examples of genetically modified organisms. Some examples are outlined below.

Golden rice and bananas

The World Health Organisation (WHO) estimates that between 250,000 and 500,000 children go blind every year due to vitamin A deficiency (VAD). Of the children that go blind, approximately 50% of them will die. It is estimated that up to 2.5 million people die worldwide due to VAD. The majority of VAD occurs in developing countries with little access to fresh wholefoods. In Asia, rice is the staple food. Scientists have been able to genetically modify rice so the **provitamin A is expressed in the rice grains** instead of just the leaves. This version of rice has been called 'golden rice' due to the yellow colour of the rice grain resulting from the presence of provitamin A. Golden rice was developed in 1999/2000 and the first field trial occurred in 2004. This genetically modified rice has the potential to save millions of lives each year, yet countries have been slow in passing legislation for farmers to grow it. However, the Philippines is the first country to legalise the farming of golden rice to help address their country's cases of vitamin A deficiency. In Africa, bananas are the staple food rather than rice. Scientists have also been able to genetically modify bananas to include provitamin A. Scientists have also had some success with biofortifying rice with iron and zinc.

Figure 187 A comparison of the golden rice grain and white rice grain

Helpful online resources

International Rice Research Institute: The Road to Golden Rice
<https://www.youtube.com/watch?v=L05d0_tkR_s>

Herbicide resistant crops

Plants naturally compete with other plants for sunlight and nutrients. On farms, crops compete with weeds for resources. This competition can result in less nutrient availability for the crops and a lower yield overall. Therefore, many farmers use herbicides to eliminate weeds from their fields, but crops are also susceptible to the herbicides. Scientists have been able to produce genetically modified crops that are **resistant to herbicides**, known as Roundup Ready crops (Roundup is a commonly known herbicide). This means that when the fields containing Roundup Ready crops **are sprayed with the herbicide**, only the weeds are killed, and **the crop is unaffected** (see *Figure 188*). This results in less competition for resources and the crop produces a higher yield. The increased yield is more profitable for the farmers, but it also means that there is more food available for the growing population. Two examples are Roundup Ready soybean and Roundup Ready corn, which were introduced in the late 1990s.

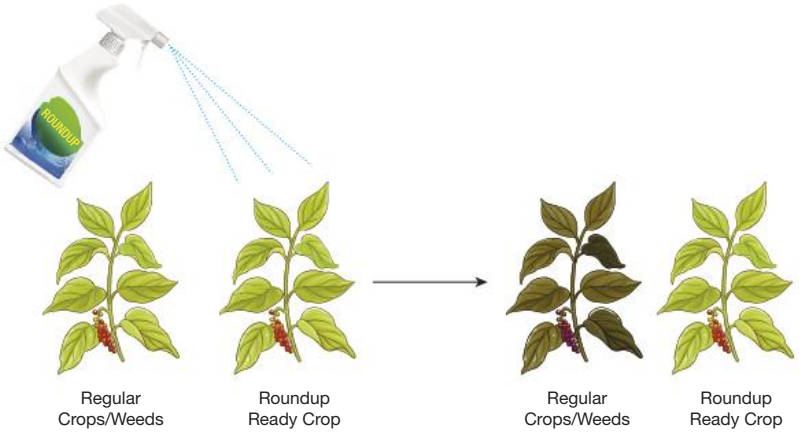


Figure 188 Roundup is a herbicide that contains a chemical toxic to standard plants and weeds. Roundup Ready crops have been genetically modified making them immune to Roundup whereas weeds are susceptible to it.

Pest resistant crops

Crops can be genetically modified to be more resistant to attack from pests such as insects. Scientists can do this by introducing genes found in soil bacteria into the particular crop, for example corn. This enables the crop to produce a protein that is activated when eaten by certain target insects. This activated protein pierces holes in the insects' digestive system, causing it to leak and die of starvation. This means that the crop now has the ability to **produce its own insecticide** and protect itself from certain insects. This is beneficial for farmers and the growing population because it results in less crop damage from insects and a higher yield. It also reduces the chemical pollution of soils as farmers **do not have to spray their crops with synthetic insecticides**. The insecticide protein produced is not toxic to humans and other mammals because our digestive systems do not possess the complementary receptor to bind with it. In fact, studies have shown that humans digest this insecticide protein into amino acids just like any other protein found in our food, such as meat, fish and tofu (see *Figure 189*).

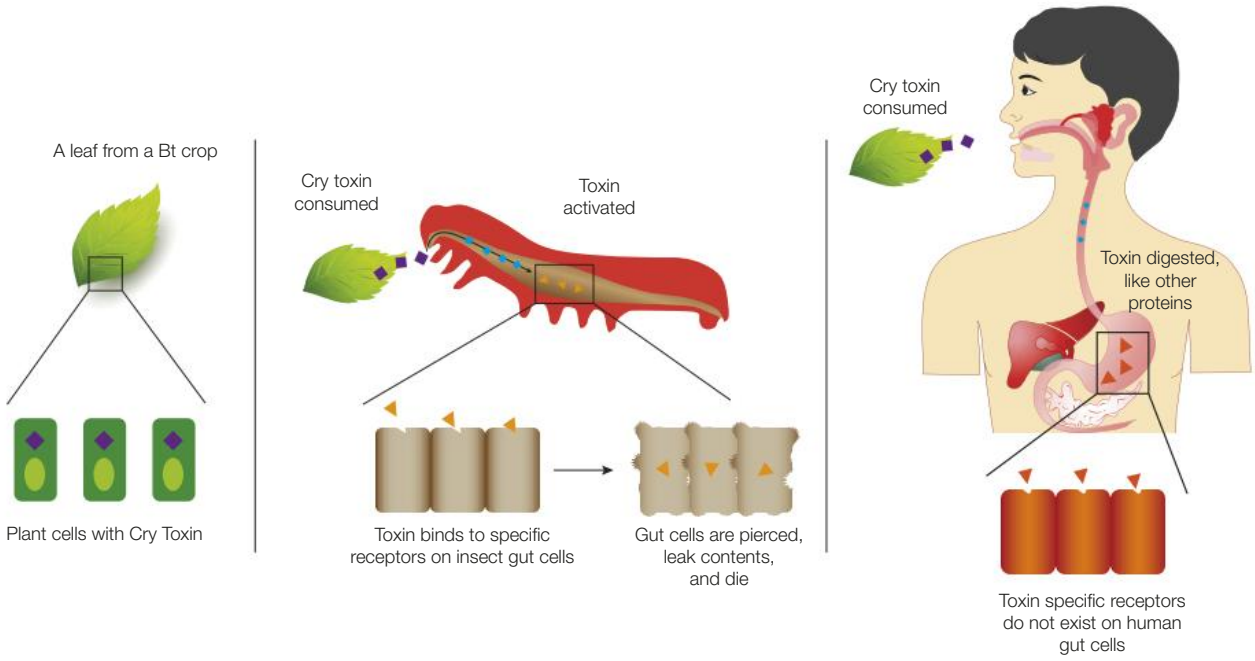


Figure 189 How the insecticide protein known as 'Cry', which is produced by genetically modified pest resistant crops, affects certain insects but not humans

Disease resistant crops

Genetically modified crops make it possible to save some crops from extinction and increase yields of others by providing immunity to certain diseases. There are many examples of diseases that infect and destroy crops. One example is the PVY virus that infects potatoes and can reduce crop yields by up to 70%. GM potatoes that are resistant to the PVY virus have been developed and approved for use in Argentina.

Researchers in Australia have also been successful in modifying the Cavendish banana to protect it from Panama disease caused by a fungus. They did this by inserting two genes into the plant, one of which was a gene from a wild banana plant that confers resistance to the disease. This research could save the Cavendish banana from extinction and keep the banana industry alive. In addition, further research could be conducted to genetically modify the extinct Gros Michel banana to be resistant to Panama disease too and bring about the return of the sweeter banana to the supermarket. For more information on the susceptibility of bananas to Panama disease, please watch the YouTube Video below.

Helpful online resources

SciShow: Bananas Are Losing the War on Fungus
<https://www.youtube.com/watch?v=9H0dy8fv33M>

Tomatoes with increased shelf-life

Transgenic tomatoes, known as ***FlavR SavR®***, have been developed by transferring an antisense gene into the tomato genome. This gene interferes with the production of an enzyme that degrades cell walls and results in softening of the fruit. This interference technology therefore extends the shelf-life of the tomatoes by interfering with rotting enzyme activity. The changes allow tomatoes to be shipped over greater distances and stored for longer periods. Refer to *Figure 1810*.

Figure 1810 FlavR SavR® tomatoes

Helpful online resources

FuseSchool - Global Education: GM Crops | Genetics | Biology | FuseSchool
<https://www.youtube.com/watch?v=kZIYkYNpnP0>

Additional current and potential applications of genetic engineering

Some additional examples of genetically modified organisms are outlined in the table below:

Example of GMO	Possible benefits
Nitrogen fixing crops (crops that can produce their own nitrates from N_2 in the atmosphere).	Reduced fertiliser use and therefore reduced risk of fertiliser runoff causing eutrophication and algal blooms.
Abiotic stress resistance (improved ability of crops to withstand high temperatures, drought and/or high salinity).	GM crops can be cultivated (grown) on land where climate is unfavourable to most plants, increasing availability of food.
Bioremediation (using GM bacteria to clean up contaminated water/soil e.g. oil spills).	GM bacteria could potentially be produced to digest the variety of hydrocarbons in crude oil and reduce environmental damage.
GM plastic digesting bacteria.	Genetically engineering plastic digesting bacteria to break down plastic at a much faster rate. These GM bacteria could be applied to oceans and landfill to breakdown plastic that can kill animals and even microplastics that enter human food chains.
GM pigs for xenotransplantation of organs.	Waiting list for organs is longer than donor organs available. Pigs' organs can be genetically modified to express human proteins reducing rejection of organ and could potentially save lives.
GM marine bacteria to produce spider silk.	Spider silk has many applications due its lightweight, strength and biodegradable properties. It is highly sought after so this could allow the upscaling of production to provide to medical, clothing and aerospace industries.

There are many more possible applications that are currently being researched and the potential options are endless. *Figure 1811* shows a transgenic mouse that glows green as it contains a fluorescent protein, originally from a glowing jellyfish. A glow in the dark mouse might not seem very useful, but the technology behind it has multiple applications. The technique has been applied to fish to produce glow in the dark Glofish® that are popular in the pet industry. It has also been applied to cancer treatment to fluorescently label cancer cells to track their presence and movement in the body. The fluorescent genes are also used by scientists in a similar manner to fluorescent probes. They can use it as a **biomarker** by inserting the fluorescent gene with the gene of interest. This allows scientists to **visually determine** which mice have developed from cells that incorporated the recombinant DNA into their genome. This expediates the identification process as they do not have to run genetic tests to determine which mice are transgenic.

Figure 1811 A fluorescent transgenic mouse

Helpful online resources

Kurzgesagt - In a Nutshell: Are GMOs Good or Bad? Genetic Engineering & Our Food
<https://www.youtube.com/watch?v=7TmcXYp8xu4>

LSG Science: Animal Pharm Episode 2
<https://www.youtube.com/watch?v=ZRkweynk1Ik>

CRISPR/Cas9

In nature, viruses commonly infect bacteria and kill them. Bacteria developed a defence system against viruses however, called CRISPR. When viruses infect bacteria, a copy of the viral DNA is stored in a section of the bacterial DNA called CRISPR. The CRISPR sequence allows bacteria to remember their previous viral invaders, and if re-infected, guide RNA and a Cas (**C**RISPR **as**sociated) enzymes are sent to kill the virus. It is essentially a mini-immune system for bacteria.

Since its discovery, CRISPR has been adapted by scientists so that it can be used in human and other species' cells to precisely edit DNA. There are many Cas enzymes, but scientists have discovered that the Cas9 enzyme is the best for editing animal cells.

How it works

The CRISPR/Cas9 system consists of two key molecules:

Key Molecule	Function
An **enzyme** called **Cas9**	Cas9 acts as a pair of **'molecular scissors'** that can **cut** the double stranded DNA of host cell at a specific location.
Guide RNA (gRNA)	A short RNA sequence (about 20 bases long) that is synthetically made to be **complementary** to a specific section of DNA. The guide RNA binds to DNA and **'guides' Cas9** to the right part of the genome to ensure that the Cas9 enzyme cuts at the right point in the genome.

Scientists discovered that the Cas9 enzyme could be programmed using guide RNA to cut genes at specific places. To do this, they need to know the sequence of the target DNA so they can synthesise a guide RNA that is complementary to a specific section of the desired gene sequence.

The guide RNA and Cas9 protein can be transferred into the target organism. The Cas9/guide RNA complex scans the DNA throughout the organism searching for its complementary section on the DNA molecules. When it is located, the guide RNA guides the Cas 9 enzyme to the cutting site, breaking through both the strands. This means that, at least in theory, the guide RNA will only bind to the target sequence and no other regions of the genome (see *Figure 1812*).

CRISPR/Cas9 technology has the capacity to edit parts of genes by removing, adding or altering sections of DNA. It has great potential for creating treatments for many different genetic diseases and other applications.

Refer to the 'Helpful online resources' below to watch a video with a very good analogy to help your understanding of CRISPR technology. It uses a toy train (Cas9) and train track (DNA) to help explain how CRISPR/Cas9 works.

Helpful online resources

WIRED: Crispr Gene Editing Explained

<https://www.wired.com/video/watch/crispr-gene-editing-explained>

TED-Ed: How CRISPR lets you edit DNA - Andrea M. Henle

<https://www.youtube.com/watch?v=6tw_JVz_IEc>

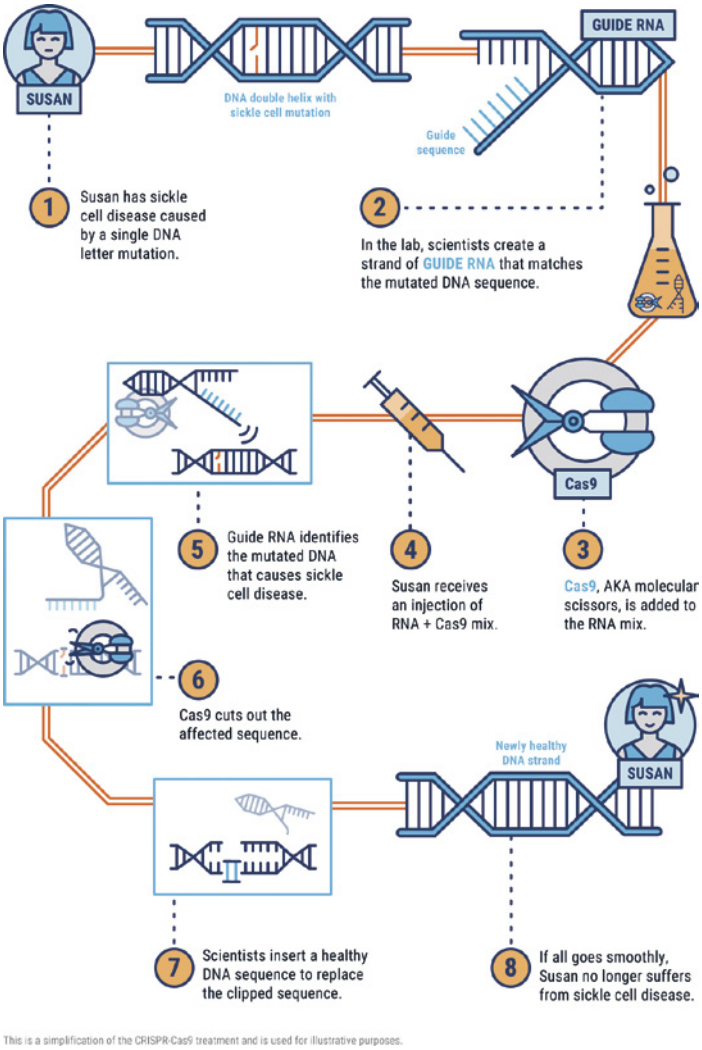


Figure 1812 An example of how CRISPR/Cas9 could treat genetic diseases like sickle cell anaemia in the future (CB Insights)

Applications

CRISPR/Cas9 is currently the fastest and best system for editing genes. It can also be applied to the DNA of virtually any species giving rise to many possible applications. Research involving this technology is evolving and a version has already been developed that can turn specific genes on or off without cutting the DNA. This development could alleviate some of the ethical concerns with its use as it is not making any permanent changes to the hosts' DNA. Some examples are outlined in the table below:

Application	Explanation
Cure genetic diseases	Potential to cure genetic diseases such as sickle cell anaemia, cystic fibrosis and Duchenne muscular dystrophy (DMD).
Huntington's disease	Used to inhibit the formation of proteins that cause Huntington's disease.
Agriculture	Creating crops that are disease resistant, non-browning, drought tolerant, etc. to produce higher yields.
Mosquito-borne diseases	Mosquitos have been genetically engineered to only produce male offspring that don't bite. They have been released into the wild as part of trials to help reduce the spread of zika and Dengue in multiple countries including Florida in the USA. They have also been edited to combat malaria. Refer to 'Helpful online resource' below for more information.
Cancer	Can be used to program immune cells to target specific mutated proteins on an individuals' cancer cells.
Studying the genome	Scientists can turn on/off certain genes to research the effect and gain a greater understanding of our development.
Designer babies and pets	Parents could potentially choose desired traits and 'design' their baby or pet using this technology. Refer to the 'Helpful online resources' below for more information.
Cure HIV/AIDS	Used to cut HIV code out of immune cells to cure the disease. Scientists have already had success in mice and macaques. A human clinical study just started in 2022. Refer to the 'Helpful online resources' below for more information.

Helpful online resources

Kurzgesagt - In a Nutshell: Genetic Engineering Will Change Everything Forever – CRISPR
<https://www.youtube.com/watch?v=jAhjPd4uNFY&t=33s>

Kurzgesagt - In a Nutshell: Genetic Engineering and Diseases – Gene Drive & Malaria
<https://www.youtube.com/watch?v=TnzcwTyr6cE>

Osmosis: CRISPR-Cas9 and the age of gene-edited humans
<https://www.youtube.com/watch?v=1viRt8jV-vk>

WIRED: A Bold Effort to Cure HIV Using CRISPR
<https://www.wired.com/story/a-bold-effort-to-cure-hiv-using-crispr/>

Limitations

There are many ethical, moral and biological issues associated with the use of this technology. Some limitations are outlined in the table below:

Limitation	Explanation
Off-target activity	There is potential for the CRISPR/Cas9 to cut in the wrong location if the guide RNA sequence is also located in other areas of the genetic code. A possible consequence is cancer.
Mosaic generation	Treated patients could have a mixture of treated and untreated cells.
Immune system complications	The CRISPR/Cas9 treatment could trigger an immune response. The immune system could see Cas9 as a foreign protein and initiate inflammatory response.
Research on germ line cells	Because any changes made in germline cells will be passed on from generation to generation, it has important ethical implications that must be considered (e.g. the infant produced from these cells cannot consent to the treatment).
Illegal research	The technology is cheap, easy to perform and readily available raising concern of unauthorised research. An example of this has occurred recently, where a scientist performed secret experiments on twin embryos using CRISPR to edit a gene associated with resistance to HIV. Refer to the 'Helpful online resources' on HIV on the previous page for more information.

Social and ethical issues

Bioethics is involved with the study of biological ethical issues. This involves many disciplines, including law, philosophy, theology and the social sciences. The greatest challenge for society is to keep pace with ever-growing biotechnological developments. Bioethics deals with basic human values; knowing right from wrong, from IVF to euthanasia and all stages in between.

Genetic engineering offers unlimited potential from improving food availability and nutritional value to disease prevention and cure. Unfortunately, these technologies also bring with them a range of problems and potential issues that humans are forced to consider.

The 'Australasian Association of Bioethics and Health Law'(AABHL) is Australia and New Zealand's leading organisation in this area. Its main goals are to:

1. Increase public awareness of bioethics and legal issues.
2. Advance the study of bioethics and legal issues.
3. Facilitate communication between the public, governments and the media.

Helpful online resources

University of Oregon: What is bioethics? | Philosophy, Medicine, and Clinical Ethics
<https://www.youtube.com/watch?v=rspuMMm_fTQ>

Depending on the specific technology, there are a range of concerns and as a consequence, the list of potential issues is vast. They fit into a range of categories including ethical, social, environmental, economic, individual, cultural and religious.

A few of the more common issues are briefly outlined below:

- Individual risks of unknown side-effects. Alterations in genomes could change an organisms' metabolism, growth rate, response to external environmental factors, etc. This could also influence the community of species surrounding it.
- Humans could be exposed to new allergens that are introduced into genetically modified food. Antibiotic resistance genes could also be transferred to gut bacteria from genetically modified food.
- Transfer of herbicide and/or pest resistant genes to weeds could allow weeds to grow uncontrolled and outcompeting native species (resulting in a loss of biodiversity). This could also result in farmers having to use stronger chemicals to combat the resistant weeds that could be ingested by other animals and/or humans.

- Not growing GM crops results in more expensive food for the consumer. Non-GM crops require more water, more chemicals and produce a lower yield and the costs are passed on to the consumer.
- Exploitation of vulnerable individuals who are manipulated for gain.
- Reduction in biodiversity due to increased monoculture using transgenic crops.
- Ethical issues involving the mistreatment of other species for our own selfish interests.
- Effects on evolution by blurring boundaries between species.
- Fair access of technologies to underdeveloped or developing nations.
- Respect for human life, such as the possible embryo destruction occurring in scientific research.
- Religious and cultural opposition to practices such as sex selection in embryos.
- Private companies could claim ownership of the GMOs they produce and charge an unreasonable price.
- Companies could patent genes giving them the right to 'own' the research on that gene for 20 years to try and develop a drug for a specific disease. They could then charge whatever price they wanted because they would be the only company with that treatment.
- The potential opening of 'Pandora's box' with regards to editing human beings for desired traits.

Helpful online resources

FuseSchool - Global Education: Gene Technology | Genetics | Biology | FuseSchool
<https://www.youtube.com/watch?v=2fIpr1ADwkw>

ASAP Science: Can We Genetically Improve Intelligence?
<https://www.youtube.com/watch?v=vr5n_ZOZ6E8>

Vsauce3 (ASAP Science): Can You Genetically Enhance Yourself?
<https://www.youtube.com/watch?v=N-48RVaqZck>

Designing new proteins

There are approximately 42 million proteins in the average human cell, highlighting their importance. Each protein has its own unique shape, which determines its function. The shape of a protein is defined by its primary structure, the order of amino acids in the chain. If the sequence of amino acids determines the shape of a protein, it should therefore be possible to predict the 3D shape of the protein, based on the 1D sequence of amino acids. Theoretically, it is possible, but it takes a lot of processing power because there are almost limitless possibilities of protein folding based on its sequence (an estimated 10^{300} possibilities). This is called the '**protein folding problem**'. Scientists have been trying to work out how proteins fold for 50 years using a variety of techniques. Solving the protein folding problem would allow scientists to design new proteins from scratch for a variety of applications.

Given the astronomical number of possible folds, the computer processing power required to predict the 3D shape of proteins has only recently been developed. This has helped researchers to start 'cracking the code' of the structure of proteins, allowing them to **design new proteins**. Once a new protein has been designed using computer software, the **protein still needs to be synthesised**. This is performed using **biotechnology** discussed earlier in the chapter. Knowing the amino acid sequence, allows a corresponding DNA strand to be synthesised, which can then be inserted into a bacterial plasmid. The transformed bacteria then translate the synthetic gene to produce the new protein, which is harvested and purified before application.

Researchers have experienced increased success in designing new proteins within the last few years, and the success keeps growing. In 2022, an **artificial intelligence (AI) system called AlphaFold** was developed. AlphaFold was trained using approximately 170,000 known protein structures and sequences and can accurately predict the 3D shape of proteins based on the amino acid sequence. AlphaFold is freely available to the scientific community and is helping to accelerate research in many fields.

Some current and potential applications of new protein designs include:

- Discovering and engineering enzymes to digest plastic waste.
- Creating new and more efficient vaccines for diseases such as SARS-CoV 2 and RSV.
- Creation of narrow spectrum drugs that focus on one target reducing side effects.
- Creation of new synthetic antibiotics to combat antibiotic resistance and 'superbugs'.
- Development of new materials such as protein sheets that could be used in solar cells.
- The Drugs for Neglected Diseases initiative (DNDi) is developing new drugs for less common and neglected diseases.
- The creation of new proteins for cancer immunotherapy.
- Increasing our understanding of the evolution of proteins.

Helpful online resources

Science Magazine: The protein folding revolution
<https://www.youtube.com/watch?v=cAJQbSLIonI>

Institute for Protein Design: What is the Institute for Protein Design?
<https://www.youtube.com/watch?v=jBNCj2vqau0>

DeepMind: Protein folding explained
<https://www.youtube.com/watch?v=KpedmJdrTpY>

1.8 Review questions

Multiple choice questions

1. A bacterium has been found that produces a form of biodegradable plastic. Genes from this bacterium have been transferred to a weed species that is now capable of producing this plastic.

   This technology is possible because

   J genes in different species have the same basic chemical components.

   K all species have the same genes, but they take different forms in each species.

   L all genes carry the same genetic information.

   M genes transferred between species will not alter the genetic composition of the host species.

2. A particular species of soil bacterium (*A. tumefaciens*) can infect roses and some fruit tress causing a loss of productivity. A related species (*A. radiobacter*) can undergo genetic modification by including a plasmid that contains a gene coding for an antibiotic that will destroy *A. tumefaciens*.

   A. radiobacter also has a gene that confers resistance to this antibiotic. A transfer gene located on the plasmid enables insertion of the modified antibiotic gene into *A. radiobacter.*

   In treating plants infected with *A. tumefaciens* a suspension of the genetically modified *A. radiobacter* was applied to the soil.

   Which one of the following would be necessary regarding the genetic modification of *A. radiobacter* for the treatment to work?

   J Removal of the plasmid transfer gene.

   K Destruction of the antibiotic gene.

   L Removal of the plasmid containing the modified gene.

   M Destruction of the antibiotic resistance gene.

3. There are many important steps involved in the manipulation of DNA. Which one of the following correctly describes an important step in selecting or removing genes of interest from DNA?

   J A short piece of single stranded DNA whose sequence is complementary to a part of the gene is used as a probe.

   K A DNA restriction enzyme is used to join a specific segment of DNA to a probe that can identify the complementary DNA sequence.

   L A bacterial plasmid is inserted into a cell to form recombinant DNA.

   M A DNA ligase enzyme is used to cut DNA at specific recognition sites.

4. Which of the following is **not** an ethical consideration regarding testing on animals?

   J The treatment must be tested on animals prior to testing on humans.

   K The least number of animals should be tested on.

   L It costs less money to test on mice than humans.

   M The research on animals has potential to reduce human suffering.

5. Scientists have been successful in inserting the human insulin gene into bacteria. The recombinant bacteria are then cultured, cloning the insulin gene as a result.

   Which of the following options likely explains why multiple copies of the insulin gene produced by bacteria are not transferred to diabetic patients following the cloning gene process?

   J All the bacteria cloned are unable to produce the human insulin protein.

   K Bacteria cannot synthesise exact copies of the human insulin gene.

   L Bacteria synthesise the human insulin protein which is then harvested.

   M As the insulin gene is on the bacterial plasmid and not on the circular chromosome, it cannot be transcribed and translated by bacteria.

6. Tomato crops are highly susceptible to frost, which can wipe out farmers' crops and reduce yields. Scientists have researched the possibility of creating genetically modified (GM) anti-freeze tomatoes by inserting the anti-freeze gene from deep sea flounder into tomato crops.

   Which of the following options is an ethical consideration with regards to the GM anti-freeze tomatoes?

   J Could there be any unknown side effects from the consumption of these GM tomatoes?

   K Would vegans choose to consume GM anti-freeze tomatoes?

   L Are the GM tomatoes going to be a popular choice to consumers?

   M Could GM anti-freeze tomatoes be a risk to people with allergies to fish?

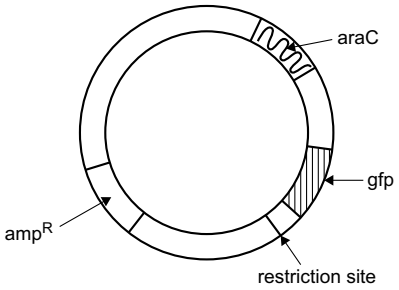
Use the following information to answer Questions 7 - 9.

The steps involved in cloning a gene of interest (GOI) are outlined below:

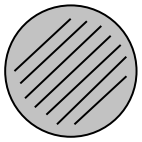
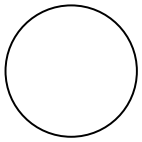
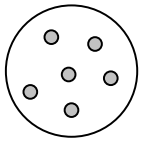
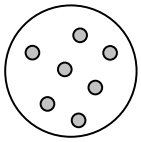
1. A plasmid and source of GOI is cut with a specific restriction enzyme.
2. The GOI is joined to the plasmid by DNA ligase.
3. The recombinant plasmids are transferred to bacteria.
4. The bacteria are then cultured on nutrient agar plates with different conditions (outlined in table on the following page)

Refer to the diagram below showing a plasmid used in this gene cloning process and the positions of one restriction site and three genes:

- amp^R – confers resistance to the antibacterial agent ampicillin.
- gfp – encodes the green fluorescent protein (GFP), which fluoresces under UV light.
- araC – encodes a protein required to promote the expression of gfp when arabinose is present.



A bacterial transformation experiment was conducted, and the results are shown in the table below:

Plate	A untransformed bacteria only	B untransformed bacteria only	C transformed bacteria	D transformed bacteria
Diagram of plate				
Added to plate	nutrient agar only	nutrient agar and ampicillin	nutrient agar, ampicillin and arabinose	nutrient agar and ampicillin
Description of result	lawn of bacteria	no growth	bacterial colonies present	bacterial colonies present

7. Scientists use bacteria to clone genes because:

   J they themselves are clones with no variation at all so they can reliably clone a gene.

   K many copies of the gene can be produced quickly as bacteria divide exponentially by mitosis.

   L the plasmids can be cut at multiple sites allowing the GOI to be inserted with both ends ligated to the plasmid.

   M their plasmids can be manipulated to contain the GOI but also be inserted back into the bacteria successfully.

8. The plate from the experiment that would contain fluorescent bacteria under UV light is:

   J A

   K B

   L C

   M D

9. Which of the following statements is correct?

   J Plate A has bacterial growth because a streaking method was used to apply the culture instead of an aseptic technique.

   K Plate B has no bacterial growth because it was a control plate to show that no bacteria will grow if no bacteria culture is applied to it.

   L Plate A only has untransformed bacteria because recombinant plasmids could not be transferred into them.

   M Plate B was a control plate to show that the ampicillin kills untransformed bacteria.

10. Scientists clone genes of interest prior to transgenesis.

    Multiple copies of a gene are required:

    J to insert into the many cells that make up multicellular organisms.

    K to insert into the nucleus of the desired cell as it increases the chance of the gene incorporating into the genome.

    L to incorporate into every single chromosome within the desired cell.

    M to produce guide RNA for CRISPR/Cas9.

11. Human immunodeficiency virus (HIV) is the virus responsible for causing acquired immunodeficiency syndrome (AIDS). Scientists have found it hard to cure HIV/AIDS because the virus has an enzyme called reverse transcriptase that converts the viruses RNA code into DNA and then another enzyme, integrase, which integrates the viral DNA into the hosts DNA.

    Scientists could find a cure for HIV/AIDS using CRISPR/Cas 9 because:

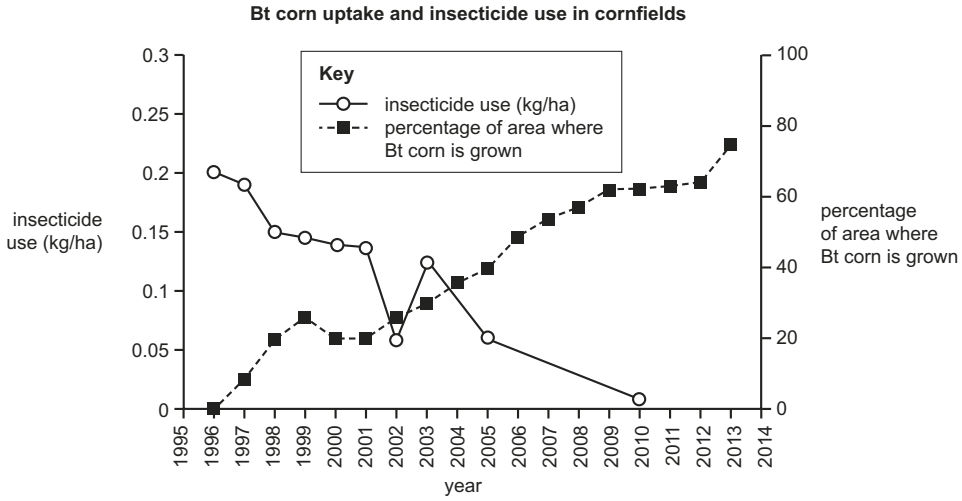
    J guide RNA could be programmed to recognise the AIDS DNA and Cas 9 could cut it out of the genome.

    K CRISPR/Cas9 could potentially be programmed to insert a section of DNA into infected patients' genomes to produce proteins to combat the effects of the virus.

    L Cas 9 could cut the viral DNA out of the hosts genomes.

    M CRISPR/Cas 9 could be programmed to repair DNA damaged by the HIV virus.

12. *Refer to the following graph to answer the question below.*



Source: 'Smarter Pest Control', special section, *Science*, vol. 341, 16 August 2013, p. 731

Bt corn is an example of a genetically modified (GM) crop. In this example, the transferred gene promotes expression of an insecticide protein.

Which of the following options describes a benefit of Bt corn?

J Bt corn saves time spent on manual labour for corn growing farmers.

K Herbicide use decreases as a result of Bt corn uptake.

L It is not possible for insects to develop resistance to insecticide expressed from Bt corn.

M Crop yields are significantly lower for Bt corn due to lack of insecticide use.

Use your understanding of Science as a Human Endeavour to answer questions 13 to 15.

13. A limitation of DNA profiling would be that:

    J it can be used to resolve paternity issues.

    K it cannot be reliably used in some cases where a person is made up of cells from two or more individuals (chimeras).

    L the technology requires further research before it can be implemented as a reliable tool for paternity issues.

    M although it can be used to genetically differentiate between individuals in society it cannot differentiate between members of the same immediate family.

14. In Australia, the egg farming industry produces approximately six billion eggs annually. This requires approximately 20 million hens to meet these demands. Currently, the egg farming industry culls male chicks after they hatch. Fortunately, it is now possible to determine the sex of a chick prior to hatching due to recent developments in gene technology conducted by the CSIRO. This technology requires precision gene editing to add a biological marker to the sex chromosomes. This allows for egg farmers to determine the sex of pre-hatched eggs and as a result, only the female eggs can be hatched.

    Identify the **false** statement below.

    J An ethical issue that can be addressed by applying this technology to the egg farming industry is the unnecessary culling of male chicks that cannot lay eggs.

    K The pre-hatched male eggs that are not required by the egg farming industry could be applied in the vaccine industry that require fertilised chicken eggs to develop influenza vaccines.

    L An unexpected increase in sales of eggs could arise as a consequence of a more animal friendly egg laying industry.

    M A limitation of determining the sex of the chick prior to hatching technology is the ongoing practice of caged hens for laying eggs.

15. According to the World Health Organisation (WHO), approximately 250 to 500 thousand children go blind every year due to vitamin A deficiency (VAD), of which about half of them die. Most of these cases occur across Asia and Africa. As rice is the staple food of Asia, genetically modified rice has been developed so that vitamin A is expressed in the rice grain and not just the leaves, called ‘golden rice’.

    Even though GM golden rice has been available since 1999, the approval for farmers to grow GM golden rice has not been forthcoming, with the Philippines the first country to legalise its growth for seed and consumption in 2021.

    Which of the following options could explain the hesitancy of Asian nations to legalise golden rice even though many of their citizens suffer from VAD?

    J GM golden rice is a new technology that has only just been developed, and further research needs to be conducted to ensure the golden rice grains are safe for consumption.

    K Rice is not the staple food of Africa and therefore this is not a good option for African nations to help resolve their VAD issue.

    L Leaders must also consider the economic consequences of legalising the cultivation of GM golden rice due to the possibility of cross contamination with non-GM crops, and how this could affect their trade agreements with other countries.

    M The collective suffering of affected citizens could be considered a crime against humanity given the technology has been available for many years.

Free response questions

1. Cotton plants can be genetically manipulated to be resistant to a specific herbicide.
   a) Describe the main steps required to do this.

   b) Describe one benefit of doing this.

2. Name three specific proteins, or classes of proteins, made using biotechnology and state an application of each.

3. Describe two reasons why some people may have concerns about genetically modified food.

4. Describe two possible negative impacts of genetically modified crops on ecosystems.

5. Some proteins in fruits and vegetables are involved in ripening. Delayed ripening GM *FlavR SavR* tomatoes were one of the first examples of genetically modified foods approved for sale to consumers. Suggest how the addition of a gene to these GM tomatoes can prevent tomatoes from ripening early.

6. CRISPR is a recent advancement in gene editing and modification.
   a) State the function of the protein 'Cas 9' in the process.

   b) Describe how guide RNA works in ensuring that the action of 'Cas 9' occurs in the right position.

   c) Describe how the guide RNA might end up binding in an undesired position.

7. Genetic manipulation and the production of transgenic organisms pose a range potential issues. Describe two possible social and/or ethical issues.

8. Biotechnology enables parents to be to be able to select the gender of a child.
   a) Describe two reasons in favour of exercising this option:

   b) Describe two reasons against exercising this option:

9. Explain why microinjection is not always successful in altering the genetic information of a host.

10. Describe two advantages that CRISPR technology has over traditional genetic manipulation techniques in constructing transgenic organisms.

11. Cystic fibrosis is caused by a single faulty gene. Gene therapy trials have been undertaken trying to deliver the functional gene into the cells of the respiratory tract using viruses.
   a) The most common cause of cystic fibrosis is the deletion of one DNA codon in the gene coding for an ion channel protein. Explain how the deletion of one DNA codon could cause cystic fibrosis.

   b) Explain how multiple copies of the 'normal' gene are produced for use in this gene therapy.

12. Fluorescent probes are a tool used to identify transformed bacteria. Antibiotics are also used in this identification process. An antibiotic is applied to the agar that transgenic bacteria are cultured on. This kills all bacteria that haven't taken up the recombinant plasmid.
   a) Describe the likely method that scientists use to achieve this.

   b) Bacteria are often used in protein engineering. One example is in the production of human insulin for diabetics to manage their blood glucose levels. State two other example of protein engineering using bacteria.

c) Yeast can also be used as 'protein factories'. They are often used to manufacture antigen proteins to be used in the vaccine industry. Describe two advantages and one limitation of the use of yeast in protein engineering.

d) The transformation of bacteria can also be used to clone genes for transgenesis. Two examples of transgenic crops are herbicide resistant soybean and pest resistant corn. Explain how each of these two GMOs can increase yields for farmers.

13. The omega-3 fatty acid DHA is generally only found in animal products, such as fatty fish like salmon. However, in the future this could be less of an issue. Scientists in Australia have had some success in genetically engineering canola crops to secrete DHA oil instead of canola oil. The crop is called Omega-3 Canola and it is the first genetically modified crop created entirely by Australian scientists. The seeds from one hectare of the Omega-3 Canola crop provide approximately the same amount of DHA as 10,000kg of wild fish. The Australian scientists have achieved it by using gene technology to insert specific genes from marine microalgae into canola crops. Food Standards Australia and New Zealand (FSANZ) have concluded that there are no public health or safety issues associated with Omega-3 Canola but they still require more data to confirm safety prior to full approval.

    An application for Omega-3 Canola to be grown in Australia has been submitted to the Office of the Gene Technology Regulator, which has currently approved a field trial. If approved, Omega-3 Canola will be commercialised by a company called Nuseed Pty Ltd, which initially plans to release an aquaculture feed to supply to fish farmers. This is because fish rich in omega-3, like salmon, require a substantial amount of omega-3 in their diet and this is usually sourced from ocean stocks.

    Use your understanding of the interaction between science and society to answer the following questions:

    a) Discuss two positive impacts of the potential application of growing and harvesting GM Omega-3 Canola in Australia.

b) Discuss a possible unexpected consequence of growing and harvesting GM Omega-3 Canola in Australia.

c) Explain two limitations of growing and harvesting Omega-3 Canola.

14. A team of researchers developed a computer game called Foldit in 2012, that allows players to design new proteins. View the following short video for more information:

Helpful online resources

UW Medicine: Gamers design brand new proteins using Foldit
<https://www.youtube.com/watch?v=UIdbul4fiZs>

a) Protein design is very complex. Explain why it is hard to make proteins with a specific shape.

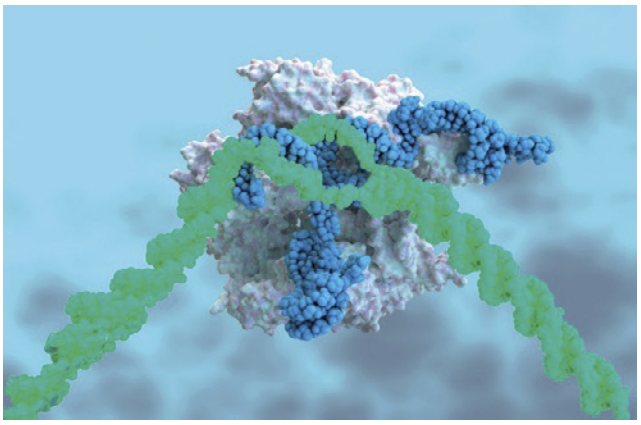
b) State two different types of new proteins that could be designed and explain how each could possibly help to combat a specific disease.

c) The computer game Foldit enables anyone to be a citizen scientist and successfully design synthetic proteins to combat real life medical issues. For example, scientists had been trying to identify the shape of an AIDS related protein for about 10 years; it took Foldit gamers 3 weeks to determine its structure.

i) Discuss how this idea has generated collaboration with citizen scientists and the impact this could have on new protein design for curing diseases.

ii) Discuss how the concept of 'citizen scientists' could be applied to another area of research.

15. The relatively new technology of CRISPR is revolutionising the editing of DNA and its applications in genetic manipulation. Recently, CRISPR edited immune cells in mice have killed cancer cells in these animals.



In this model the enzyme is coloured white, guide RNA is blue and DNA is green.

a) With reference to the diagram, explain how CRISPR edits DNA.

b) Explain a possible mode of action as to how this might enhance immune cells and enable them to destroy cancer cells.

c) Discuss two limitations that might be associated with this technology.

Science as a Human Endeavour 1.8 - Transgenic salmon

The commercial farming of fish and shellfish for human consumption is called aquaculture. Today, species of fish and shellfish are aqua-cultured in the coastal waters of places as diverse as Scotland, Norway and western Canada, as well in parts of South Australia and Tasmania.

An early driving force for the application of aqua-cultured fish technology was to increase the availability of healthy, high quality fish without contributing to the depletion of wild stocks. In recent years aqua-culture grown fish species, like salmon, has become increasingly common. According to some reports there are now more salmon farmed in this way than cattle.

1. The farmed-salmon industry is booming, both locally and overseas. Although salmon has never been more available, or affordable, aqua-cultured salmon causes environmental problems, the impacts of which are beginning to mount up. Describe some of these problems.

Refer to the 'Helpful online resource: AquAdvantage Salmon: The World's Most Sustainable Salmon? below to answer Question 2.

2. One possible solution is transgenic salmon. Known as the 'AquAdvantage' salmon, this type of salmon is sterile but grows to market size faster than a farmed salmon. Importantly,it is grown only in land-based tanks and was approved for human consumption in the United States in late 2015. According to Ronald Stotish, CEO of AquaBounty Technologies who developed the transgenic salmon, its widespread sale offers distinct benefits.

   Discuss how society influenced the research and development of GM faster growing salmon.

Helpful online resources

The Problem with Farmed Salmon | Global 3000
<https://www.youtube.com/watch?v=miFMtgMcX58>

Alliance for Science: AquAdvantage Salmon: The World's Most Sustainable Salmon?
<https://www.youtube.com/watch?v=fb2nwn8vn-s>

Topic 1 Review Test

Allocate 90 minutes to complete this Test. These are all SACE exam-style questions. Indicate your choice for each of the multiple choice questions (each worth one mark) and answer all of the other questions in the spaces provided. The number of marks for each free response question is shown in brackets. It is recommended that you compare your answers to the suggested answers section as part of your revision. Please note that the suggested answers are not extensive or exclusive.

Section 1: Multiple Choice Questions (10 marks)

1. The base composition of a particular DNA molecule was analysed and found to contain 21% Thymine. Which one of the following is most likely to be correct?

   J This DNA molecule has 21% Adenine – Thymine base pairs.

   K 29% of the bases in the molecule were Guanine.

   L This DNA molecule has 29% Guanine – Cytosine base pairs.

   M 58% of the bases in the molecule were Cytosine.

2. Which two processes require the uncoiling of the DNA and its separation into two strands of nucleotides?

   J Transcription and semi-conservative replication

   K Transcription and translation

   L Mitosis and semi-conservative replication

   M Mitosis and meiosis

3. Which one of the following is true of the genetic code?

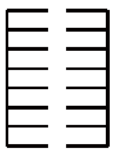
   J Four bases of DNA code for one amino acid.

   K Several codons may code for the same amino acid.

   L Some codons can code for more than one amino acid.

   M There are 64 codons and each codes for a specific amino acid.

4. A section of normal DNA was incubated with radioactively labelled nucleotides for 2 cycles. A primer and the necessary enzymes were also added. *Refer to the key below to answer the question that follows.*



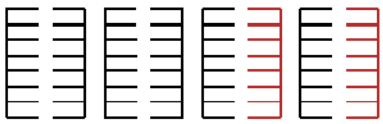
Unlabelled DNA

DNA with 1 radioactive strand

DNA with 2 radioactive strands

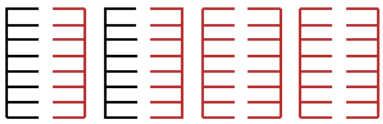
Which one of the following shows the correct outcome?

J

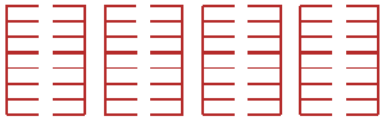


L

K

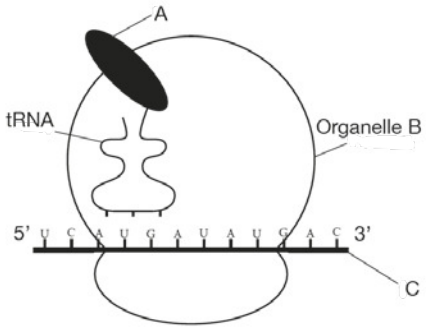


M



RT

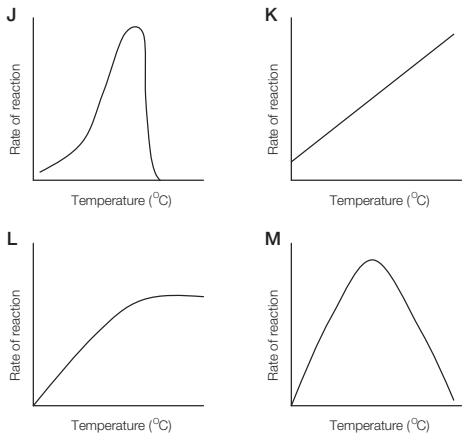
5. *Refer to the diagram below showing a stage in protein synthesis to answer the question that follows.*



Which of the following correctly labels structures/molecules A, B and C?

	Name of structure/molecule		
	A	B	C
J	Amino acid	Ribosome	mRNA
K	Polypeptide chain	Endoplasmic reticulum	DNA
L	Amino acid	Endoplasmic reticulum	DNA
M	Polypeptide chain	Ribosome	mRNA

6. Which graph below most closely represents the effect of temperature on the rate of a human enzyme controlled reaction?



7. *Refer to the graph below of the energy changes taking place during the reaction in which hydrogen peroxide is converted to water and oxygen to answer the question that follows.*

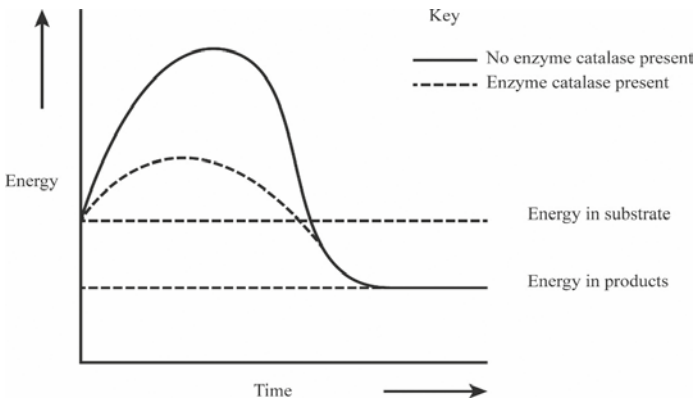
Which one of the following statements is correct?

J The reaction will only occur in the presence of the enzyme catalase.

K When catalase is present energy is not required to initiate the reaction.

L The activation energy for the reaction is higher in the presence of the enzyme catalase.

M Hydrogen peroxide breaks down at a lower temperature when catalase is present.



8. Enzyme inhibitors act in one of two ways–either as a competitive inhibitor or a non-competitive inhibitor.

   Which one of the following correctly describes the action of one of these inhibitors?

   J Non-competitive inhibitors have similar shapes to the normal substrate that binds with the enzyme.

   K Competitive inhibitors have a similar shape to the active site of the enzyme.

   L Non-competitive inhibitors have a similar shape to the active site of the enzyme.

   M Competitive inhibitors have similar shapes to the normal substrate that binds with the enzyme.

9. A mutation occurred in a section of template DNA. The original sequence and the mutated sequence are shown below:

Base triplet	36	37	38	39	40
Original DNA anticodon	TTA	CGC	CCA	ATA	AGA
Mutated DNA anticodon	TTA	CCC	CCA	ATA	AGA

   Refer to the table below which shows some mRNA codons for some amino acids and use the information to answer the question that follows.

mRNA codon	Amino acid
CGC	Arginine
CCC	Proline
GGG	Glycine
GCG	Alanine

   Which of the following statements is correct concerning this mutation?

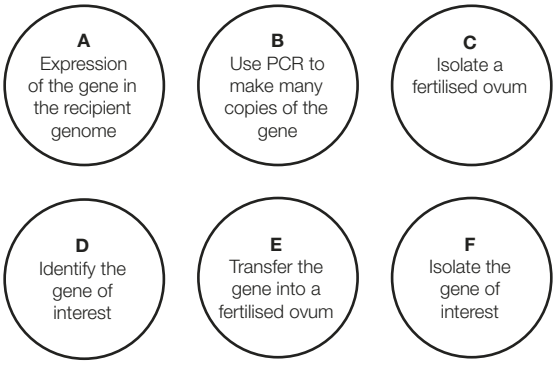
   J this is a substitution mutation and the amino acid at position 37 would be changed from arginine to proline

   K this is a deletion mutation and the amino acid at position 37 would be changed from arginine to proline

   L this is a substitution mutation and the amino acid at position 37 would be changed from alanine to glycine

   M this is a deletion mutation and the amino acid at position 37 would be changed from alanine to glycine

10. Genetically Modified Organisms (GMO) can be made using a series of steps which are listed below but in the wrong order.



   Which one of the following correctly identifies the steps in the correct order?

	Order of steps					
J	D	B	F	E	C	A
K	F	B	D	C	E	A
L	F	D	B	E	C	A
M	D	F	B	C	E	A

RT

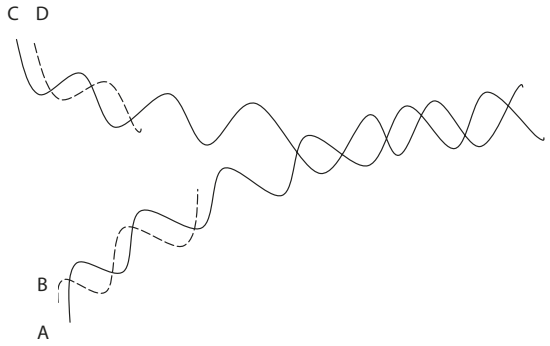
Section 2: Free response questions (70 marks)

11. The genetic code consists of DNA, which is made up of repeating units called DNA nucleotides.

    a) In the box below, draw a basic model of a DNA nucleotide. Label the phosphate group, the deoxyribose sugar and base.

(3 marks)

Refer to the diagram below which illustrates the process of DNA replication in a typical cell.



    b) With reference to the diagram above, identify *two* strands of DNA that would be identical.

(2 marks)

    c) Explain why the process of DNA replication is often termed 'semi-conservative'.

(3 marks)

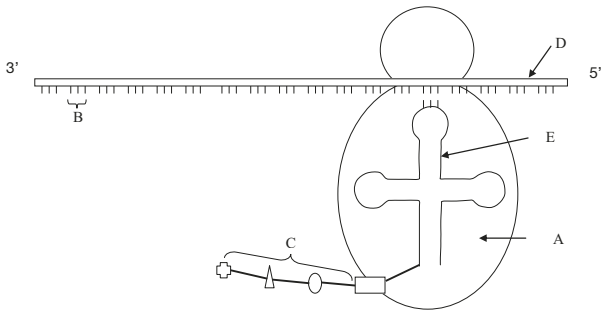
12. Collagen is the most abundant protein in mammals, accounting for approximately 30% of protein in the body. A major function of collagen is to provide structural support to connective, muscle and skin tissues.

    A specific collagen protein is made up of 1050 amino acids.

    a) State how many DNA bases are required to code for this collagen protein.

(1 mark)

Refer to the diagram below representing a cellular process to answer part b).



b) i) State the name of the process occurring in the diagram above.

(1 mark)

ii) Describe *one* similarity and *one* difference between molecule D and a molecule of DNA.

(2 marks)

iii) Explain the role of E in the production of proteins such as collagen.

(3 marks)

There are approximately 24 types of collagens found in the human body. For example, Type one collagen is found in skin and bones and Type two collagen is found in cartilage.

c) i) Explain why the different types of collagens have different functions

(3 marks)

ii) Collagen proteins have a quaternary structure. Describe what a quaternary structure is.

(1 mark)

Collagen protein powders are available and marketed towards consumers seeking certain health or cosmetic benefits. They are often marketed towards those seeking cosmetic improvement in skin quality, such as decreased wrinkles. These powders are often designed to be mixed in a drink and consumed. On social media, people have advocated for mixing them in a morning coffee as part of a daily routine.

d) Explain why mixing the collagen powder in a morning coffee is not a good recommendation.

(2 marks)

Protein consumed in the diet is broken down into small peptides and amino acids in the digestive system. Therefore, consumed collagen is unable to reach the skin in its original structure and provide anti-ageing benefits.

Additionally, the type of collagen in skin differs from the type of collagen protein sourced for supplements. Collagen is often sourced from bovine (cattle) and fish scales/cartilage.

Currently, there is a lack of good evidence from clinical studies that collagen supplements can help prevent or improve ageing skin. Many studies conducted on collagen are not independent and are funded by the wellness corporations that sell the product.

e) i) Explain how a lack of independent studies on collagen supplements can affect valid *communication* of information to consumers.

(3 marks)

ii) Discuss a possible *unexpected consequence* of consuming collagen supplements.

(2 marks)

Ultraviolet (UV) radiation exposure from the sun can damage skin and result in sunburn. This increases the degradation of collagen proteins and wrinkle formation.

f) State *one* way of preventing premature wrinkle formation.

(1 mark)

One form of osteoarthritis in humans is believed to be the result of a mutation in the DNA of the Collagen Alpha I gene (COL2A1). This gene codes for a polypeptide chain in Type 2 collagen protein found in cartilage. A small section of the mRNA coded for by both the mutant and normal forms of COL2A1 gene is shown in the table below.

mRNA codons							
Normal	...AAG	AUG	GUC	CGU	CUG	GAC	CUG...
Mutant	...AAG	AUG	GUC	UGU	CUG	GAC	CUG...

g) State *two* chemical factors that increase the chance (rate) of mutations in DNA.

(2 marks)

h) With reference to the table above, identify the mutation that has occurred in the sequence and determine the affected DNA codon for the normal and mutated sequence..

Normal DNA codon

Mutated DNA codon

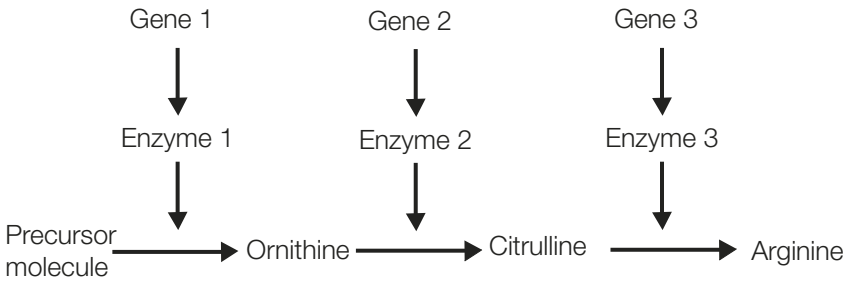
(2 marks)

i) This mutation results in one different amino acid in the polypeptide chain produced.

Explain how this mutation can give rise to this form of osteoarthritis.

(4 marks)

13. Two research scientists working in the field of DNA, *Beadle and Tatum,* hypothesised that one gene codes for one protein. In their work they exposed bread mould to radiation and noticed that this induced mutations preventing the mould from making the amino acid arginine. The pathway is given below:



A mutation at any of genes 1, 2 or 3, would prevent arginine from forming.

a) With reference to the synthesis of arginine diagram above, describe the problem being investigated.

(2 marks)

b) List two possible variables that could impact this experiment.

(2 marks)

c) Describe *one* limitation to this experiment.

(2 marks)

d) State the data that would be measured.

(2 marks)

Since *Beadle and Tatum's* original research, further research has been conducted and our understanding of DNA and its complexity has increased.

e) With reference to DNA, describe the difference between exons and introns.

(2 marks)

RT

f) It was originally thought that non-coding sections of DNA were "junk DNA".

Explain why this is now considered not to be the case.

(2 marks)

Our understanding of introns and exons has developed even further since their discovery. It is now known that a process called 'alternative splicing' can also occur in eukaryotic cells, which results in some exons being skipped (or spliced out) of the mature mRNA. This means that different mature mRNA molecules can be produced from the same pre-mRNA molecule.

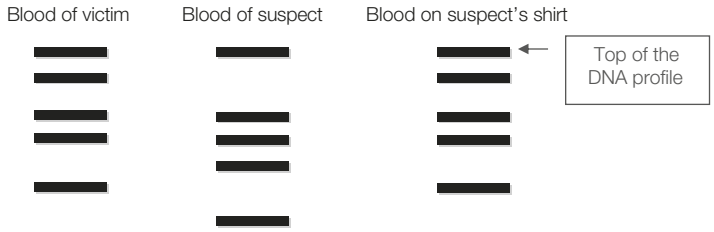
g) With reference to the information above, re-define *Beadle and Tatum's* definition of a gene: *'One gene codes for one protein.'*

(1 mark)

h) Describe *one* limitation to this revised definition of a gene.

(2 marks)

14. *Refer to the diagram of a DNA fingerprint (profile) below to answer the following questions:*



a) DNA was extracted from samples of blood at the scene of the crime. The Polymerase Chain Reaction (PCR) was used on the extracted DNA. State why PCR was used.

(1 mark)

b) State which of the three profiles contains the smallest DNA fragment and explain why.

(3 marks)

c) Describe the evidence in the diagram that enables you to conclude that the suspect was at the scene of the crime.

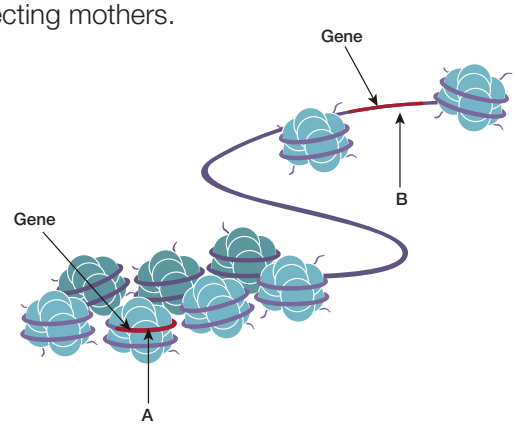
(2 marks)

15. In January 1998, Montreal experienced destructive ice storms, and is considered one of Canada's worst natural disasters. Some residents were without electricity, and therefore heating, for up to 6 weeks. Many residents also had little access to supermarkets and food as roads were blocked by snow. All of this was very stressful for affected residents, especially expecting mothers.

The natural disaster did offer a unique opportunity for scientists though. It allowed them to research the effects of stress on pregnant women and look at the effects of maternal stress during pregnancy on the unborn child.

The scientists took blood samples from approximately 40 children born within 6 months after the ice storm, when they were approximately 13-year's old.

They tested the DNA and found a correlation between the degree of epigenetic changes and the degree of stress/ hardship experienced by the mother.



Refer to the diagram to the right to answer question a):

a) i) With regards to epigenetics, describe what happens to cause the open chromatin at "B".

(2 marks)

(ii) Explain the effect epigenetic changes that result in localised condensed chromatin, seen in "A", has for a cell.

RT

(2 marks)

The placenta is an essential organ for the survival of the foetus, providing it with vital nutrients. However, it is also a sensory organ that communicates environmental factors the mother experiences with the growing foetus.

For some expecting mothers, the ice storm induced famine like conditions as access to food and electricity was cut off for up to six weeks.

b) Describe an advantage to the foetus of the placenta communicating famine like conditions through epigenetic changes in its DNA.

(2 marks)

The ice storm was only temporary however and was not an ongoing famine.

c) Discuss *one* possible negative impact of being born into an environment where food is plentiful, but epigenetic changes occurred in utero to prepare the foetus for famine like conditions.

(2 marks)

d) Describe how CRISPR could be used to reverse the effects of epigenetic changes to the DNA.

(2 marks)

Using your knowledge of science as a human endeavour:

e) Discuss one advantage to society and one advantage to governments of communicating the results of this study with the general public.

(4 marks)

Total: /80

Topic 2 Cells as the basis of life

Chapter 2.1 The cell theory

Science Understanding

The cell theory unifies all living things.

The cell membrane separates the cell from its surroundings and controls the exchange of materials, including nutrients, and wastes, between the cell and its environment.

- Describe and represent the fluid mosaic model of the cell membrane.

The discovery of cells

The discovery of **cells** was linked to developments in technology, specifically the ability to produce high quality microscopes. In this instance, the understanding of cells and their importance in the biological world involved a number of discoveries by scientists in many different countries.

1590 - A Dutch optician *Zacharias Jansen* invents the first simple microscope.

1665 - *Robert Hooke* from England studies cork with the microscope and names the structures as cells.

1675 - *Anton van Leeuwenhoek* (Dutch) discovers unicellular organisms.

1838 - *Theodor Schwann* from Germany suggests that all animals were made from cells.

1850 - *Wilhelm Hofmeister* observes chromosomes in plant leaf cells.

1855 - *Rudolph Virchow* from Germany suggests that all cells come from other cells.

1859 - *Louis Pasteur*, a French scientist, proves that 'spontaneous generation' did not occur.

1876 - *Robert Koch* observes bacteria that cause a disease called anthrax in the blood of infected animals.

1890 - *Robert Altman* discovers mitochondria.

Helpful online resources

TED-Ed: The wacky history of cell theory - Lauren Royal-Woods
<https://www.youtube.com/watch?v=4OpBylwH9DU>

Microscopes

Today there are different types of microscopes. The light microscope can magnify images up to about 1000 times but more recent advances in technology have led to the invention of transmission **electron microscopes** (TEM) which enable images of cell structures to be magnified greater than 100,000 times. As such, our understanding of cells and the **cell theory** continues to grow and develop. With a scanning electron microscope (SEM) an object is scanned to give a three-dimensional image in incredible detail.

More information about using a microscope is given as part of SIS 2.1 (which can be found in the digital version only).

Helpful online resources

Stated Clearly: A Brief History Of The Microscope
<https://www.youtube.com/watch?v=bjcewKLlb2Y>

Amoeba Sisters: Microscopes and How to Use a Light Microscope
<https://www.youtube.com/watch?v=tVcEEw6qbBQ>

The cell theory

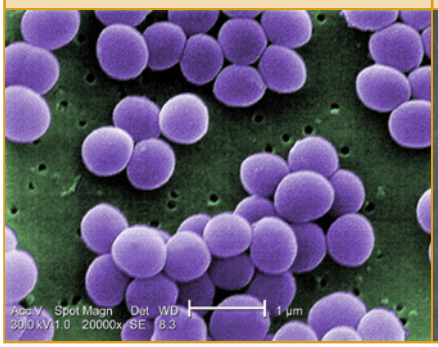
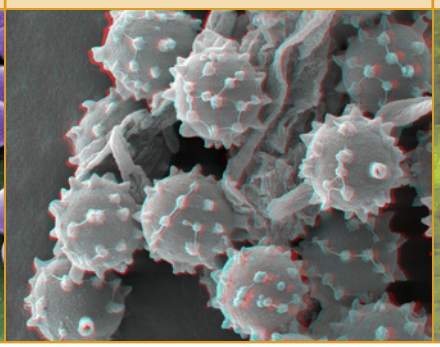
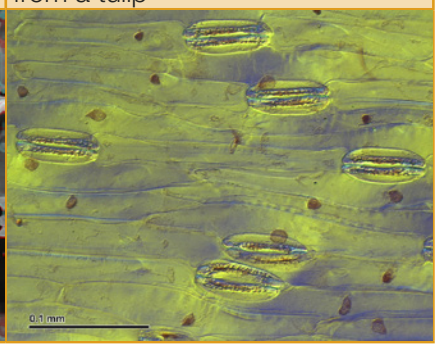
An accumulation of research and discoveries over hundreds of years has enabled scientists to formulate what is generally termed "the cell theory". The parts of the cell theory that are generally accepted are listed below:

1. Cells are the units of structure and function in all organisms.
2. New cells arise from pre-existing cells.
3. Cells require and use energy.
4. Cells contain DNA which is passed on to daughter cells; it is the genetic information.
5. Some organisms are unicellular i.e. they are made up of one cell, while others are multicellular and consist of a large number of cells of different types that have a hierarchical organisational structure.

There are some exceptions to the above points, including viral particles or viruses. These infective agents possess some characteristics of organisms but, by the strict definition of the cell theory, they are not cells or alive.

The cell is thus the smallest, independent unit of life. To biologists, something is alive if it carries out fundamental processes and therefore all living things carry out these 'life processes'. The details of cell structure and function are the subject of the following Chapter 2.2.

Refer to the table below (*Figure 211*) which contains some information and images of cells from different organisms i.e. species of bacteria, fungi, plants and animals.

Bacteria (cocci)	Fungi (spores)	Plant (leaf)
×20,000 (SEM) *Staphylococcus aureus*	×5000 (SEM) Fungal spores from puffball	×600 light microscope Leaf epidermis and guard cells from a tulip
		

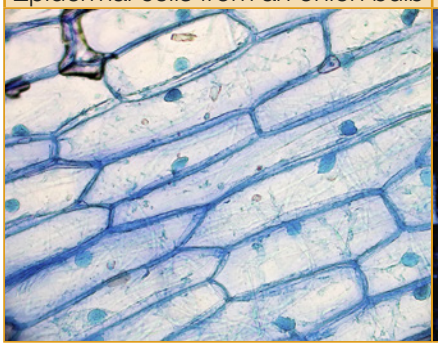
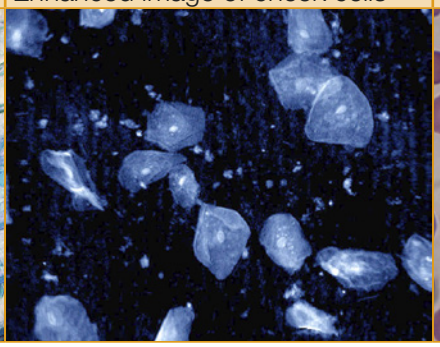
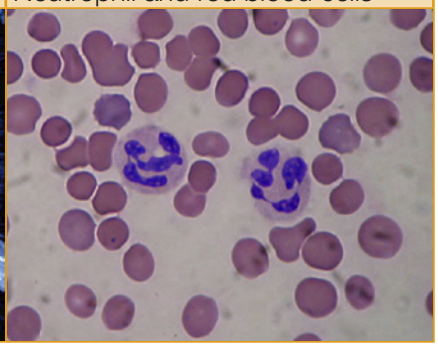
Plant (epidermis)	Animal (cheek)	Animal (blood)
×400 light microscope Epidermal cells from an onion bulb	×600 light microscope Enhanced image of cheek cells	×600 light microscope Neutrophil and red blood cells
		

Figure 211 Images of different cells from different types of microscopes

Figure 212 is a drawing which illustrates how several **tissues** (groups of similar cells that perform similar functions) in a human contain specialised cells with their own distinct structures and functions. Each cell has evolved for a particular purpose e.g. an elongated nerve cell with dendrites to transmit signals to other cells.

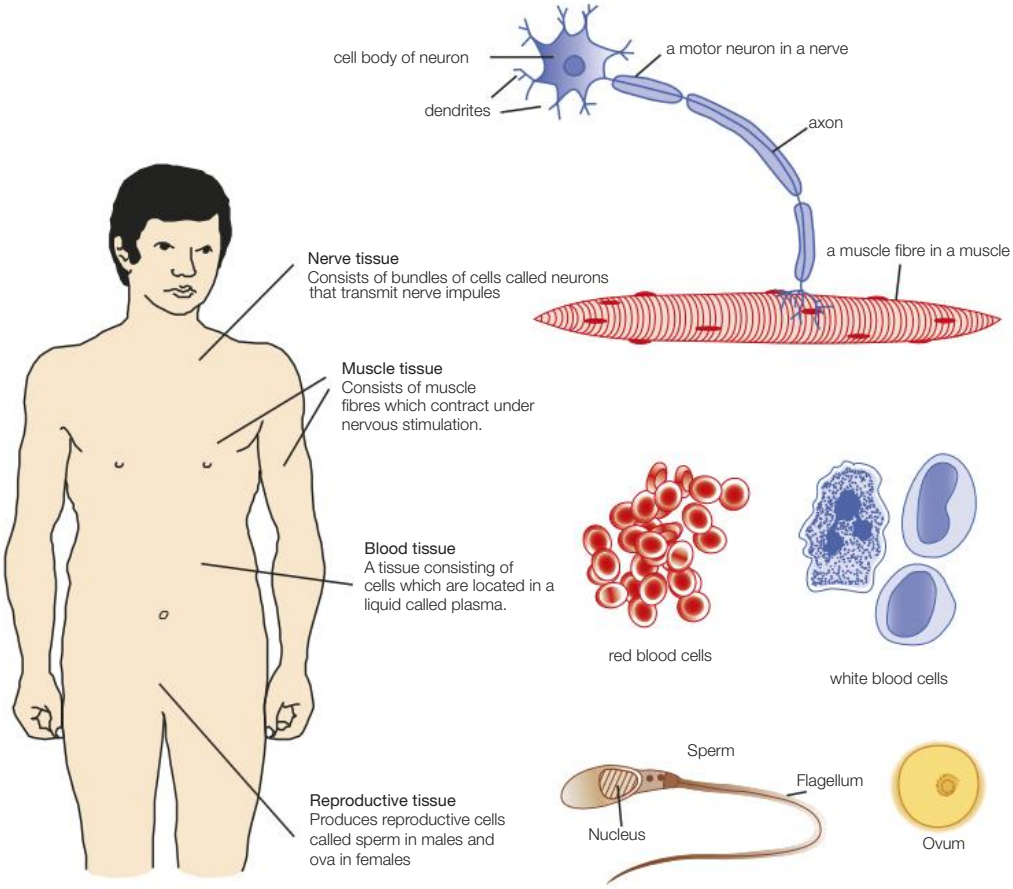


Figure 212 Some different human cells and tissues

Figure 213 is a drawing of the tissues in a plant leaf. Again, the cells making up these tissues have evolved for their particular function(s); for example, the mesophyll tissue in a leaf has lots of structures called chloroplasts and is adapted to carry out the process of photosynthesis.

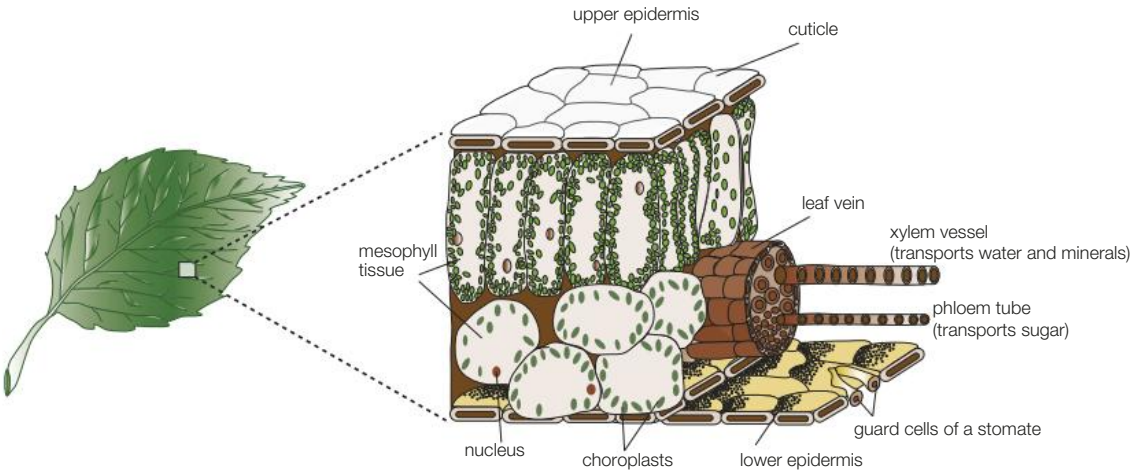


Figure 213 Some different plant cells and tissues

Structure and function of cell membranes

The cell membrane separates the cell from its surroundings and is found in all living cells. It controls the entry and exit of materials in and out of the cell, as well as having a range of other important roles in cell communication, cell adhesion and the binding of hormones.

Cell membranes consist of:

- two layers (bi-layer) of **phospholipid** molecules
- two kinds of membrane proteins:
  - **integral proteins** which are permanently in the bilayer
  - **peripheral proteins** which tend to move temporarily and are not a permanent part of the membrane.
- **cholesterol** which is usually positioned between the phospholipids (in animal cells only)
- **glycoproteins** which are membrane proteins with carbohydrate chains attached
- **glycolipids** which are phospholipids with carbohydrate chains attached

Refer to *Figure 214* that is an illustration of the structure of the cell membrane.

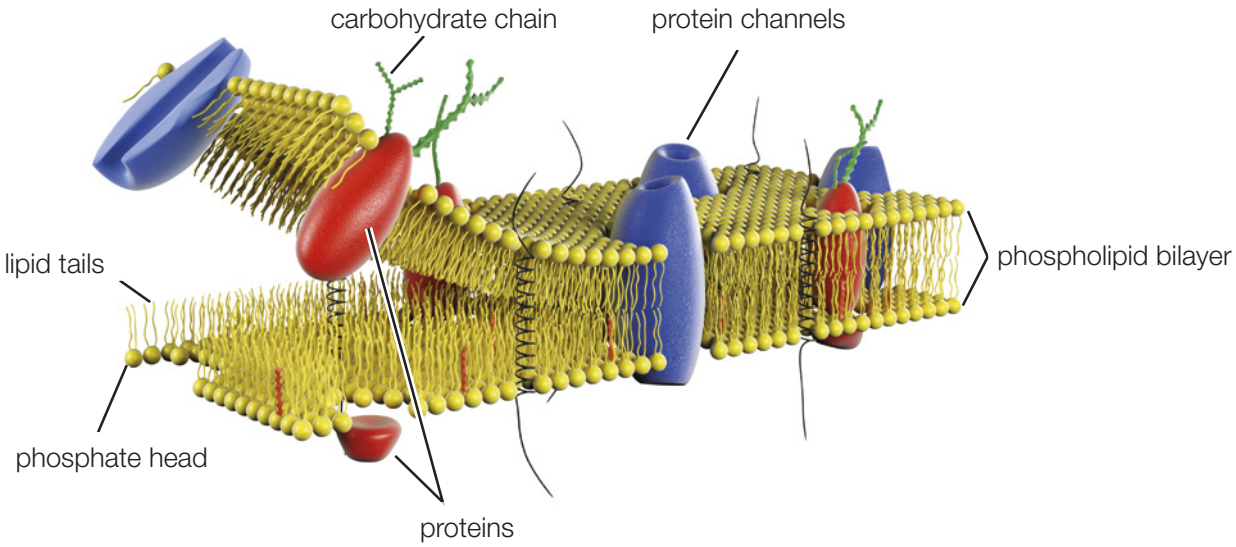


Figure 214 The structure of the cell membrane

The fluid mosaic model

Like many other structures or processes too small to see, or to comprehend, scientists have constructed a 'model' to visualise, and thus better understand cell membrane structure. This is called the '**fluid mosaic model**' (named by *S.J. Singer and G.L. Nicholson* who proposed it in 1972).

The word 'fluid' in the name of the model refers to the ability of both **lipids** and proteins to continually move in the membrane. This characteristic is critical for membrane structure in areas such as **permeability**, or ease of movement of molecules across the membrane.

The term 'mosaic' refers to the pattern formed by the variety of integral and peripheral proteins associated with the phospholipid bilayer. These proteins are fundamental to the function of the cell membrane.

Phospholipids

The phospholipid bilayer consists of two layers of lipid molecules arranged with their **phosphate groups** on the outside (i.e. facing outside the cell and towards the cytoplasm and the lipid tails projecting inwards). Refer to *Figures 215 (a)* and *(b)* which show an individual phospholipid and a section of a phospholipid bilayer.

The '**polar**' label refers to the fact that the **phosphate head** of the phospholipid has a charge associated with it and therefore can interact with (or attract) water molecules (which are also polar); whereas, the **non-polar lipid tails** do not interact with water (or are repelled by water). As the human body is around 60% water this has implications for membrane permeability, specifically the cell membrane is effectively impermeable to water soluble or polar molecules. The terms **hydrophobic** (does not dissolve in water) and **hydrophilic** (does dissolve in water) are often used in this context. The phosphate heads (on the outside) are hydrophilic while the lipid tails (on the inside) are hydrophobic.

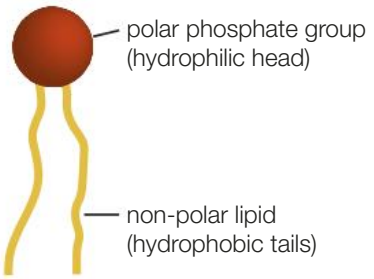


Figure 215 (a) Chemical structure of a phospholipid

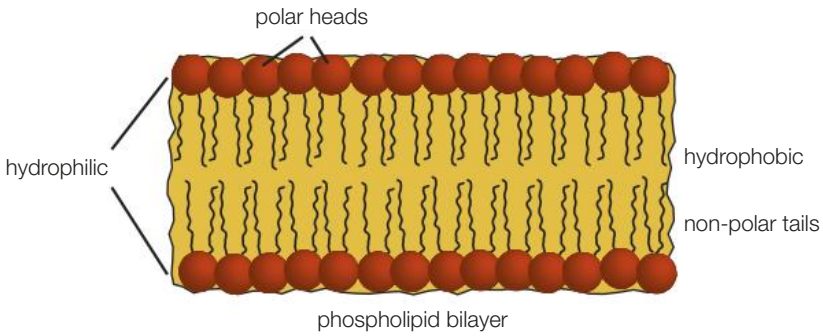


Figure 215 (b) A phospholipid bilayer

Helpful online resources

TED-Ed: Cell membranes are way more complicated than you think - Nazzy Pakpour
<https://www.youtube.com/watch?v=nsklF1w4eok>

TED-Ed: Insights into cell membranes via dish detergent - Ethan Perlstein
<https://www.youtube.com/watch?v=yAXnYcUjn5k>

Membrane proteins

Membrane proteins carry out a range of different functions.

Hormone binding sites

Many hormones transported in the blood can only bind and act on cells with **complementary protein receptors** on the outside of their membranes. Refer to *Figure 216* of a growth hormone molecule binding to a specific growth hormone receptor. This initiates cellular changes and gene activity; for example, human growth hormone stimulates growth, especially in childhood, strengthening bone and increasing muscle mass.

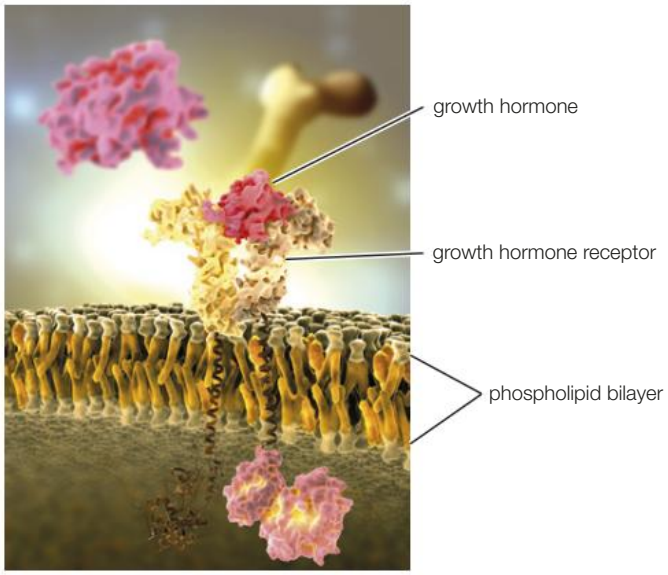


Figure 216 The binding of a hormone to a membrane receptor

Cell communication

This can occur via direct contact between cell membrane proteins of adjacent cells or via hormones or nerve transmitter chemicals (called neurotransmitters).

Cell adhesion

Integral proteins can stick out and bind to specific protein molecules on adjacent cells or attach to the **cytoskeleton**. The cytoskeleton is a framework of tiny protein tubules and filaments that extends throughout the cytosol. Its function includes attachment and movement of organelles, and movements of the cell membrane and chromosomes.

Channel proteins and pump proteins

These proteins can either allow movement of molecules by diffusion or use energy to actively move molecules in and out of cells. Refer to *Figure 217* which shows water molecules (H_2O) moving through a type of protein channel called an '**aquaporin**'. This type of protein channel regulates the flow of water in and out of the cell by a process called osmosis.

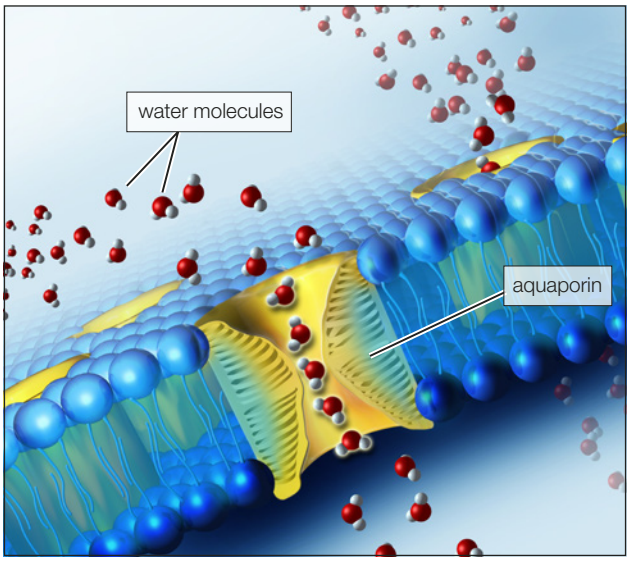


Figure 217 The process of osmosis

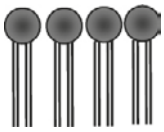
Cholesterol

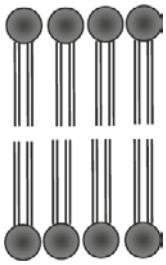
Cell membranes in animal cells contain a lipid called cholesterol which is an important molecule in regulating the **fluid nature** of the phospholipids. The cell membrane thus separates the cell from its surroundings and controls the exchange of nutrients and wastes between the cell and its extracellular environment. This will be examined in greater detail in Chapter 2.4.

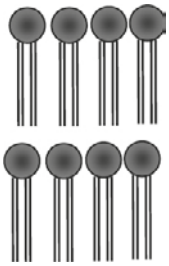
2.1 Review questions

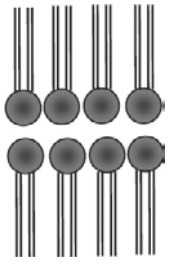
Multiple choice questions

1. Which of the following options is **not** consistent with the cell theory?
   - J All cells contain two or more chromosomes in pairs.
   - K Cells require and use energy.
   - L New cells arise from pre-existing cells.
   - M Cells are the units of structure and function in all organisms.
2. Phospholipids are built from lipid and phosphate molecules. Which one of the following diagrams most clearly resembles the arrangement of phospholipids in the cell membrane?

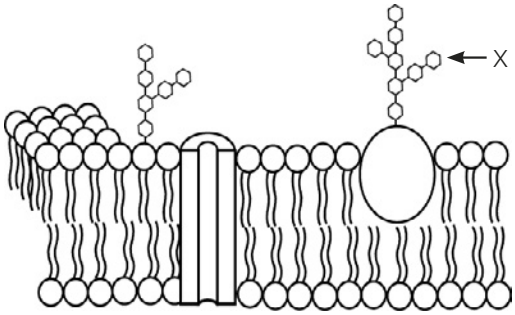
J 

K 

L 

M 

3. The diagram below shows the structure of a plasma membrane.



Structure X represents a molecule of:

J glycolipid
K phosholipid
L cholesterol
M glycoprotein

4. Which of the following processes is possible due to the fluidity of cell membranes?

J Endocytosis
K Osmosis
L ATP production
M Cell recognition

5. Which of the following molecules increases the fluidity of cell membranes?

J Glycolipids
K Glycoproteins
L Cholesterol
M Water

Free response questions

1. State four underlying principles of 'the cell theory'.

2. Describe some examples of how advances in technology have contributed to current understanding of the cell theory.

3. The cell is the unit of structure and function in all organisms.

a) Name two specialised animal cells and state how their structure is suited to their function.

b) Name two specialised plant cells and state how their structure is related to function.

4. Name the four types of molecules that make up a typical cell membrane.

5. Explain why the current model of our cell membrane structure is called the 'fluid mosaic model'.

6. Describe the functions of two protein molecules typically found in the cell membrane.
   a)

   b)

7. Cell membranes control the entry and exit of the molecules of essential substances, as well as wastes that need to be excreted.
   a) Describe how the phospholipid bilayer is involved in this process.

   b) Describe one way membrane proteins may be involved.

8. Some scientists consider viruses to be living.
   State two reasons why viruses do not conform to the cell theory.

9. Explain why phospholipids tend to form into a bi-lipid layer when they are placed in water. A labelled diagram may assist the explanation.

10. State the most likely property or structure of the cell membrane to help explain the observations below:
    a) It is difficult for water to move through the phospholipid bilayer (refer to *Figure 217*).

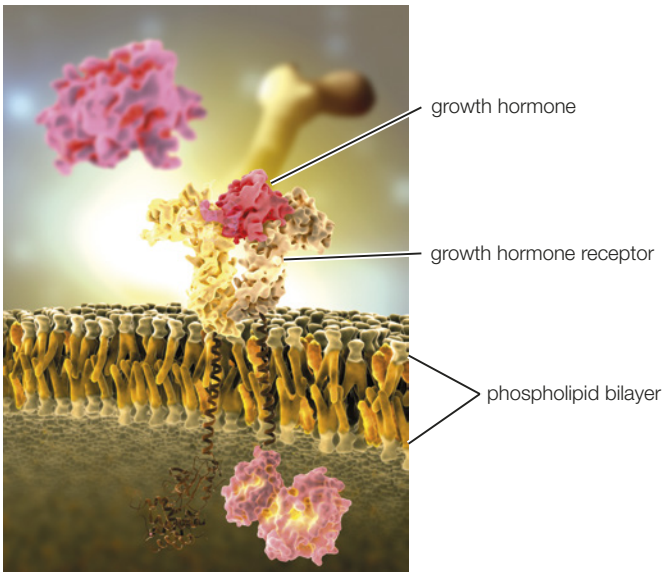
    b) It is difficult to move charged ions through the phospholipid bilayer.

    c) It is relatively easy for the bilayer to be broken and re-formed.

    d) Cells can communicate with each other.

11. Explain how the structure of the cell membrane facilitates its semi-permeable nature.

Refer to the diagram below which represents a model of human growth hormone binding to a specific growth hormone receptor embedded in the cell membrane.



12. a) Describe why human growth hormone would not be able to bind in this manner to all cells in the human body.

b) With reference to the functions of hormones discussed in Topic 1, describe how the binding of the hormone might increase bone density.

13. DDT is an insecticide that is soluble in lipids. DDT is no longer permitted to be used in developed countries due to its toxic effects on organisms; however, some developing countries still allow it to be used.

Explain why the use of DDT leads to its accumulation inside insect-eating birds and their predators found in developing countries.

Chapter 2.2 Two types of cells

Science Understanding

The major types of cell are:

- prokaryotic
- eukaryotic.

Prokaryotic and eukaryotic cells have many features in common, which is a reflection of their common evolutionary past.

- Compare prokaryotic and eukaryotic cells with respect to their:
  - size
  - internal organisation
  - shape and location of chromosomes.

Prokaryotes only exist as single cells.

Eukaryotic cells have specialised organelles which facilitate biochemical processes.

- Represent the structure and describe the function of the:
  - nucleus
  - nucleolus
  - mitochondrion
  - chloroplast
  - vacuole/vesicle
  - Golgi body (including vesicles)
  - endoplasmic reticulum (rough and smooth)
  - ribosome
  - lysosome
  - cytoskeleton.
- Compare the structures of plant, animal, and fungal cells.

Prokaryotic and Eukaryotic Cells

The Stage 1 Biology course examined the classification of organisms into three domains: Bacteria, Archaea and Eukarya. The domains of the Bacteria and Archaea are more simplistic and consist of only unicellular organisms. It is thought that these organisms evolved first on Earth and that eukaryotes evolved from them; in other words, there was a single common ancestor for all life forms and all life as seen today evolved from there. These two domains have cells that are termed **prokaryotic** whilst the Eukarya are organisms made up of **eukaryotic cells**.

Prokaryotic cells

Prokaryotic cells are smaller, simpler and less specialised, essentially containing no membrane-bound structures called **organelles** inside them.

Refer to *Figure 221* which shows a typical prokaryotic cell. This diagram is modelled on a rod-shaped single bacterium and the internal make up reveals the typical structures found in a prokaryotic cell:

- the **cytoplasm** consists of the fluid **cytosol** with suspended internal structures
- **ribosomes**, which are non-membrane bound organelles (i.e free-floating in the cytoplasm) that assist in the synthesis of proteins
- a **cell membrane** (or plasma membrane), which is surrounded by a **cell wall**
- a **single circular chromosome** made up of DNA and proteins

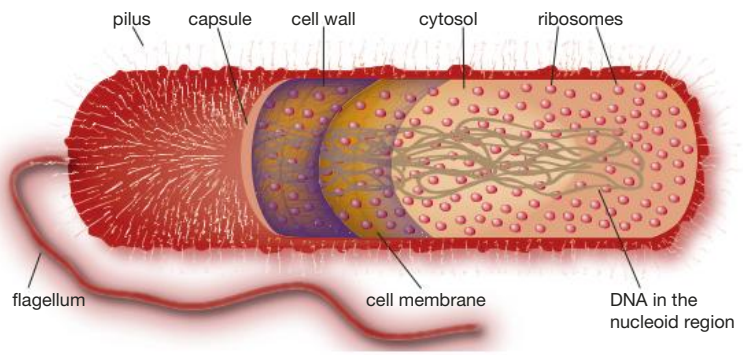


Figure 221 A typical prokaryotic cell

- small circular rings of DNA called **plasmids** are often present in the cytoplasm, but are not shown in this diagram

In many species of prokaryotes, structures called pilli (singular pilus) cover the surface and are involved in adhesion, and one or a collection of flagella (singular flagellum) that provide the cell with motility (or movement).

Information about stromatolites

The discovery of fossilised stromatolites provide the earliest direct evidence of life on Earth. These have been found in countries across the world, ranging from Turkey, Canada and the Pilbara region in Western Australia. It is accepted that the oldest of these date back to 3.5 billion years ago, although the mid-2016 discovery by Australian scientists of traces of fossilised stromatolites in Greenland may lead to this being pushed back another 200 million years to 3.7 billion years.

Stromatolites form when colonies of cyanobacteria (Domain: Bacteria) bind thin films of sediments together. Over time this results in the formation of layers of rock. Stromatolites are still found today in isolated shallow ocean bays, the most famous of which is Shark Bay in Western Australia. The diagram above shows stromatolites at low tide along the edge of Shark Bay.

Helpful online resources

Jamie Foster: What are Stromatolites?

<https://www.youtube.com/watch?v=N-G7IJCkyvg>

SciShow: The Oldest Fossils Ever Found!

<https://www.youtube.com/watch?v=Evy8Mixomao>

Eukaryotic cells

Eukaryotic cells tend to be larger and more complex; they are predominantly found in multicellular organisms, but not exclusively. These cells contain many membrane-bound structures called organelles which have specific structures that suit their particular function in the cell.

Refer to *Figure 222* showing a typical eukaryotic cell in a plant which shows a significant number of these organelles, including **nucleus**, **mitochondria**, **Golgi bodies** and **chloroplasts**. These organelles will be studied in greater detail later in this chapter.

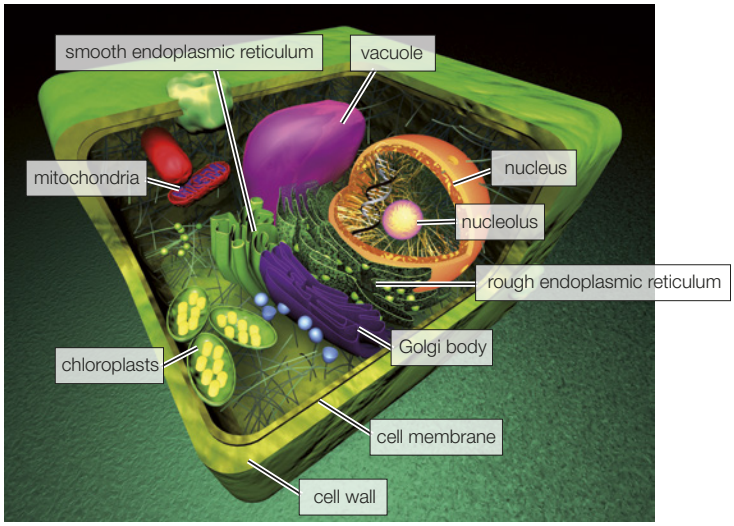


Figure 222 A typical eukaryotic (plant) cell

The table below provides a comparison of prokaryotic and eukaryotic cells. Whilst there are a number of ***differences*** *between prokaryotic and eukaryotic cells there are also a number of structural and functional* ***similarities****, a fact that supports and is a reflection of their common evolutionary past.*

Feature	Prokaryotic cells (e.g. bacteria, archaea)	Eukaryotic cells (e.g. protists, fungi, plants and animals)
Size	generally smaller (most bacteria 1-10µm)	generally larger (most animal & plant cells 10-100µm)
Cell type	unicellular	unicellular or multicellular
Chromosome shape	one circular chromosome	many linear chromosomes (generally in pairs)
Location of chromosome(s)	in cytoplasm	in nucleus
Membrane-bound organelles	none	many different types
Ribosomes	smaller ribosomes are present and free floating in the cytoplasm	larger ribosomes are present and generally attached to a rough endoplasmic reticulum (can also be free floating in the cytoplasm)
Cell division	binary fission	mitotic division
Cell wall	present but consists of a different carbohydrate to eukaryotic cell walls (peptidoglycan)	only present in plant (cellulose) and fungi (chitin) cells but both consist of a different carbohydrate to prokaryotic cell walls
Cell membrane and cytoplasm	present	present

Helpful online resources

RicochetScience: Prokaryotic Vs. Eukaryotic Cells
<https://www.youtube.com/watch?v=RQ-SMCmWB1s>

Cognito: GCSE Biology - Cell Types and Cell Structure
<https://www.youtube.com/watch?v=qHkUOlC8Nbo>

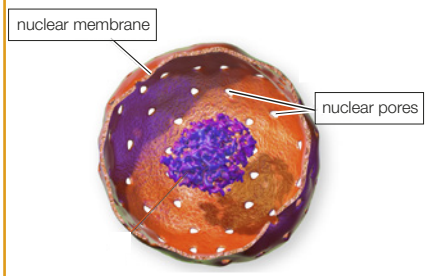
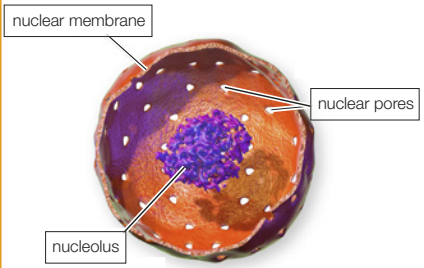
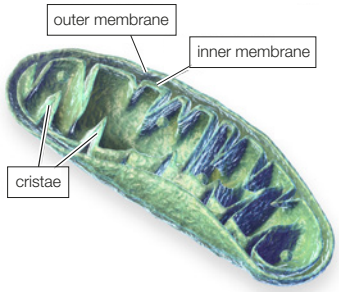
Amoeba Sisters: Prokaryotic vs. Eukaryotic Cells (Updated)
<https://www.youtube.com/watch?v=Pxujitlv8wc>

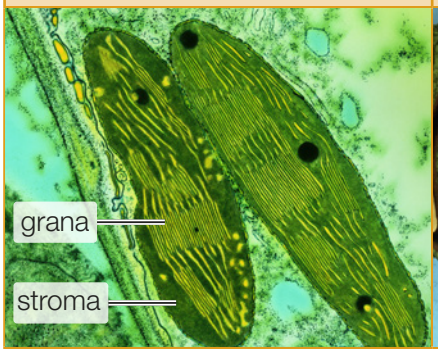
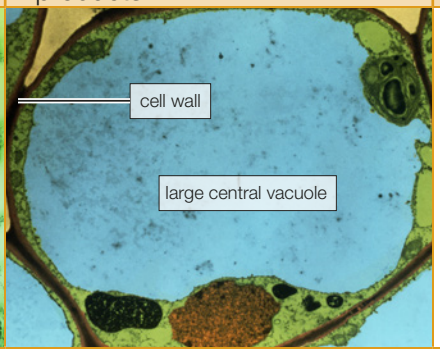
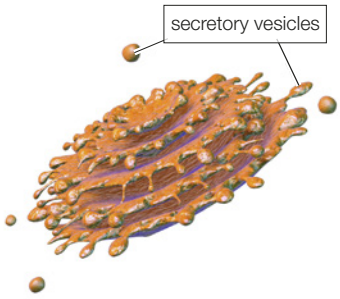
Organelles in eukaryotic cells

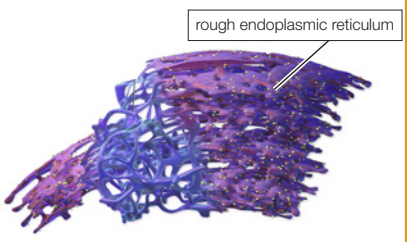
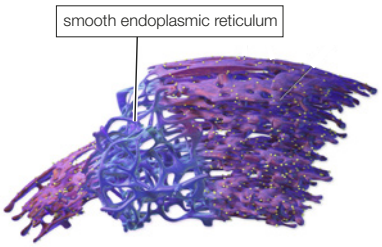
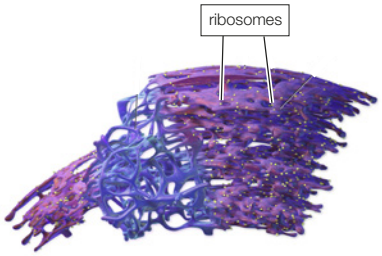
Cells are the unit of structure and function of all organisms and as such, carry out life's essential processes. Whilst eukaryotic cells are more structured and compartmentalised with many biochemical processes occurring in and on their organelles, prokaryotic cells still possess the molecules, including DNA, proteins and other structures, necessary for them to survive and reproduce.

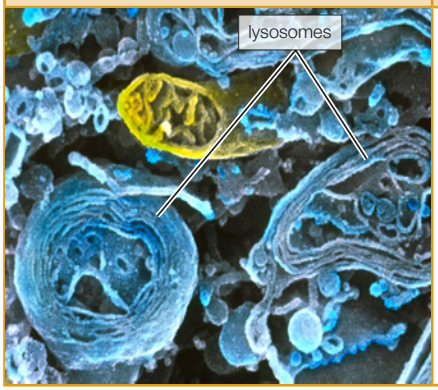
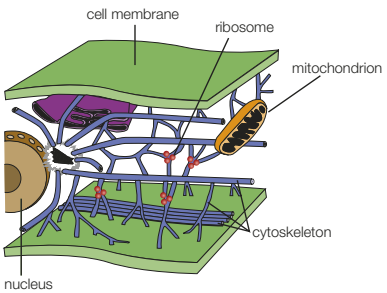
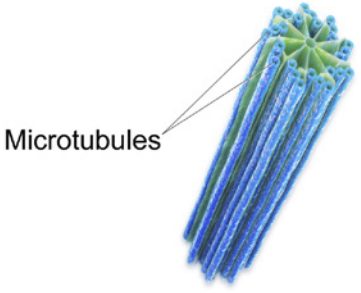
The following table (pages 172 & 173) provides the following information, with regard to the important organelles and structures found in eukaryotic cells:

- their structure
- their main function
- a 3-D image based on appearances as seen in electron microscopes (EM) or actual EM images

Nucleus	Nucleolus	Mitochondrion
Structure Is the largest organelle. It consists of DNA (chromosomes) and a nucleolus, and is surrounded by a nuclear membrane containing nuclear pores.	**Structure** Composed of RNA and proteins.	**Structure** Consists of a double membrane. The inner membrane is folded into cristae to increase surface area. Contains its own circular DNA (mtDNA).
Functions Controls all cell activity. It regulates the transcription of genes and directs protein synthesis.	**Functions** Synthesis of ribosomal RNA (rRNA) and the assembly of ribosomes.	**Functions** Site of latter stages of aerobic respiration, which synthesises ATP molecules that provide energy for the cell.
		

Chloroplast	Vacuole	Golgi body (including vesicles)
Structure Consists of a double membrane. The stacks of internal membrane structures called grana contain the pigment chlorophyll. Contains its own circular DNA (cpDNA).	**Structure** Vacuoles consist of a single membrane bound sac and their contents depend on the type of eukaryotic cell and function. Large central vacuoles in plant cells store water and small molecules such as ions, enzymes and harmful/waste molecules.	**Structure** A stack of flattened, membrane-bound sacs that are not connected to each other. Sacs are surrounded by vesicles. Vesicles are generally smaller than vacuoles and consist of a single membrane bound sac. The contents depend on the type of vesicle and function (e.g. transport, secretory, lysosome).
Functions Site of photosynthesis, usually in the cells of the leaves of a plant. Produces glucose and oxygen for plant and other organisms.	**Functions** Many functions including: • storage of water in plant cells • provides structural support and regulates osmotic potential in plant cells • nutrient storage • storage and disposal of waste products	**Functions** Modification, processing and packaging of proteins into vesicles for storage within the cell or movement out of the cell by exocytosis.
		

Rough endoplasmic reticulum (RER)	Smooth endoplasmic reticulum (SER)	Ribosome
Structure Network of interconnected flattened membrane sacs that span from the nucleus to cell membrane. Contains ribosomes attached to its surfaces (hence rough).	**Structure** Network of interconnected flattened membrane sacs that does not contain ribosomes attached to its surface (hence smooth).	**Structure** Consists of proteins and ribosomal RNA (rRNA). Ribosomes can be attached to a RER or free floating in cytoplasm.
Functions Increases surface area for cellular processes. Attached ribosomes synthesise proteins that RER packages into vesicles and secretes to the golgi body.	**Functions** Synthesis of lipids.	**Functions** Site of translation (protein synthesis).
		

Lysosome	Cytoskeleton	Centriole
Structure Membrane-bound vesicle containing digestive enzymes (lysozymes).	**Structure** Microscopic internal framework of tiny protein micro-filaments and tubules.	**Structure** Small structure composed of protein microtubules.
Functions Destroy foreign bodies (e.g. bacteria) and recycle cellular materials (e.g. non-functional organelles).	**Functions** Support and movement of organelles inside cell, movement of cell membrane (e.g. exocytosis), assembly of the spindle prior to mitotic division and, in animal cells, maintenance of cell shape.	**Functions** Duplicates prior to cell division so that each daughter cell receives a centriole. Microtubules extend from centrioles at opposite poles of cells to attach to centromeres of chromosomes and align them along metaphase plate. They also assist in separation of sister chromatids (mitosis) and homologous chromosomes (meiosis).
		

Helpful online resources

Nucleus Medical Media: Biology: Cell Structure:
<https://www.youtube.com/watch?v=URUJD5NEXC8>

Comparing plant, animal and fungal cells

Plant, animal and fungal cells are all examples of **eukaryotes**. As such, they share a number of common characteristics including a cell membrane, nucleus, mitochondria, endoplasmic reticulum, Golgi body and ribosomes. These three eukaryotes have evolved separately and have different structures and functions; however, they all contain a nucleus with **DNA bound to histone proteins**. Most plants, animals and fungi (e.g. mushrooms) are multicellular, but they can be unicellular (e.g. fungal yeasts). Plant cells contain chloroplasts and are autotrophic, but animal and fungal cells do not contain chloroplasts.

Additionally, animal cells do not contain a cell wall but plant and fungal cells do. These cell walls consist of different carbohydrates though. Plant cell walls consist of cellulose, whereas fungal cell walls consist of chitin. Cell walls provide a level of structure and support for plant and fungal cells; for example, to assist in the maintenance of plant cell shape and to provide support for organs like leaves.

Refer to *Figure 223* and the table below for a summary of some of the typical differences between plant, animal, and fungal cells.

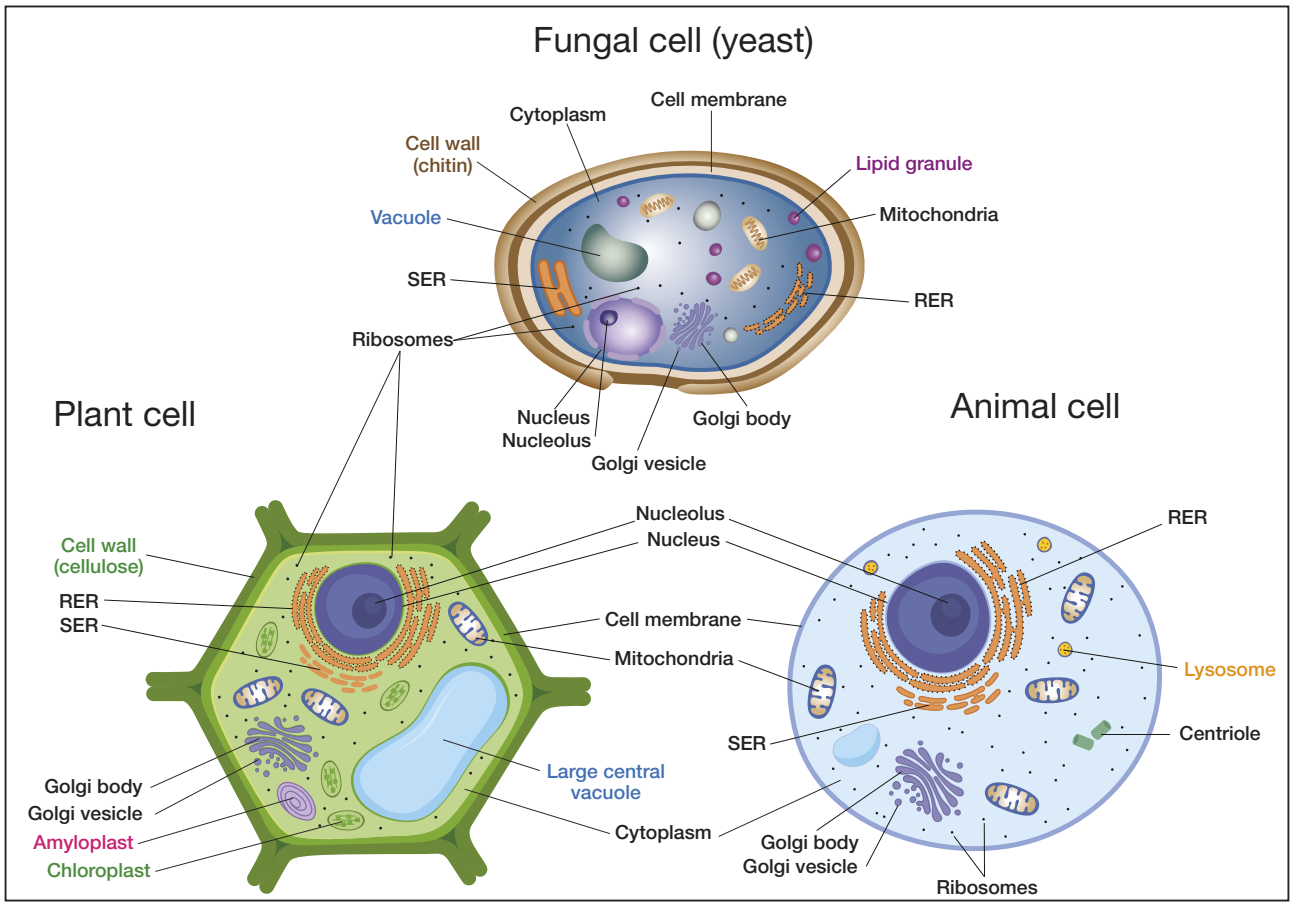


Figure 223 The structural differences between plant, animal and fungal cells

Feature	Comparison of fungal, animal and plant cells
Size	Generally, fungal cells are the smallest (2-10μm), animal cells are larger than fungal but smaller than plant cells (10-30μm) and plant cells are the largest (10-100μm).
Cell wall	Plant cells contain cell walls (made of cellulose), fungal cells contain cell walls (made of chitin), but animal cells do not contain cell walls.
Shape	Plant and fungal cells tend to be more rigid and regular in shape than animal cells due to the presence of a cell wall.
Chloroplasts	Found in some types of plant cells but not in animal or fungal cells.
Vesicles	Tend to be larger, fewer in number and permanent in plant cells. Animal cells tend to contain more vesicles that are smaller and generally temporary. Fungal cells also contain vesicles for transport of molecules and communication purposes.
Lysosomes	Found in some animal cells. Lysosome is a term generally reserved for this organelle in animal cells. Some plant and fungal cells have acidic vacuoles that perform a similar function.
Cell membrane	All three contain cell membranes but have slightly different structure. Animal cell membranes include cholesterol, but plant and fungal cell membranes do not. Plant cell membranes consist of sterols, and fungal cell membranes consist of ergosterols (instead of cholesterol).
Mitotic division	Animal cells contain centrioles for cell division, but plant and fungal cells do not.
Anaerobic respiration	Plant and fungal cells perform alcohol fermentation whereas animal cells perform lactic acid fermentation.

Helpful online resources (360° VR Videos)

Use the following URL or QRC to view the following 360° videos. This is best viewed using a virtual reality headset for phones; however, this is not required. Simply launch the video in your YouTube app on your device, place the phone in your headset and move your head around to see the "cells" in 360°. If you don't have a VR headset for phones, you just have to use your hands/arms to move the phone instead.

XVIVO Scientific Animation: Cellscape VR Biology Guided Tour Animation
<https://www.youtube.com/watch?v=0A56uOVluNM>

Plant Energy Biology: Virtual Plant Cell: Cell Explore, 2018. VPC 360° video
<https://www.youtube.com/watch?v=rmgf0VDDlH8>

2.2 Review questions

Multiple choice questions

1. Which of the following can be used as a defining characteristic of a typical prokaryotic cell?
   - J the presence of chromosomes
   - K the absence of chromosomes
   - L the absence of membrane bound organelles
   - M the presence of a cell wall
2. Which one of the following correctly identifies the four main structures or molecules seen in prokaryotic cells?

J	DNA & RNA	ribosomes	mitochondria	cell membrane
K	nucleus	chloroplasts	mitochondria	cell wall
L	nucleus	ribosomes	cytoplasm	cell wall
M	DNA & RNA	ribosomes	cytoplasm	cell membrane

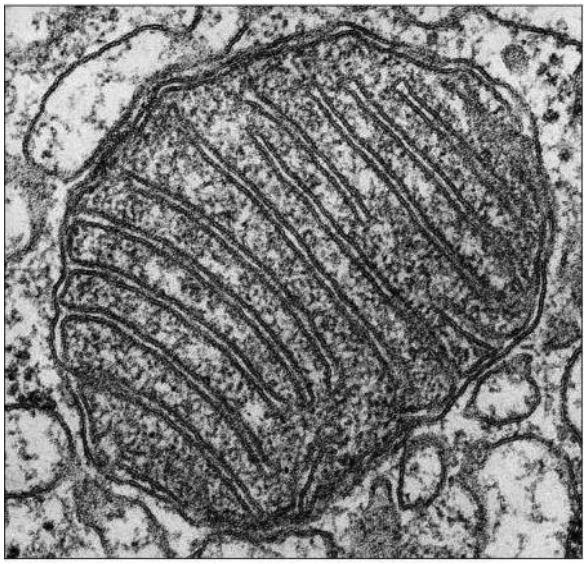
3. Which of the following alternatives correctly identifies a type of cell, the arrangement of DNA in that cell and the type of cell division it undergoes?

	Cell	DNA arrangement	Type of cell division
J	Prokaryote	Circular	Binary fission
K	Eukaryote	Circular	Mitosis
L	Prokaryote	Linear	Mitosis
M	Eukaryote	Linear	Binary Fission

4. Which one of the following has the structures arranged in order of increasing size?

	Smallest → Largest			
J	O_2 molecule	Ribosome	Prokaryotic cell	Nucleus
K	Prokaryotic cell	O_2 molecule	Ribosome	Nucleus
L	O_2 molecule	Prokaryotic cell	Nucleus	Ribosome
M	Prokaryotic cell	O_2 molecule	Nucleus	Ribosome

5. *Refer to the diagram below of an organelle found in many plant cells to answer the question that follows.*



Which of the following processes occurs in this structure?

J Carrying out photosynthesis.

K Vesicle formation for packaging proteins and other macromolecules.

L DNA replication to double the amount of DNA for cell division.

M Aerobic respiration for the production of energy.

6. The movement of chloroplasts within the cytoplasm of some green plants maximises the exposure of the chloroplasts to sunlight

Which one of the following cell structures enables this movement of chloroplasts?

J Endoplasmic Reticulum

K Cytoskeleton

L ATP synthesis

M Cell membrane

7. All specialised cells that secrete protein molecules:

   J have a rigid cell wall.

   K contain numerous lysosomes.

   L have an extensive Golgi apparatus.

   M contain functional chloroplasts.

8. Centrifugation is a process in which the components of cells can be separated by spinning ruptured cells at high speed. The largest and heaviest components sediment out at the bottom at relatively slow speed. As the cellular contents are centrifuged at higher speeds more components sediment out.

   Refer to the diagram below of the centrifugation process to answer the question that follows.

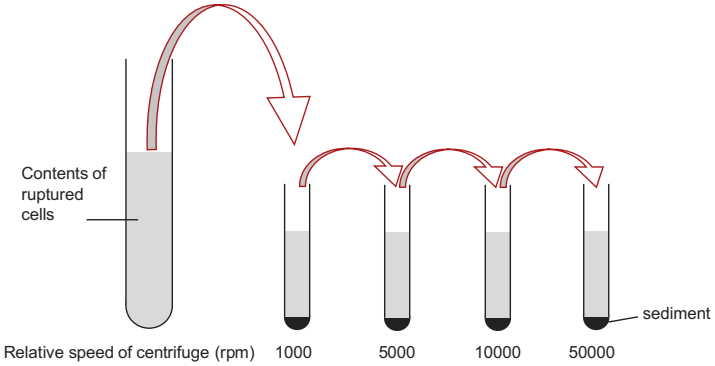
   Which one of the following would represent the order in which the cellular components would be recovered from the sediment?

   J nuclei, mitochondria, lysosome ribosomes

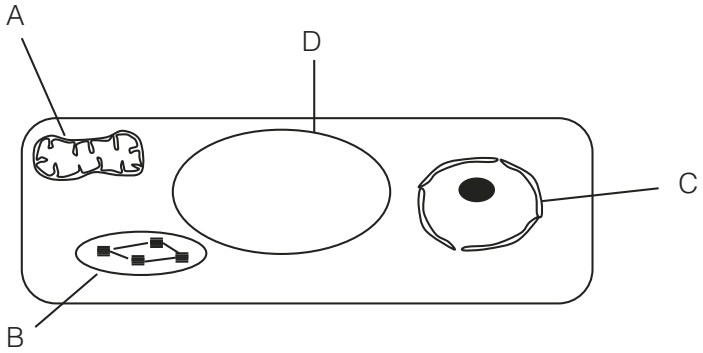
   K nuclei, ribosomes, lysosome, mitochondria

   L lysosome, ribosomes, nuclei, mitochondria,

   M lysosome, mitochondria, nuclei, ribosomes



9. *Refer to the diagram below which shows a cell that was drawn from a photomicrograph*.



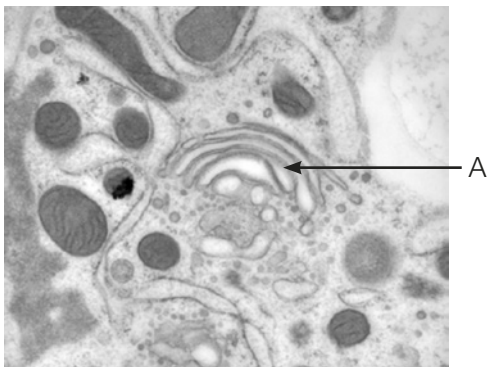
The correct sequence of the names of the organelles labelled A, B, C and D is:

	A	B	C	D
J	chloroplast	nucleus	vacuole	mitochondria
K	mitochondria	vacuole	nucleus	chloroplast
L	chloroplast	vacuole	nucleus	mitochondria
M	mitochondria	chloroplast	nucleus	vacuole

10. Which one of the following alternatives correctly identifies an organelle, the type of cell in which it might be found and its function?

	Organelle	Type of cell	Function
J	Nucleus	Prokaryotic	Direct protein synthesis
K	Smooth endoplasmic reticulum	Eukaryotic	lipid synthesis
L	Golgi body	Eukaryotic	protein synthesis
M	chloroplast	Prokaryotic	Photosynthesis

11. *Refer to the electron micrograph on the right (approx. 10,000×) to answer the following question.*



(from http://www.botany.unimelb.edu.au)

Which one of the following functions best describes the role of the organelle labelled A?

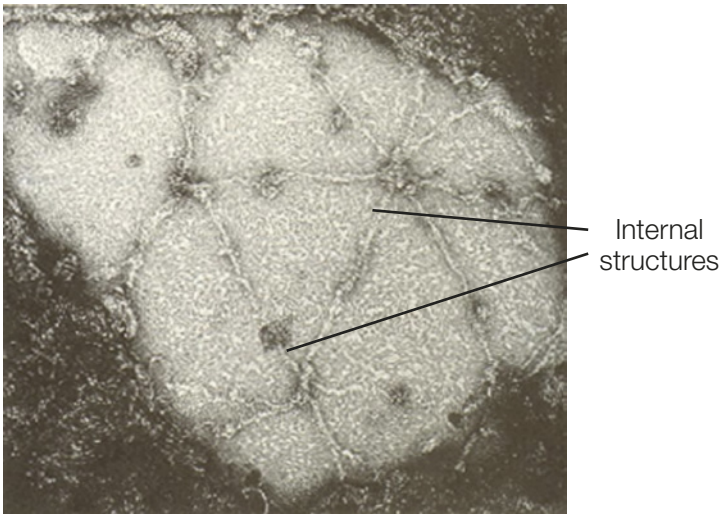
J To package proteins from the ribosome to enable their transport through the cell via the endoplasmic reticulum.

K To receive proteins from the endoplasmic reticulum and modify them for delivery to their final destination.

L To gather newly synthesized protein molecules before transporting them to the Golgi body for modification.

M It is the site of protein synthesis.

12. *Refer to the photograph to the right that represents some internal cellular structures found in red blood cells (magnification approx. 10,000×) to answer the following question.*



(from http://www.coe.drexel.edu)

These internal cellular structures could be directly involved with:

J the movement of O_2 molecules into the cell.

K packaging products made in the cells to be secreted from the cell.

L actively transporting glucose molecules into the cell.

M restoring the shape of the blood cells after they become distorted travelling through blood capillaries.

13. Which of the following cells does not contain DNA bound to histone proteins?

J Yeast cell.

K Cheek cell.

L Palisade leaf cell.

M E. coli cell.

14. Identify the correct statement below regarding types of cells and cell walls.

J An animal cell does not contain a cell wall because its cell membrane provides the same level of structure and support as a cell wall made from cellulose.

K Bacterial cells contain cell walls composed of the carbohydrate cellulose.

L Fungal cells contain cell walls composed of the carbohydrate chitin.

M Plant cells contain cell walls composed of the carbohydrate peptidoglycan.

15. Which of the following statements is correct with regards to the cell membrane of eukaryotic cells?

J Plant and animal cells contain cell membranes, but fungal cells do not.

K Plant, animal and fungal cells all contain a cell membrane with the exact same structure.

L Plant cells contain a cell membrane that has cholesterol embedded within the phospholipid bilayer to increase its fluidity.

M Fungal cells contain a cell membrane that has ergosterols embedded within the phospholipid bilayer to increase its fluidity.

Free response questions

1. Complete this table for a prokaryotic cell, including as much detail as possible.

Structure	Structural feature(s)	Special function(s)
Ribosome		
Cell wall		
Cell membrane		
Chromosome		

2. Complete this table for organelles found in eukaryotic cells.

Organelle	Present in fungal, animal and/or plant cells?	Structural features	Special functions
Nucleolus			
Lysosome			
Vacuole/vesicle			
Chloroplast			
Mitochondrion			
Smooth endoplasmic reticulum			

3. Describe three differences between prokaryotic and eukaryotic cells.

4. Prokaryotic cells do not contain a nucleus, mitochondria or an endoplasmic reticulum. Given the importance of these organelles, describe how it is possible for them to divide, transform energy and carry out essential metabolic processes.

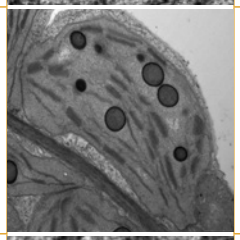
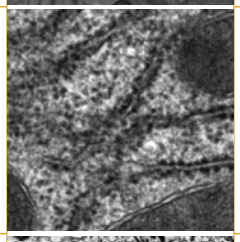
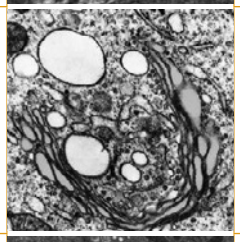
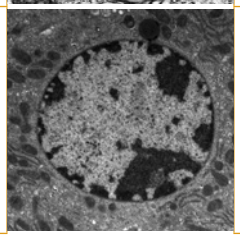
5. State two functions of the cytoskeleton.

6. Name four organelles that are not membrane bound.

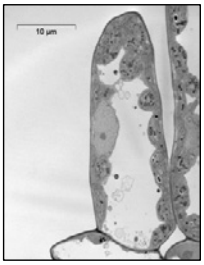
7. "Prokaryotic and eukaryotic cells have much in common which is a reflection of their evolutionary history."
   a) Describe two similarities between these two types of cells.

   b) With reference to the statement above, explain why it is theorised that eukaryotic cells evolved from prokaryotic cells.

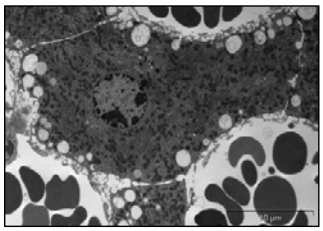
8. Complete the table below:

	Electron micrograph (sizes not shown)	Name of organelle	Present in fungal, animal and/or plant cells	Important structural features	Function
A					
B					
C					
D					
E					

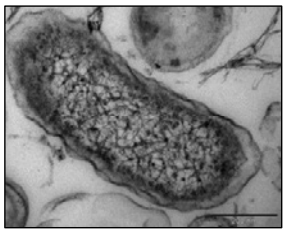
9. Refer to the following electron micrographs of three different cells to answer the questions that follow:



A: Plant cell



B: Liver cell



C: Bacterial cell

a) Name one organelle that you would expect to find in all three types of cells.

b) State one difference between DNA in cell C compared to cells A and B.

c) Explain why cell C cannot be part of a tissue.

10. Not all cells have the same number or type of organelles. For each of the specialised cells below, state one organelle that could be present in large numbers and justify why.

a) sperm cell

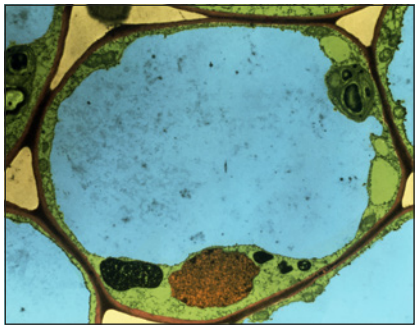
b) palisade leaf cell

c) secretory cell in pancreas

d) phagocyte (white blood cell that engulfs foreign cells by endocytosis)

e) B plasma cell (white blood cell that secretes proteins called antibodies)

11. Refer to this diagram of a plant cell taken with a scanning electron microscope. Two particular features of the cell contribute to its ability to maintain its shape and structure. Identify the two structures and describe how each provides this support.



12. Explain the likely reason for the two following scenarios, with reference to the function of the organelle mentioned.

a) A nucleolus becomes darker and larger within a cell's nucleus.

b) Numerous vesicles are found in the cytoplasm of a cell.

Chapter 2.3 Energy transformations

Science Understanding

Cells require inputs of suitable forms of energy, including light energy or chemical energy in complex molecules.

- Distinguish between autotrophs and heterotrophs.

The sun is the main source of energy for life.

- Recognise that photosynthesis is important in the conversion of light energy into chemical energy, as illustrated by the following equation:

$$6CO_2 + 6H_2O \xrightarrow[\text{chlorophyll}]{\text{light}} C_6H_{12}O_6 + 6O_2$$

$$\text{carbon dioxide} + \text{water} \xrightarrow[\text{chlorophyll}]{\text{light}} \text{glucose} + \text{oxygen}$$

Energy transformations occur within all living cells.

- Explain how most autotrophs and heterotrophs transform chemical energy for use through aerobic respiration, as illustrated by the following equation:

$$C_6H_{12}O_6 + 6O_2 \longrightarrow 6CO_2 + 6H_2O$$

$$\text{glucose} + \text{oxygen} \longrightarrow \text{carbon dioxide} + \text{water}$$

- Explain that fermentation is an anaerobic alternative to aerobic respiration:
  - in plants and yeast:

$$C_6H_{12}O_6 \longrightarrow 2C_2H_5OH + 2CO_2$$

$$\text{glucose} \longrightarrow \text{ethanol} + \text{carbon dioxide}$$

  - in animals:

$$C_6H_{12}O_6 \longrightarrow 2C_3H_6O_3$$

$$\text{glucose} \longrightarrow \text{lactic acid}$$

- Compare the amount of energy released through aerobic respiration and fermentation.
- Recognise that energy is required to break chemical bonds and energy is released when new bonds are formed.
- Describe the formation of ATP from ADP and P_i.
- Describe the conversion of ATP to ADP and Pi which releases energy for some metabolic reactions.

An introduction to energy

All cells require inputs of suitable forms of energy. This includes **light energy** for plant cells that contain **chlorophyll**, or **chemical energy** stored in complex molecules for animal cells. Energy obtained by cells is used for processes such as movement, synthesis of materials and to help cells maintain a stable internal environment. Energy is a difficult concept to define but it does obey several fundamental rules or principles as follows:

- it cannot be created or destroyed
- energy transformations (or conversions) occur within cells e.g. light energy into chemical energy in cells performing **photosynthesis**
- life stops without continued input of energy
- chemical reactions in cells require an energy 'push' or activation energy to start
- from an energy perspective, chemical reactions may be classified into two categories:
  - those that have a nett release of energy in the cell
  - those that need a continual supply of energy to keep them going

The main source of energy for life is **the sun**. Energy is radiated to the Earth from the sun in physical form as **light energy** and **heat energy**. Light energy that strikes and is absorbed by plants (and other photosynthetic organisms) is used for photosynthesis. Heat energy that reaches the Earth ensures surface temperatures remain suitable for life.

Forms of energy

Energy is identified in different forms and a few of the important types in biological systems are identified below:

Chemical energy

This is the energy stored in the chemical bonds of complex molecules. Typically, carbohydrates (16.7kJ), lipids (37.7kJ) and proteins (16.7kJ) in particular, which contain usable amounts of energy for cells.

Radiant (light) energy

Light energy is a form of radiant energy that is radiated from the sun and transformed into chemical energy during photosynthesis. Some of this is transferred to all animals via feeding relationships.

Heat (thermal) energy

This is the energy that is caused by the movement of atoms or molecules in a substance. Heat energy increases as atoms vibrate faster or molecules move faster; this has implications for all metabolic reactions.

Kinetic energy

Kinetic energy is the energy associated with the movement of molecules, cell components or whole objects, including organisms. Energy may be required to move molecules; for example, active transport of required substance into a cell or to move chromosomes during cell division.

Refer to *Figure 231*, which illustrates some examples of energy transformations in cells/organisms.

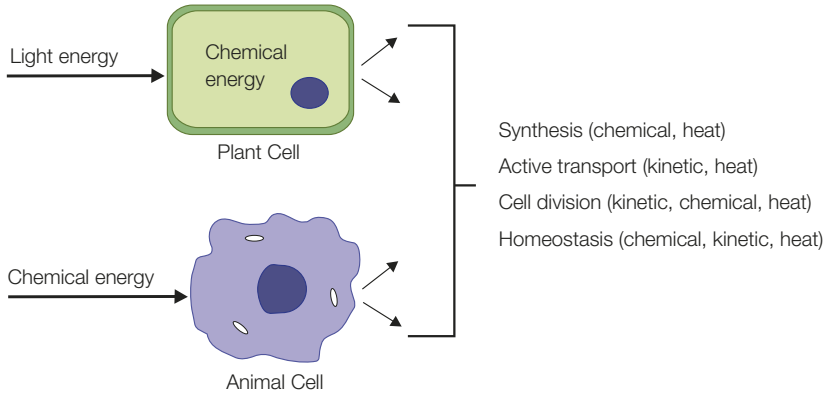


Figure 231 Energy transformations in cells/organisms

Autotrophs and heterotrophs

An **autotroph** is an organism that synthesises **organic molecules** (e.g. proteins, nucleic acids, carbohydrates) from simple **inorganic molecules** (e.g. carbon dioxide, water, mineral ions). Autotrophs may obtain their initial input of energy from light energy (photo-autotroph) or from inorganic molecules e.g. hydrogen sulphide (chemo-autotroph). The most obvious autotrophs are plants but there are many species of unicellular eukaryotes that are autotrophs, such as phytoplankton in the oceans and algae in freshwater lakes.

A **heterotroph** is an organism that obtains its organic molecules by consuming other organisms or parts of them.

Both autotrophs and heterotrophs transform energy through processes called **aerobic respiration** and **anaerobic respiration** (discussed later in this chapter) to make energy available for life's processes.

Figure 232 explores this concept in more depth, providing a flowchart to classify autotrophs and heterotrophs depending on both their input of energy and their source of carbon. Four types of organisms are identified:

- photo-autotrophs
- chemo-autotrophs
- photo-heterotrophs
- chemo-heterotrophs

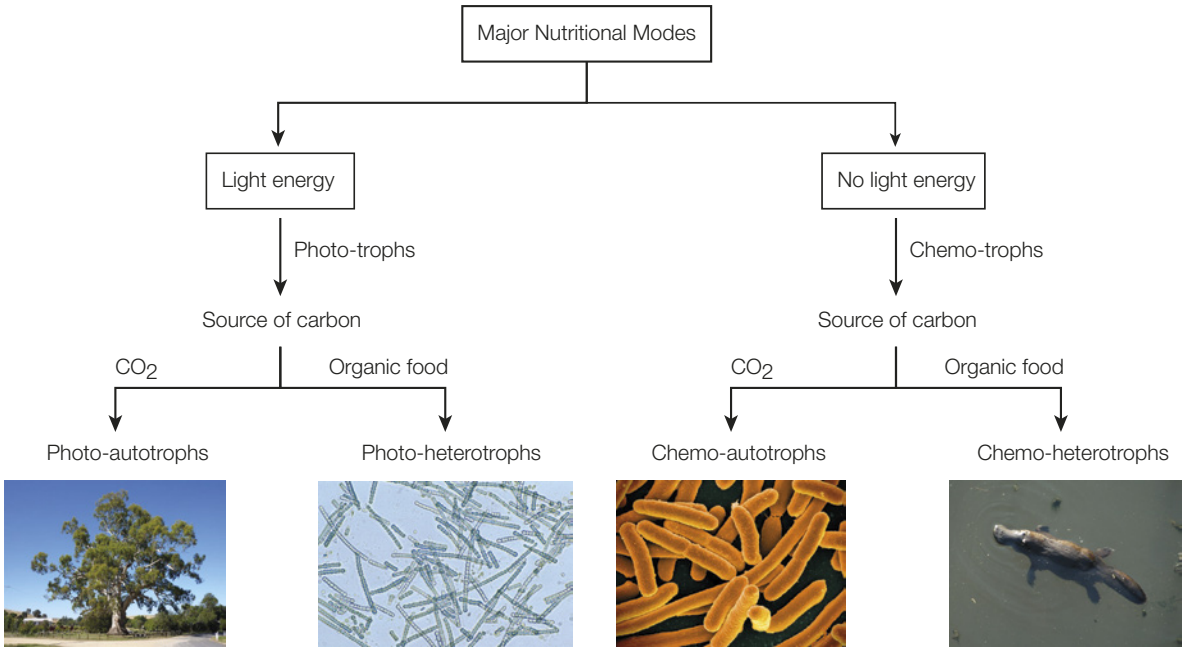


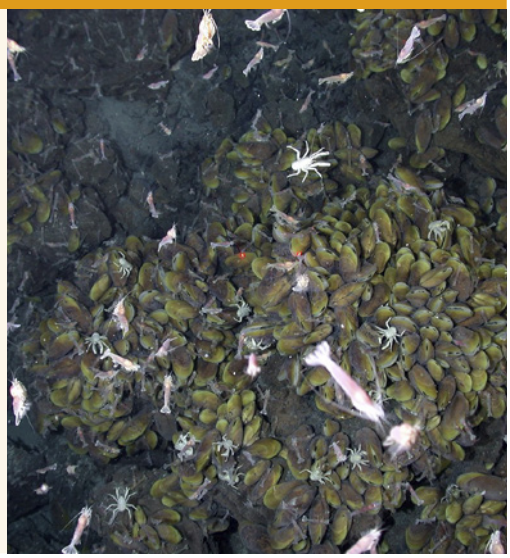
Figure 232 Classification of autotrophs and heterotrophs with examples of organisms

Helpful online resources

Amoeba Sisters: Autotrophs and Heterotrophs
<https://www.youtube.com/watch?v=f8G7IulYxiA>

Life in the dark

Light energy is not the source of energy for all life on Earth. This was first realised in the late 1970s when cone-shaped structures located around volcanic cracks at the bottom of oceans called hydrothermal vents were discovered. Despite them being 2-3 km underwater in conditions of total darkness, these vents support a wide diversity of life. Here energy is captured not by photo-autotrophs (that absorb light energy) but by chemo-trophic species of bacteria that obtain energy from energy-rich substances that form near the vent. Some of this energy is transferred to tubeworms and other animals via feeding relationships. Refer to the photograph that shows some of the organisms in a community that are supported by a hydrothermal vent. Additionally, use the following URL or QRC to view actual footage of a hydrothermal vent and the life it supports.



Helpful online resources

Oceanexplorergov: Galápagos Rift 2011 - New Hydrothermal Vent Discovered
https://www.youtube.com/watch?v=2FFnrW_SUdM

Photosynthesis

The light energy that falls on and is absorbed by cells in the leaves of plants enables the process of photosynthesis to occur. In this process, light energy is trapped by the green pigment chlorophyll and this enables light energy to be transformed into chemical energy, which is stored in the chemical bonds of organic molecules like glucose and starch.

Chloroplasts are the membrane-bound organelles which are the site of photosynthesis. They are abundant in the mesophyll tissue of leaves, arranged in layers so as to maximise their exposure to light energy that passes through the upper surface of the leaf (see *Figure 233*).

Guard cells regulate the opening and closing of the stomates, and they are clearly visible in the lower epidermis. When the stomates are open, gas exchange, essential for the process of photosynthesis, can readily occur.

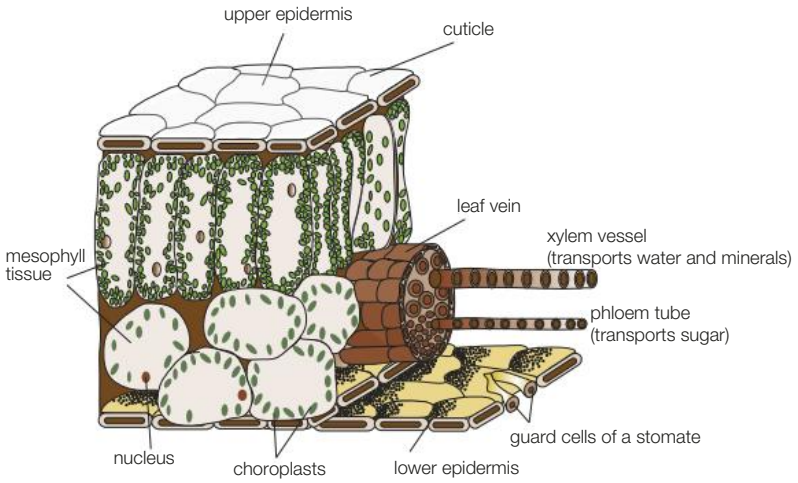


Figure 233 Mesophyll cells and chloroplasts in a leaf

Photosynthesis is not a simple one-step biochemical reaction but in fact **consists of a series of metabolic reactions** occurring in the chloroplasts, some are dependent on light energy (light dependent reactions) while others occur without light (light independent reactions).

Chemical and word equations for this process are shown below:

$$6CO_2 + 6H_2O \xrightarrow[\text{chlorophyll}]{\text{light}} C_6H_{12}O_6 + 6O_2$$

$$\text{carbon dioxide} + \text{water} \xrightarrow[\text{chlorophyll}]{\text{light}} \text{glucose} + \text{oxygen}$$

2.3

Figure 234 illustrates a cutaway computer illustration showing the internal structure of a chloroplast. The **grana** (stacks of membranes) are the sites for the first steps of photosynthesis that require light. The starch grains (coloured magenta) are vacuoles that contain starch, which is a storage carbohydrate in plants made by assembling glucose molecules into a complex carbohydrate.

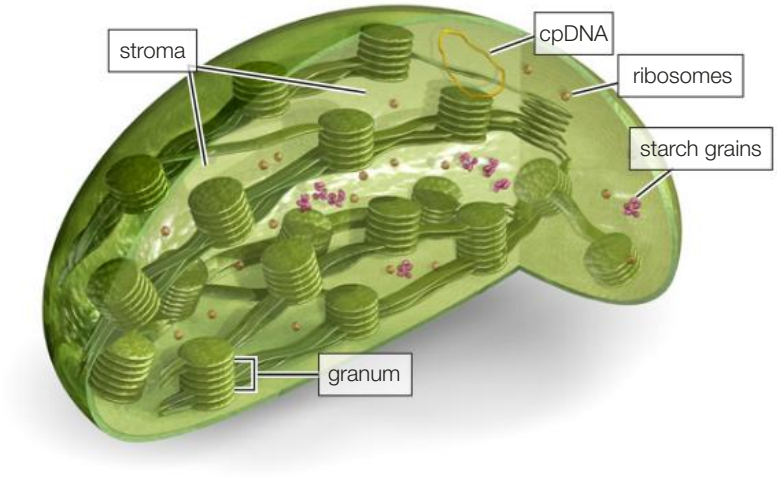
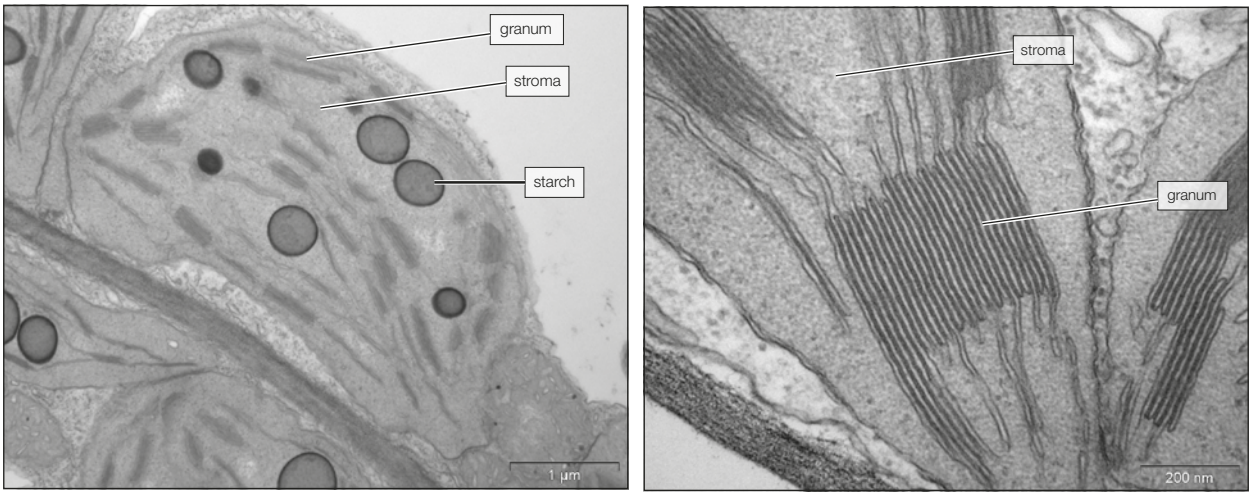


Figure 234 The internal structure of a chloroplast

Figures 235 (a) and (b) are two electron micrographs showing the internal structure of chloroplasts. The grana are the stacks of membranes and the **stroma** is the fluid **matrix** surrounding the membranes.



Figures 235 (a) and (b) Electron micrographs of a chloroplast

Limiting factors that affect photosynthesis

According to the summary equations for photosynthesis, the main requirements for the process are: carbon dioxide, water, light energy and chlorophyll. As photosynthesis is an enzyme–controlled metabolic pathway it is also temperature dependent (refer back to Chapter 1.4). A **limiting factor** is a factor that affects the rate of a process; in this case, the rate of photosynthesis. By implication, it is the lower level of the factor in question that is slowing the rate of photosynthesis.

Carbon dioxide

Refer to *Figure 236* representing a graphical display of data obtained in the laboratory to test the effect of varying the carbon dioxide concentration in the surrounding atmosphere. This is based on the assumption that the stomates in the lower epidermis are open, permitting the diffusion of carbon dioxide into the leaf and thus the cells in the mesophyll. It can clearly be seen that the rate of photosynthesis increases as the concentration of carbon dioxide increases; all other limiting factors would be constant in this experiment.

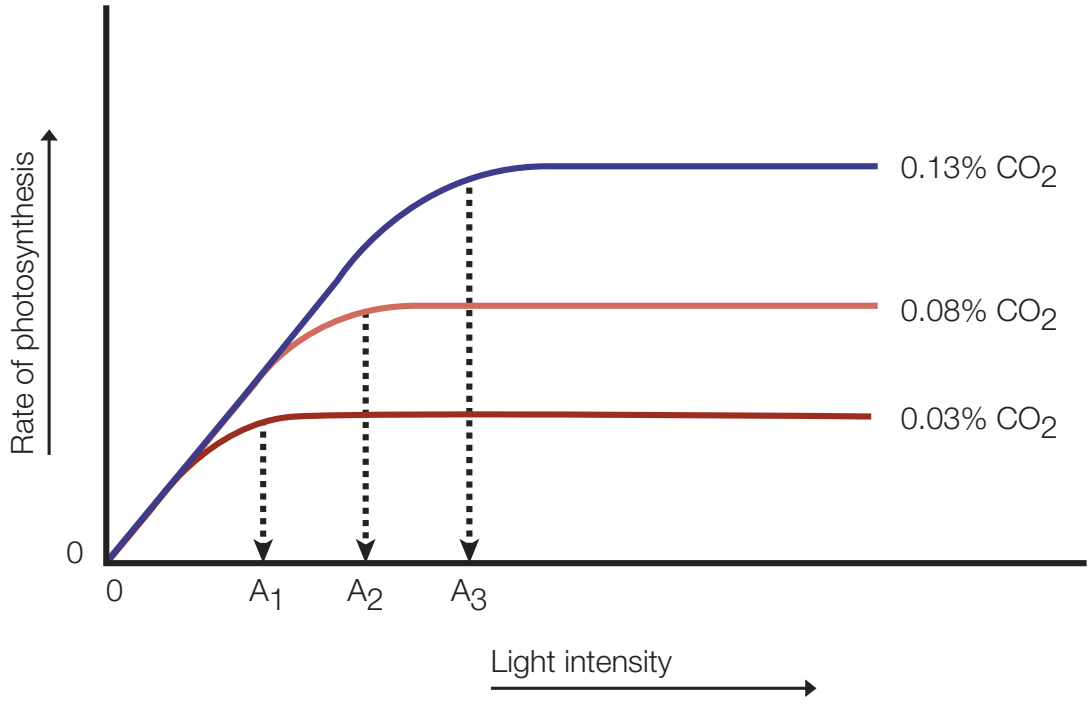


Figure 236 The effect of light intensity and carbon dioxide concentration on photosynthesis

Light

Light is the source of energy input for the process of photosynthesis. Consequently, at low levels of light intensity there will be a low rate of photosynthesis and as the light intensity increases so will the rate of photosynthesis (see *Figure 236*).

Energy release from molecules

All living things require energy to survive. Autotrophs and heterotrophs, however, obtain their original input of energy (and also the element carbon) in different ways. Many organic molecules contain stored chemical energy that can be transformed for cellular use when chemical bonds are broken and new bonds are formed. Most autotrophs and heterotrophs transform chemical energy for use through a process called aerobic respiration. Before this process is studied, it is useful to have an understanding of the main energy 'currency' in cells, a molecule called ATP.

ATP/ADP and Pi

ATP (adenosine triphosphate) is the cell's **immediate source of energy** and is used for almost every energy-requiring reaction or process that occurs in cells. Essentially, as large molecules are broken down, some of the chemical energy stored in the chemical bonds they have is released and used to generate (or synthesise) ATP.

The ATP molecule

- is generally considered the most important molecule associated with life, second only to DNA
- provides energy for all of life's processes from muscle contraction to transmitting nerve impulses to synthesising the complex molecules needed by all cells.
- is maintained in large quantities by cells; each cell is thought to have approximately 1 billion ATP molecules at any given time.
- is an energy coupling unit; linked with ADP (adenosine diphosphate), it is not a store of energy but an energy 'currency' (i.e. the ATP can be 'spent' to provide energy and more can be generated).

When ATP (that has a chain of three phosphate groups) becomes converted to ADP (that has two phosphate groups), the chemical bond between the second and third phosphate groups is broken, releasing free energy for cellular use.

Figure 237 illustrates the **ATP/ADP cycle**, where ATP breaks down to form ADP and Pi releasing a constant amount of free energy which is available for cellular use. Conversely, some of the energy released from aerobic respiration (about 40%) is used to drive the conversion (or synthesis) of ADP and Pi to ATP. Energy not transferred in this way (about 60%) is 'lost' from the cell as heat energy (helping us to maintain a temperature of 37°C). ATP can be **regenerated very quickly,** and as it is soluble, can be **transported readily** throughout the cell to where it is required.

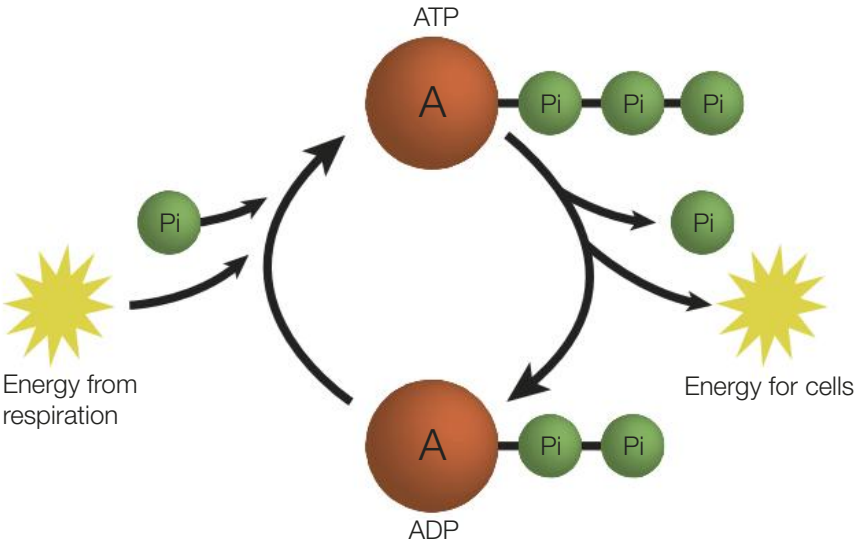


Figure 237 The ATP/ADP cycle

Helpful online resources

Kurzgesagt - In a Nutshell: Why Are You Alive – Life, Energy & ATP
<https://www.youtube.com/watch?v=QImCld9YubE>

Aerobic respiration

Aerobic respiration is the type of cell respiration used to release energy stored in chemical bonds in glucose when **oxygen is available.**

Chemical and word equations for this process are shown below:

$$C_6H_{12}O_6 + 6O_2 \longrightarrow 6CO_2 + 6H_2O$$

glucose + oxygen ⟶ carbon dioxide + water

Helpful online resources

Amoeba Sisters: What is ATP?
<https://www.youtube.com/watch?v=23ZzI6WZS28>

As with photosynthesis, aerobic respiration is not a one-step biochemical reaction but has three stages, each consisting of a series of metabolic reactions:

- glycolysis
- Krebs cycle
- electron transport chain

(*Details of these processes are not required in this course*)

Glycolysis is the first stage of aerobic respiration and takes place in the cytosol. The last two stages occur in the **mitochondrion** (see *Figure 238* for a visual summary of stages of aerobic respiration).

In glycolysis, glucose (a 6-carbon sugar) is broken down by several reactions to form two 3-carbon molecules, both of which are called pyruvate. In the presence of oxygen, the pyruvate molecules then enter the mitochondria and it is here that the remaining two stages, the Krebs cycle and electron-transfer chain occur. For each glucose molecule, the products are 6 carbon dioxide molecules, 6 water molecules and a quantity of free energy. Although some energy is needed to start the breakdown of glucose in this way, the nett (or overall) result is the capture of some of this free energy in the production of around 36 molecules of ATP. As seen previously, this is the energy currency used to supply energy as needed by the cell.

Fermentation

Eukaryotic cells have evolved the capacity to extract energy from the breakdown of glucose in the **absence of oxygen.** This process is an anaerobic (occurs without oxygen) alternative to aerobic respiration (that requires oxygen) and differs in plants and yeast (alcohol fermentation) when compared to animals (lactic acid fermentation).

Both types of fermentation mentioned above occur in the cytosol after the process of glycolysis, previously mentioned in aerobic respiration. Chemical and word equations for these processes are shown below:

In yeast (and some plants)

$$C_6H_{12}O_6 \longrightarrow 2C_2H_5OH + 2CO_2$$

glucose ⟶ ethanol + carbon dioxide

In animals (and some bacteria)

$$C_6H_{12}O_6 \longrightarrow 2C_3H_6O_3$$

glucose ⟶ lactic acid

The amount of energy released by each type of fermentation is enough to synthesise only 2 ATP molecules per glucose molecule. This is clearly less efficient than aerobic respiration which typically yields 36 ATP molecules per glucose molecule (see *Figure 238*).

Alcohol produced by alcohol fermentation is a waste product and if it accumulates to high levels it will stop fermentation from occurring (in plant and yeast cells). Lactic acid produced by lactic acid fermentation is a waste produced by cells that carry the process out e.g. muscle cells. It diffuses out of cells into the bloodstream where it is transported to other tissues, including the liver where it is broken down for excretion by the kidneys. Production of high levels of lactic acid during very strenuous exercise, contributes to muscle fatigue and soreness.

Energy is still available to cells in the waste products of alcohol and lactic acid and these are involved in further metabolic pathways to release this energy and make it available for cellular use.

Refer to the following table which compares the two processes and illustrates the different amounts of energy released in fermentation compared to aerobic respiration.

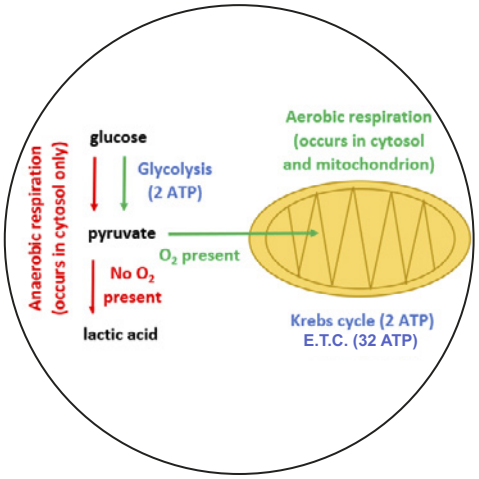


Figure 238 A basic summary of the three stages of aerobic respiration and anaerobic respiration

	Fermentation	Aerobic respiration
Oxygen required?	no oxygen required	oxygen required in latter stages
Site of process	cytosol	cytosol and mitochondria
Products formed	ethanol and carbon dioxide (some plants and yeast) lactic acid (animals and also some bacteria)	carbon dioxide and water
Energy release (from 1 molecule of glucose)	2 ATP molecules	36 ATP molecules

Helpful online resources

Cognito: GCSE Biology - Respiration
<https://www.youtube.com/watch?v=U4WwWuVZSe4>

2.3 Review questions

Multiple choice questions

1. Which of the following best describes the mode of nutrition of a heterotroph?

   J It synthesises its organic molecules from inorganic substances.

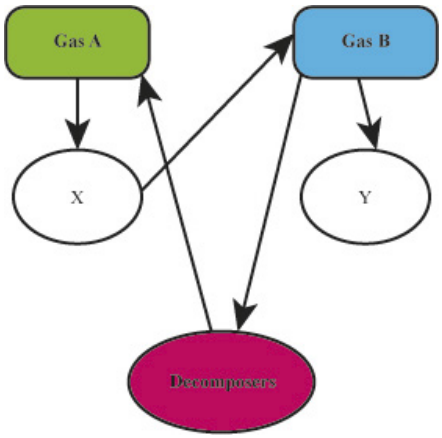
   K It ingests only non-living organic matter.

   L It produces its organic molecules from chemical reactions using light.

   M It obtains organic molecules from other organisms.

2. *Refer to the diagram of gases A and B in the atmosphere to answer the question that follows. The arrows indicate the direction of the movement of the gases between organisms X, Y and Decomposers.*

   Which of the following correctly identifies Gas A, Gas B and the type of nutrition used by organisms X and Y?



			Type of nutrition	
	Gas A	Gas B	X	Y
J	O_2	CO_2	Autotrophic	Heterotrophic
K	O_2	CO_2	Heterotrophic	Autotrophic
L	CO_2	O_2	Heterotrophic	Autotrophic
M	CO_2	O_2	Autotrophic	Heterotrophic

3. Refer to the two respiration pathways to answer the following question.

   Pathway A **glucose + oxygen → carbon dioxide + water**

   Pathway B **glucose → alcohol + carbon dioxide**

   Which one of the following statements concerning these pathways is correct?

   J More ATP is able to be produced for use by the cell from 1 glucose molecule in B when compared to pathway A.

   K Pathway A does not occur in plants.

   L Pathway A releases more energy than pathway B.

   M To provide the same amount of energy for cell activities, more glucose molecules would need to be broken down in pathway A compared to pathway B.

4. Which of the following statements is true concerning the following reaction?

   ADP + P → ATP

   J it is not reversible.

   K there is a net gain of energy to the cells as the reaction proceeds.

   L it occurs in yeast cells during fermentation.

   M enzymes are not required.

5. During fermentation:

   J carbon dioxide is not released.

   K oxygen is taken in and carbohydrate molecules are broken down.

   L lactic acid is produced by plant cells.

   M carbon dioxide is released during the breakdown of carbohydrates in plant cells.

6. Which of the following is most likely to be true when comparing the relative rates of aerobic respiration and lactic acid fermentation in an athlete as the rate of exercise increases?

   J At slow rates of exercise the rate of aerobic respiration is likely to be higher than the rate of lactic acid fermentation.

   K The rate of both reactions is generally constant as the rate of exercise increases.

   L At high rates of exercise the rate of aerobic respiration is likely to be higher than the rate of lactic acid fermentation.

   M The rates of lactic acid fermentation and aerobic respiration are independent of the rate of exercise.

7. Which of the following best explains why ATP is better than glucose as an immediate source of energy for cell metabolism?

   J ATP is soluble in cells whereas glucose is not.

   K When ATP breaks down it releases a suitable amount of energy for cellular reactions.

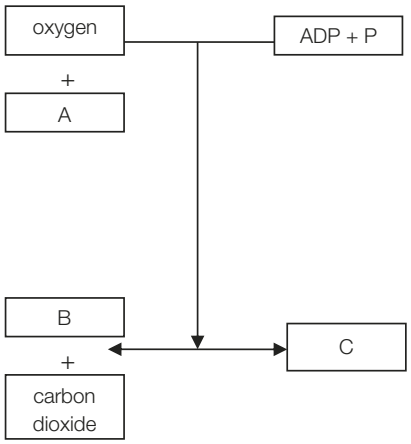
   L ATP is found inside cells whereas glucose is not.

   M When 1 molecule of ATP breaks down it releases more energy than 1 molecule of glucose.

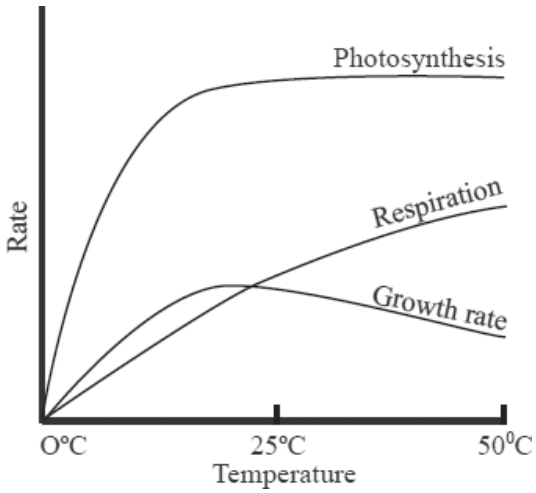
8. *Refer to the diagram on the right to answer the following question.*

   Which of the following options correctly identifies A, B and C?

	Name of substance		
	A	B	C
J	H_2O	glucose	ATP
K	glucose	H_2O	ATP
L	H_2O	glucose	CO_2
M	glucose	H_2O	ethanol



9. *Refer to the graph below showing the effect of temperature on respiration and growth in small wheat seedlings to answer the question that follows.*



   Which one of the following is an inference supported by the data?

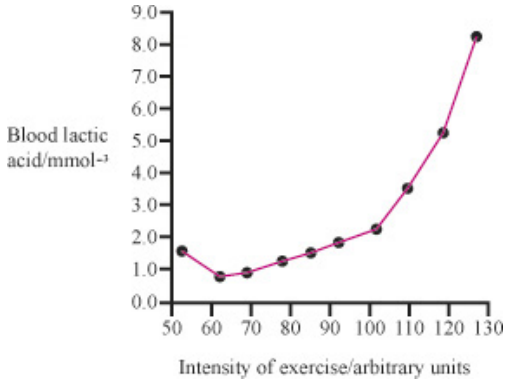
   J High rates of photosynthesis give rise to a steady increase in the growth rate.

   K Low growth rates are to be expected when the rate of photosynthesis is at its maximum.

   L The bigger the difference between the rate of photosynthesis and the rate of respiration, the faster the growth rate will be.

   M High temperatures slow the rate of photosynthesis and hence the growth rate is reduced.

10. *Refer to the graph below which shows the relationship between intensity of exercise and the concentration of lactic acid in the blood.*



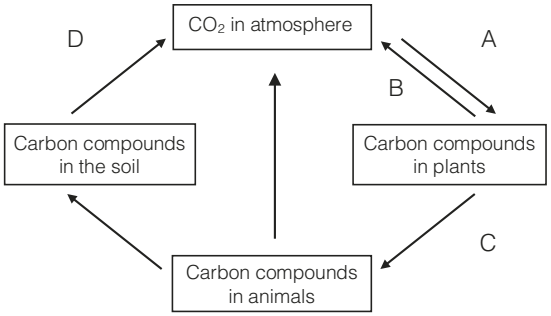
Which one of the following is correct concerning the amount of O_2 available, the rate of fermentation and the rate of exercise?

	Rate of fermentation	Amount of O_2 available to tissues	Intensity of exercise
J	high	high	high
K	low	high	low
L	low	low	high
M	high	low	low

11. *Refer to the diagram on the right which shows part of the carbon cycle.*

Which process best represents aerobic respiration?

J A
K B
L C
M D



12. *Refer to the information in the table below from 4 students' results in an experiment to investigate the effect of light intensity on the rate of photosynthesis.*

Light intensity (lux)	Time taken for leaf discs to rise (sec)				
	Student 1	Student 2	Student 3	Student 4	Average
5	106	124	68	93	98
10	17	32	15	38	26
15	32	28	31	29	30
20	43	40	28	32	36

Which of the following concerning this data is most likely to be a true statement?

J The data obtained at 20 lux is more accurate than that obtained at 5 lux.

K The data obtained at 15 lux is more precise that that obtained at 5 lux.

L The differences obtained at 5 lux between the four students' data was more likely caused by systematic errors.

M The close correlation in the individual student data at 15 lux was more likely the result of a low level of systematic error.

13. *Refer to the information and table below to answer the following question.*

An experiment was conducted by four groups of students to test the effect of glucose concentration on yeast fermentation rate. The fermentation rate was determined by measuring the rate of temperature change of the fermenting mixture. Each group used an alcohol thermometer to measure the temperature and conducted three trials. A teacher also conducted a trial but used an electronic probe to determine the temperature.

Group	Each group's thermometer readings (°C)			Electronic thermometer reading (°C)
	1st measurement	2nd measurement	3rd measurement	
1	18.0	17.0	17.5	20.1
2	18.0	18.0	18.5	20.5
3	21.0	21.0	20.5	19.9
4	18.0	19.0	21.0	20.2

Which one of the following statements is not supported by the data collected during this experiment?

J Group 1's data is the most inaccurate of the four groups.

K Group 2's data is precise but not accurate.

L Group 3's data is both precise and accurate.

M Group 4's data is precise but likely to be affected by a systematic error.

Use the following information to answer Questions 14 and 15.

Rotenone is an insecticide and a piscicide (a substance that kills fish). The rotenone molecule interferes with one of the essential reactions within the electron transport chain in animal cells.

14. Which one of the following statements best explains the effect of rotenone in causing death in insects and fish?

J Aerobic respiration in the mitochondria would be interrupted.

K The rate of glycolysis in the cytoplasm would increase.

L The cell membrane would become impermeable to oxygen.

M ATP would build-up in the mitochondria.

15. A practice that some people used in the past to catch fish more easily was to put extracts containing rotenone in bodies of water to poison the fish. However, when the rotenone poisoned fish were consumed by humans, no poisonous effect(s) were observed.

Which one of the following statements best explains this observation?

J The rotenone remains dissolved in the water and is not absorbed by the fish.

K Rotenone only impacts organisms that respire anaerobically.

L Human cell metabolism does not involve the electron transport chain.

M Rotenone can not pass through the cell membranes of humans who have eaten the contaminated fish.

Free response questions

1. For each hierarchy level below, state one example to illustrate where energy would be required:

a) molecular

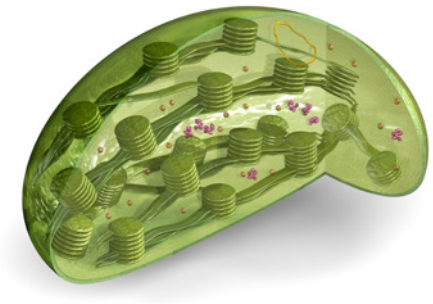
b) organelle

c) cell

d) organ

e) organism

2. Refer to the image of the chloroplast below:



a) Describe two structural features of the chloroplast that would suit its function in a plant cell.

b) Explain why photosynthesis is considered to be a form of autotrophic nutrition.

3. Describe the effect of each of the following factors on the rate of photosynthesis:
   a) light intensity

   b) CO_2 concentration

   c) temperature

4. Describe why organisms require two types of respiration and cannot rely on one type only.

5. Write word and chemical equations for:
   a) alcohol fermentation

   b) lactic acid fermentation

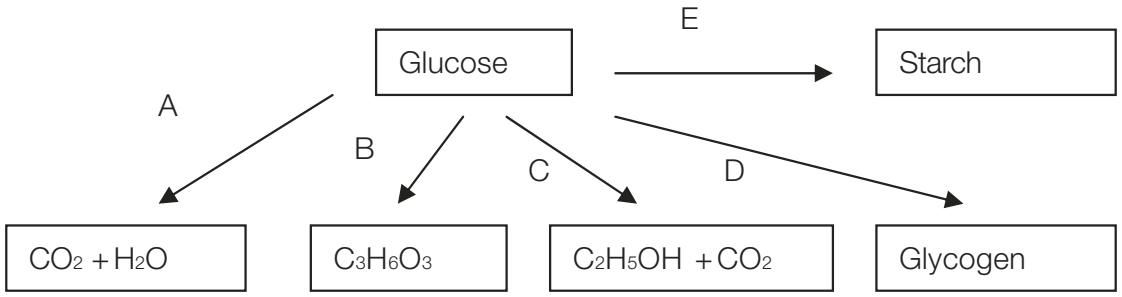
6. State two examples of human activities that use the anaerobic process of fermentation.

7. Not all energy from aerobic respiration is transferred to ATP. Describe what happens to the energy that is not transferred to ATP.

8. *'Heterotrophs can manufacture organic molecules, but not from inorganic materials.'* Explain your understanding of this statement using an example.

9. Organisms transform energy for cellular use through processes such as aerobic respiration. Explain what it means to say that there is a nett release of energy in the process of aerobic respiration.

10. Refer to the following diagram to answer the questions that follow.



a) State which of these reactions occur in plants.

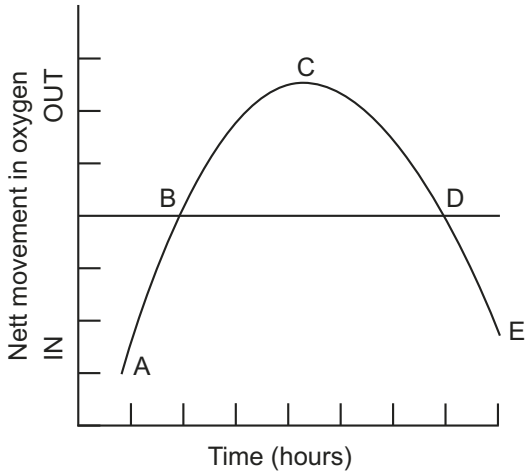
b) State which of these reactions occur in animals.

c) State which reactions provide energy for the synthesis of ATP.

d) State which reactions are synthesis reactions and require a nett input of energy.

e) State which reaction may lead to muscle fatigue.

11. *Refer to the graph below which shows the nett movement of oxygen into and out of the leaf, which was measured over a 6-hour period, to help you answer the questions that follow.*



a) State at what point of the graph the light intensity is likely to be greatest and justify your answer.

b) Name and write chemical equations for the two biochemical reactions that are likely to be causing fluctuations in the oxygen levels of the leaf.

c) State at what point(s) on the graph the rate of photosynthesis is equal to the rate of aerobic respiration.

d) Explain why a plant cell needs aerobic respiration to provide energy when it can use photosynthesis.

12. One scientist made the following statement regarding ATP; “hooking and unhooking the last phosphate on ATP keeps the whole world going”. Provide one conclusion regarding this statement.

13. Yeast is able to respire aerobically and carry out fermentation. State when each process will occur and determine how much glucose each process would need to produce the same number of ATP molecules.

14. Explain what it means to say that ‘not all cells in autotrophs are capable of autotrophic nutrition’.

Science as a Human Endeavour 2.3 – Life elsewhere in the solar system

Prior to the late 1970s the prevailing model for the location of life on Earth was based on the belief that all life depended on light energy from the sun. This ‘no light no life’ model had to be replaced after the discovery of life in total darkness at hydrothermal vents. Scientists suddenly realised that if life could thrive without light, maybe it could exist elsewhere devoid of light. One obvious candidate was the 400 or so subterranean lakes beneath the surface of Antarctica. After many years of refining new drilling technologies to use to obtain water samples from some of these lakes, life was indeed found in one of them, *Lake Whillans*. In 2014 it was announced that Lake Whillans is home to almost 4000 species of unicellular heterotrophic organisms despite the water being a chilly 0.5ºC, completely dark and 800m beneath the west Antarctic ice sheet.

Europa, a moon of the planet Jupiter, has a smooth surface made up of water-ice. The discoveries at hydrothermal vents and in *Lake Whillans* mean if Europa has cold, dark water ocean then it could contain life. This has renewed calls for NASA to do something to find out and so have reports that Europa’s ocean floor is rocky and may have hydrothermal vents.

Please refer to the two short YouTube videos in the Helpful Online Resources below, to answer the questions that follow.

Use your understanding of science as a human endeavour to answer the following questions:

1. Discuss the new evidence that led to the refinement of the original models proposed for life to develop, and an unexpected consequence this could have for society.

Science as a Human Endeavour 2.3 – Life elsewhere in the solar system

2. Discuss how the possible discovery of life on Europa by the Europa Clipper could impact our model of the classification of life and a possible social impact that could result from such a discovery.

Helpful online resources

NASASolarSystem: Alien Ocean - NASA's Mission to Europa
<https://www.youtube.com/watch?v=W1xUyJfd4dY>

Newsy: How To Look For Life On Europa — Jupiter's Watery Moon
<https://www.youtube.com/watch?v=M7zsoZ473lU>

Chapter 2.4 Movement of substances

Science Understanding

In order to survive, cells require an input of matter, including gases, simple nutrients, and ions, and the removal of wastes.

- Compare the inputs and outputs of autotrophs and heterotrophs.

Substances move in and out of cells by processes such as:

- diffusion
- facilitated diffusion
- osmosis
- active transport
- endocytosis
- exocytosis

- Explain how the structure of a membrane facilitates different processes of movement through it.
- Explain the roles of transport proteins, including channel proteins (such as aquaporins), and carrier proteins.
- Explain how the exchange of materials across membranes is affected by factors including:
  - surface-area-to-volume ratio of the cell
  - concentration gradients
  - the physical and chemical nature of the materials being exchanged.

Cell requirements

Chapter 2.3 examined the energy requirements of cells in some detail, including how energy is made available and transformed for cellular purposes. Two major groups of organisms, autotrophs and heterotrophs, were also categorised based on their original source of energy and the element carbon. The cells of all organisms need very specific nutrients and materials for their survival. In addition to light, photo-autotrophs also need carbon dioxide and water for photosynthesis to produce organic molecules. Plants require a range of inorganic nutrients to supply a source of elements including nitrogen, phosphorus, magnesium, sodium, cobalt and many others in minute quantities (trace elements).

The cells of heterotrophs cannot convert inorganic material into organic molecules and therefore a range of elements need to be provided by the organic molecules in the food the organism consumes. A typical diet of a heterotroph will contain proteins, carbohydrates, lipids and nucleic acids, as well as water, mineral nutrients (e.g. calcium and magnesium ions) and vitamins (e.g. vitamin C).

Waste removal

As well as useful products, most metabolic reactions in cells produce waste products and if these accumulate they will generally be toxic to cells and organisms. One example is carbon dioxide produced by all cells during aerobic respiration. As soon as it is produced, it is transported out of cells and then moves in the bloodstream of animals, including humans, to be excreted by the lungs. In plants carbon dioxide can be used in photosynthesis but if the rate of aerobic respiration is greater than the rate of photosynthesis (as it is at night) then carbon dioxide will be excreted from the leaves.

Urea, another metabolic waste in animals, is produced during the breakdown of amino acids in the liver (through a process called deamination). It then moves out of liver cells into the bloodstream where it is transported to the kidneys to be excreted in urine. There are numerous waste products produced by both plants and animals that need to be excreted to ensure the composition and conditions within cells are maintained relatively constant. This is important because it permits metabolic processes to occur efficiently without disruption.

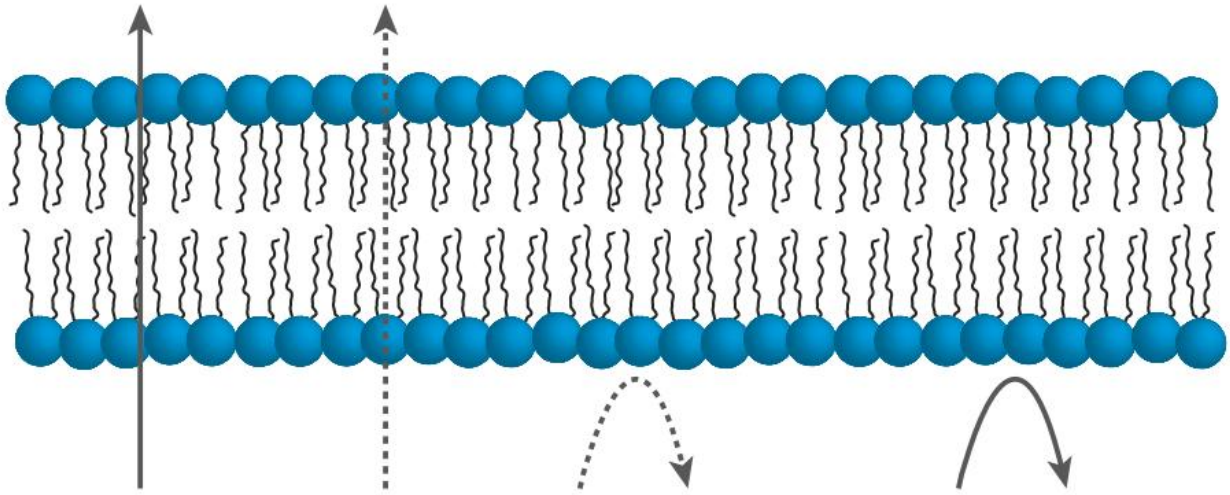
Whether materials are moving into or out of cells, crossing from inside the cell to outside or vice versa, they all need to cross the cell membrane. Chapter 2.1 discussed how the cell membrane separates the cell from its surroundings and controls the exchange of materials, nutrients and wastes between the cell and the extracellular environment surrounding the cell.

Movement of substances in and out of cells

Some properties of the cell membrane which have an impact on the movement of substances are summarised below (see Chapter 2.1 for more detail):

- the membrane is a phospho-lipid bilayer with non-polar tails facing inwards (hydrophobic)
- the polar phosphate heads (hydrophilic) face outwards as well as on the inside surface of the membrane
- as a result of this bi-layer, the membrane is said to be **semi-permeable** i.e. it will allow the passage of some molecules freely but not others
- there are two different types of integral proteins embedded in the bilayer which will assist in moving molecules. These are called **channel proteins** and **carrier proteins**
- the bilayer has fluid-like properties. This permits it to break and reform as well as enclose materials e.g. proteins in vacuoles (or vesicles) for bulk transport.

Figure 241 represents a summary of the relative membrane permeability of many of the important substances that need to move across the cell membrane. This will provide a useful reference about the different types of ways in which molecules move across membranes studied in this chapter. This Figure will also assist in the later sections, especially how the physical and chemical nature of substances influences the movement of them.



High permeability	Moderate permeability	Low permeability	Very low permeability
some gases CO_2, O_2	water	polar organic molecules glucose	ions sodium, potassium
very small uncharged polar molecules ethanol	urea		charged polar molecules and macromolecules amino acids, ATP, proteins, polysaccharides, nucleic acids

Figure 241 Relative membrane permeabilities

Substances move across membranes by both **passive processes** and **active processes**.

Passive processes

Diffusion

Diffusion occurs in both liquids and gases, the molecules of which are in a state of constant random motion. Small, uncharged molecules are free to cross membranes by diffusing between the phospholipids e.g. oxygen and carbon dioxide.

Diffusion can be defined as the nett random movement of molecules that results in their uniform distribution. The movement is said to be **passive** because no input of energy is required. Diffusion occurs from a region of high concentration of molecules to a region of low concentration of them. This difference in concentrations is referred to as the **concentration gradient**. The steeper the gradient, the greater the rate of diffusion. Refer to *Figure 242* representing diffusion.

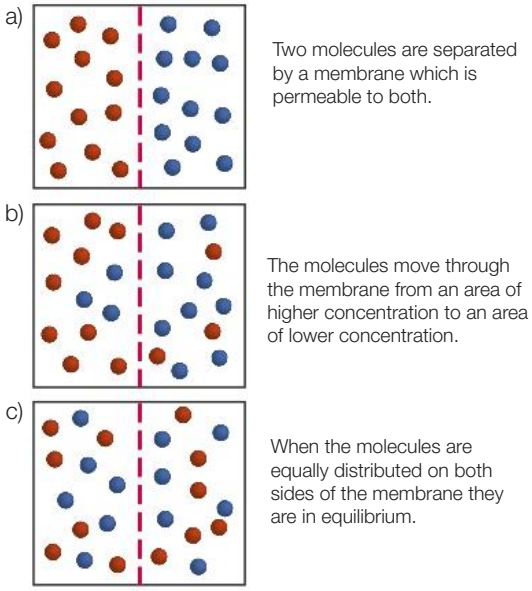


Figure 242 The process of diffusion

As shown in *Figure 242* there is a nett movement of molecules from high concentration to low concentration. The molecules are now evenly distributed (uniform) on both sides of the membrane. Although there is no nett movement of molecules, the molecules are still in a state of constant random motion and can cross from one side to the other. *Figure 243* illustrates the simple transport of materials **across the phospholipid bilayer** by diffusion. This could be a typical animal cell membrane with oxygen diffusing into the cell and carbon dioxide diffusing out of the cell.

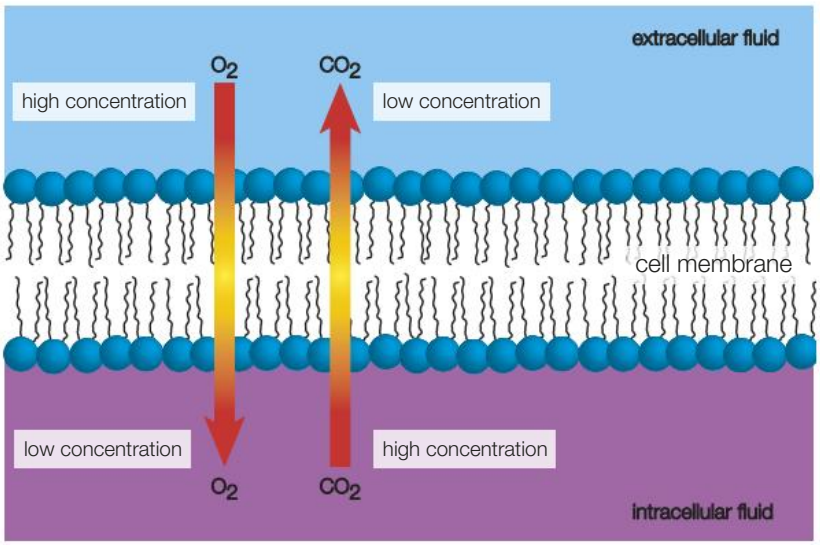


Figure 243 Transport of materials across a membrane by diffusion

Helpful online resources

Cognito: What is Diffusion? How Does it Work? What Factors Affect it?
<https://www.youtube.com/watch?v=lxHMJaXOzP4>

Amoeba Sisters: Diffusion
<https://www.youtube.com/watch?v=jhszFBtBPoI>

Facilitated diffusion

The properties of the cell membrane make it difficult for the molecules of many substances to diffuse across it. The presence of two types of integral proteins; channel proteins and carrier proteins, assist here. This is still a form of diffusion because molecules move from high concentrations to lower concentrations and an input of energy is not required. **Facilitated diffusion** allows substances to cross membranes more quickly. Substances that enter cells by facilitated diffusion include those with hydrophilic molecules (e.g. glucose and certain drugs) and ions (e.g. sodium and potassium ions). Refer to *Figure 244 (a) and (b)* illustrating facilitated diffusion.

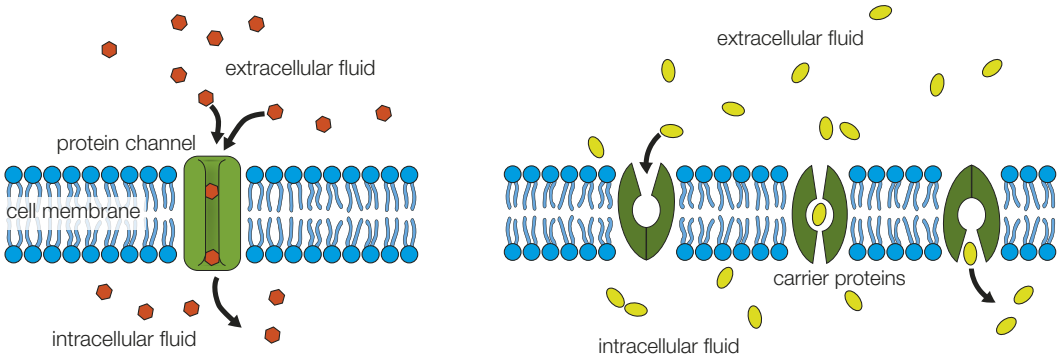


Figure 244 (a) and (b) Facilitated diffusion

Figure 244(a) represents a channel protein which provides a pore or channel for those molecules that are unable to freely diffuse across the cell membrane. *Figure 244*(b) represents a carrier protein. These carrier proteins generally bind to a specific molecule which then changes its shape and then releases the molecule inside the cell.

Facilitated diffusion:

- uses proteins in the phospholipid bi-layer
- does not require an input of energy and involves molecules or ions moving down the concentration gradient and has a degree of specificity e.g. aquaporins discussed in Chapter 2.1 that transport water.

Helpful online resources

Medical Animations: Detailed Animation on Facilitated Diffusion

<https://www.youtube.com/watch?v=kK-N8jUH5Xs>

Osmosis

Osmosis is the name for the diffusion of water from an area of high water concentration to an area of low water concentration. The movement of water differs to the aforementioned diffusion processes, because the movement of water is also affected by the concentration of solutes. Therefore, water molecules will move from a low solute concentration (high water concentration) to a high solute concentration (low water concentration) through a semi-permeable membrane. The process is **passive** and results in an equal solute concentration on either side of the membrane.

When two solutions have the same solute concentration on either side of the membrane they are said to be **isotonic**. Water molecules will move across the membrane in both directions but there will be no nett movement. If the external solution is **hypotonic** it means that there are more free water molecules (low solute concentration) and hence water tends to move into the cell. If the external solution is **hypertonic**, it means it has a greater solute concentration and thus less free water molecules (high solute concentration) and hence water moves out of the cell.

In *Figure 245*, the solution on the right is fully hypotonic (i.e. no solute; all water molecules), whereas the solution on the left is hypertonic, because it has many water molecules with solute bound to it, leaving very few free water molecules. As a result, there is a nett movement of water from the right to the left. The blue structure represents a semi-permeable membrane, permeable to water but not solute molecules. Generally, osmosis will have a greater impact on animal cells which may burst, as they lack the cell wall of a plant cell which makes them more rigid. The pressure causing the water to move in the direction it does is called the **osmotic pressure.**

Figure 246 shows the effect of osmosis when red blood cells and plant cells placed in solutions of different solute concentrations.

Water molecules can move directly through the phospholipid bi-layer or through specific channel proteins called **aquaporins**. Aquaporins help regulate the movement of water into and out of cells. One example of the importance of aquaporins is in the kidneys. When an individual is dehydrated, the brain increases the release of a hormone called anti-diuretic hormone (ADH). ADH signals the kidneys to increase the number of aquaporins in the nephron to reabsorb more water back into the capillaries. This is explored further in Chapter 3.3.

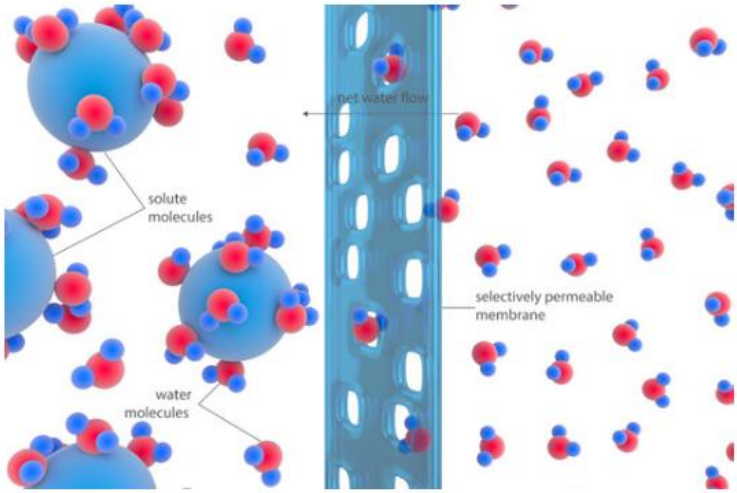


Figure 245 The process of osmosis

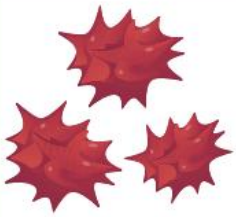
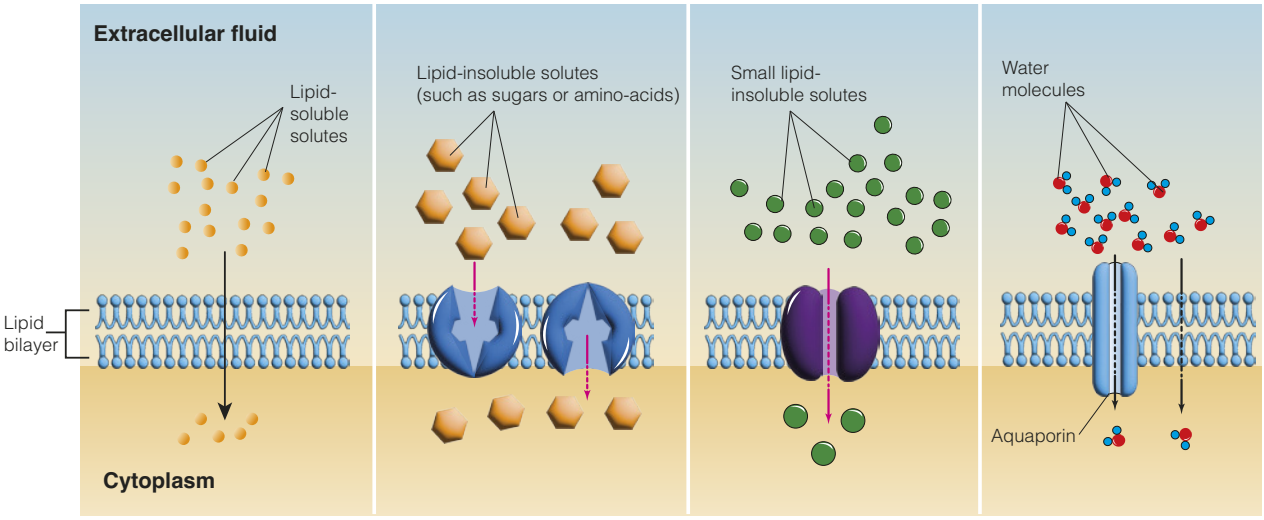
	Hypertonic Solution	Isotonic Solution	Hypotonic Solution
Human Red Blood Cells			
	Shriveled cells	Normal cells	Cells swell and eventually burst
Plant Cells			
	Cell body shrinks from cell wall	Flaccid cell	Normal turgid cell

Figure 246 The effects of osmosis on the human red blood cells and plant cells when placed in differing solute concentrations



a) Simple diffusion of fat-soluble molecules directly through the phospholipid bilayer

b) Carrier-mediated facilitated diffusion via carrier specific for one chemical; binding of substrate causes transport protein

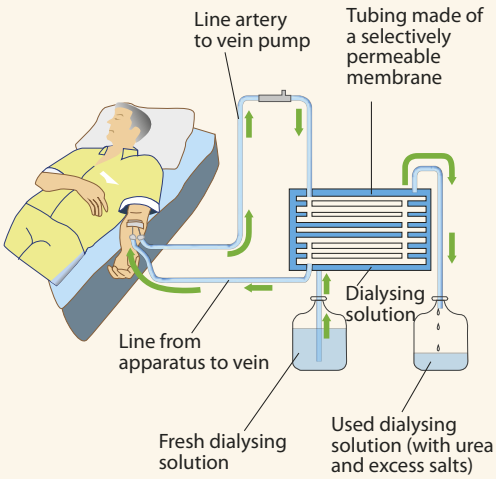
c) Channel-mediated facilitated diffusion trough a channel protein; mostly ions selected on basis of size and charge

d) Osmosis, diffusion of a solvent such as water through a specific channel protein (aquaporin) or trough the lipid bilayer

Figure 247 A visual summary of the differences between the different types of passive transport

Information about kidney dialysis

A practical application of the principles of diffusion and osmosis can be seen in the process of kidney dialysis. Osmosis is utilised is with kidney dialysis which artificially mimics the function of the human kidney by using appropriate membranes and diffusion gradients. The kidneys remove waste and surplus water and minerals from our blood. Without this function, serious illness and death will follow. Fortunately, dialysis is a process available to people without (fully) functioning kidneys. *Refer to the diagram to the right.*



In dialysis, a patient's blood is passed over a selectively permeable membrane. On the other side of the membrane is a solution of water, glucose and salts. Waste (e.g. urea) and surplus minerals from the blood will diffuse through the membrane (since their concentration will be lower in the dialysis fluid), leaving the patient's blood free of waste. Red blood cells and large molecules (e.g. proteins) are too large to diffuse through the membrane. Filtered blood (at the right temperature) is returned to the patient's vein.

Helpful online resources

Cognito: GCSE Biology - What is Osmosis?

<https://www.youtube.com/watch?v=vCJVXYmXkzM>

Amoeba Sisters: Osmosis and Water Potential (Updated)

<https://www.youtube.com/watch?v=L-osEc07vMs>

Active processes

Active transport

Active transport is a process in which solutes are moved **against the concentration gradient** i.e. they move from areas of low concentration to areas of high concentration. This is not a passive process and thus an input of **energy from the breakdown of ATP is required.** This is made possible using the carrier proteins previously mentioned, but in this case energy is required for a conformational change in the shape of the protein to pump the molecules either into or out of the cell.

Figure 248 illustrates the action of a carrier protein (green), involved in moving solute out of the cell against the concentration gradient. It can also be seen that ATP breaks down to ADP plus Pi, releasing energy for the process. This process is involved in the movement of sodium and potassium ions in the generation and transmission of nerve impulses through nerve cells in animals called neurons (located in bundles inside nerves).

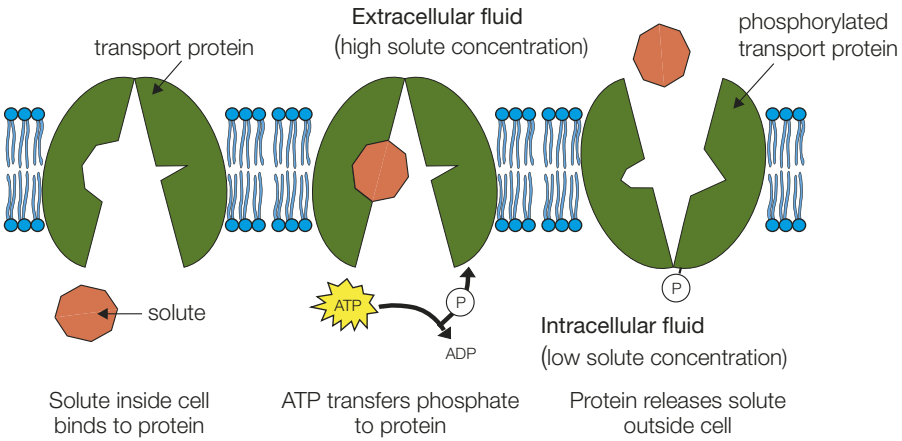


Figure 248 The process of active transport

Another example is seen in the small intestine of humans where glucose may first move into the blood by diffusion (through villi) but when the concentration is lower in the small intestine, compared to the cells that absorb glucose, active transport is used.

Helpful online resources

Cognito: GCSE Biology - Active Transport

<https://www.youtube.com/watch?v=tM0bGaaQ2jY>

Endocytosis and exocytosis

In *Figure 241* it was noted that there are several large molecules, in particular proteins, polysaccharides and nucleic acids, that cannot move in or out of cells either through the phospholipid bilayer or via the integral proteins involved in transporting molecules through the cell membrane.

Endocytosis is the process in which large molecules (or particles in bulk) are taken into the cell. Essentially, vacuoles (or vesicles) form from the cell membrane as a section of the membrane forms a small depression that encloses the molecules that are to move into the cell (invagination). The cell membrane fuses and the vesicle is pinched off and moved by the cytoskeleton into the cell. This is represented in *Figure 249*.

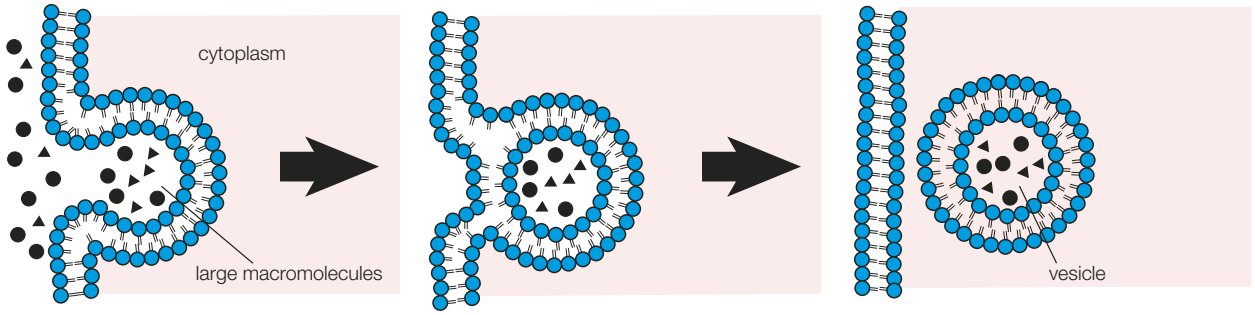


Figure 249 The process of endocytosis

Examples of endocytosis include:

- white blood cells, called phagocytes (macrophages), engulfing a bacterium to destroy it
- cells of the small intestine ingesting lipid droplets

Exocytosis is the process in which large molecules (or particles in bulk) are transported out of the cell. This could be seen as the opposite process to endocytosis. Molecules are packaged inside vesicles which are then transported to the cell membrane by the cytoskeleton. These fuse with the cell membrane which then opens to release the molecules outside of the cell. This process is represented in *Figure 2410*.

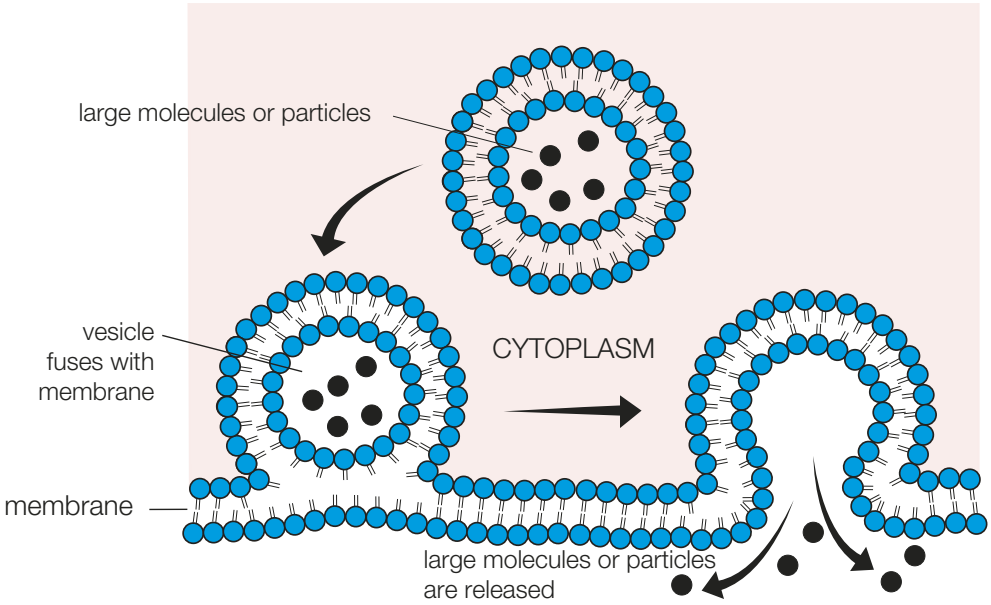


Figure 2410 The process of exocytosis

Examples of exocytosis include:

- hormones made inside cells that are secreted into the bloodstream e.g. cells in the pancreas that secrete insulin
- the release of digested cell debris by lysosomes

Helpful online resources

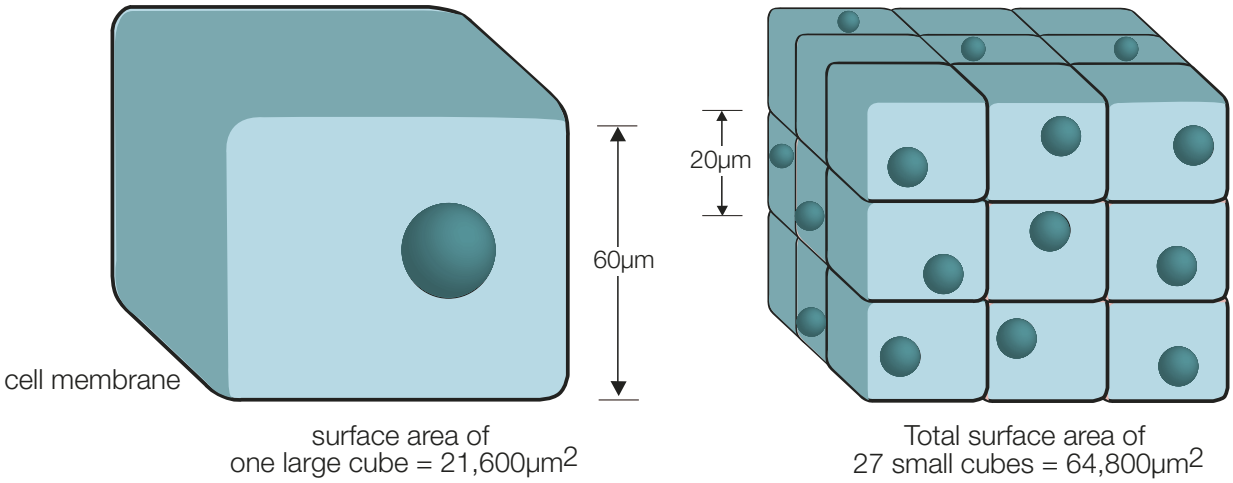
Osmosis: Endocytosis and Exocytosis
<https://www.youtube.com/watch?v=HMbNAKUX3i4>

Richochet Science: Active, Passive, and Bulk Cell Transport
<https://www.youtube.com/watch?v=BGeSDI03aaw>

Factors affecting the exchange of materials

Surface area to volume ratio

The surface area to volume ratio (SA:V) is an important concept relating to the exchange of materials by cells. The ratio is a numerical value that represents the relationship between the external surface area of a cell's membrane and the volume of the cytoplasm. Essentially, the larger the SA:V, the greater the efficiency of the exchange of materials (excluding other limiting factors e.g. temperature, concentration gradients). It is a fact that as cells grow larger they will have less cell membrane area relative to the volume of the cytoplasm. Refer to *Figure 2411 (a) and (b)*.



Figures 2411(a) and (b) The effect of cells of different sizes on SA:V ratio

With reference to *Figure 2411*, if a 60 micrometre (µm) cube shown in *Figure 2411 (a)* is cut into 27 smaller cubes, the total volume would be the same in each case, but there is obviously a much greater surface area in *Figure 2411 (b)*. The shape of a cell also affects the SA:V. Cells that are very long, thin or flat tend to have more cell membrane area relative to the volume of the cytoplasm.

In summary, cells with a larger SA:V are able to obtain nutrients and dispose of their waste more efficiently. Most cells are microscopic so as to maximise the SA:V ratio.

Concentration gradient

The greater the difference in concentration on either side of the cell membrane is termed a greater concentration gradient. Effectively, the greater the concentration gradient, the more rapid the rate of diffusion.

Figure 2412 represents the effect of substrate concentration on the rates of both simple and facilitated diffusion.

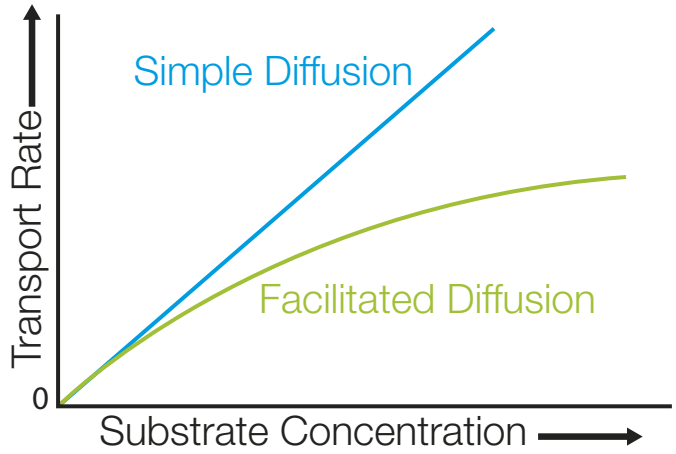


Figure 2412 The effect of concentration on the rates of diffusion

Diffusion is a linear relationship; the higher the concentration gradient, the faster the rate of diffusion, whereas, as can be seen with facilitated diffusion at high concentrations, the rate of diffusion tends to reach a maximum beyond which no further increases in rate occurs, this is often referred to as a plateau.

This effect is due to the channel or carrier proteins being fully occupied (saturated) and thus unable to increase the rate of diffusion further. Organisms have developed structures and processes to help maximise concentration gradients across cell membranes and exchange surfaces and thus maximise the rate of exchange of materials. An example of this is increasing the rate of blood flow through capillaries in the lungs to maximise diffusion of oxygen from alveoli into the blood.

Nature of the substances being exchanged

Both the physical (in particular, size) and the chemical nature of molecules influences their ability to move across the cell membrane and the manner in which they do so.

Some relevant knowledge has already been presented:

- In Chapter 2.1 where the structure and chemical composition of the membrane was studied in some detail.
- Earlier in this chapter, *Figure 241* grouped molecules according to their permeability, based both on size and chemical composition.

Below is a short summary in point form of the main physical and chemical properties of molecules that influence their movement across membranes. The two characteristics of the cell membrane that are largely responsible for the selective nature of the exchange are the lipid nature of the membrane and the two types of transport proteins embedded in it.

- Small, uncharged molecules will generally move more easily across the cell membrane by diffusion, whilst larger molecules, like proteins or nucleic acids, are transported by processes such as endocytosis or exocytosis.
- Molecules that dissolve in lipids are generally able to move through the cell membrane by diffusion.
- Most water-soluble (or polar) molecules have difficulty moving through cell membranes and will need to go through by facilitated diffusion (e.g. glucose, amino acids).
- Ions (e.g. sodium and potassium ions) will not move easily and will require a type of transport protein associated with facilitated diffusion.
- Water moves slowly through the phospholipid bilayer but more rapidly through specific aquaporins.
- Some molecules bind selectively with carrier proteins and these actively pump them across the cell membrane.

Helpful online resources

Cognito: GCSE Biology - Surface Area to Volume Ratio
<https://www.youtube.com/watch?v=HMbNAKUX3i4>

2.4 Review questions

Multiple choice questions

1. Which of the following is a cellular process which depends on the energy provided by ATP?
   - J osmosis
   - K protein synthesis
   - L binding of a hormone to a cell receptor molecule
   - M diffusion of oxygen into a cell
2. The packaging and transport of macromolecules inside a cell could involve
   - J the movement of vesicles containing the macromolecules by the cytoskeleton.
   - K the transport of the molecules from the Golgi apparatus to the endoplasmic reticulum.
   - L the process of exocytosis.
   - M the in-folding of the cell membrane to form a vesicle.
3. Which of the following statements regarding diffusion is not correct?
   - J Increasing the temperature usually increases the rate of diffusion.
   - K The greater the concentration gradient the faster the rate of diffusion.
   - L Diffusion is a passive process.
   - M The rate of diffusion is not influenced by the chemical composition of the molecule diffusing.

4. Red blood cells have an internal solute concentration of approximately 0.9%. Which of the following statements correctly describes what will happen to red blood cells when they are placed in a 2% salt solution.

   J the red cells will shrink due to osmosis

   K the red cells will swell due to osmosis

   L the red cells will shrink due to the movement of salt out of the cell

   M the red cells will swell due to the movement of salt into the cell

5. *Refer to the following table which shows the surface area (arbitrary units) and volume (arbitrary units) for each of 4 cells J, K, L and M.*

   Which cell would gain the most mass if placed in distilled water?

Cell	SA	Volume
J	2000	500
K	8000	3000
L	5000	900
M	1100	400

6. *Refer to the diagram below which shows a food particle being ingested by a cell.*

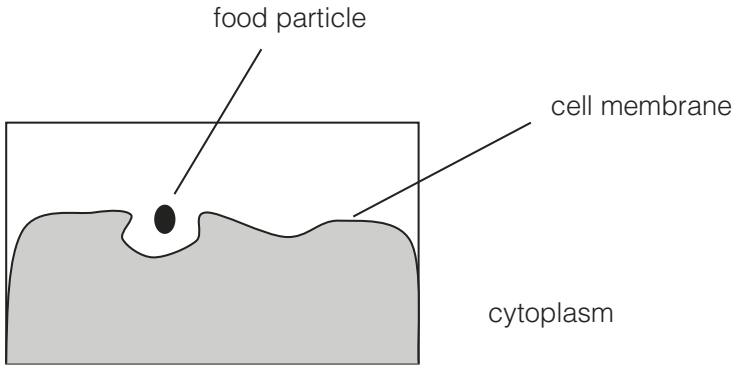
   Which of the following statements is correct?

   J A hole forms in the membrane to allow access by the food particle.

   K The movement is termed exocytosis.

   L The cytoskeleton is involved in the process.

   M Because of its large size, the food particle is unable to enter the cell contents.



7. Which of the following statements regarding facilitated diffusion is correct?

   Facilitated diffusion:

   J is facilitated by energy in the form of ATP.

   K is the passive movement of molecules against the concentration gradient.

   L allows very large substances such as bacteria to move through the cell membrane.

   M is diffusion of substances through transmembrane proteins.

8. *Refer to the following table, which shows the normal concentration of sodium and potassium ions in a tissue cell and in the surrounding fluid.*

	Concentration (mM / dm^3)	
Ion	Cytoplasm	External tissue fluid
Potassium	125	10
Sodium	30	140

   Which one of the following statements is supported by the data?

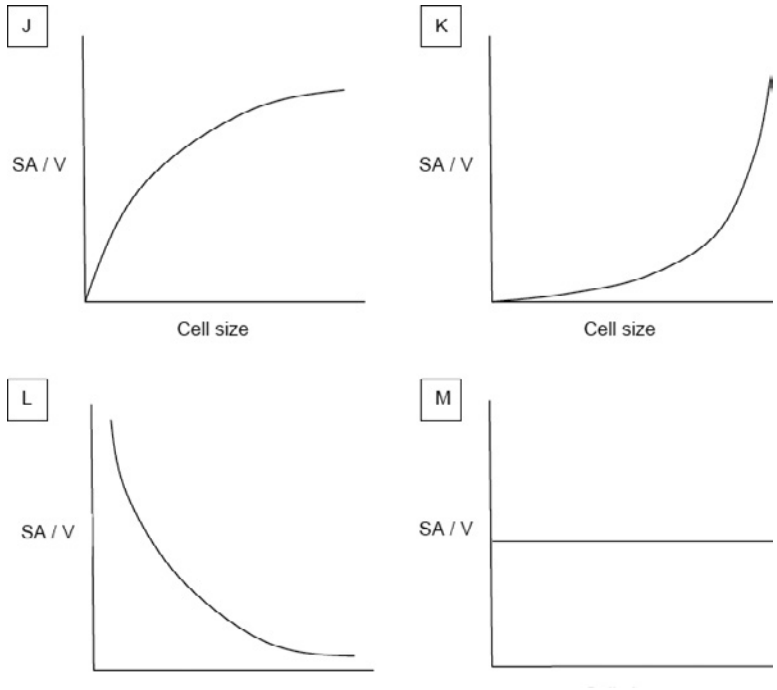
   J An active process would be required to transport potassium across the membrane and into the cell.

   K Sodium ions are too large to diffuse into the cell.

   L Sodium ions are moved out of the tissue cells by a passive process.

   M Potassium ions accumulate inside tissue cells by passive means.

9. Which of the following graphs best represents how the surface area to volume ratio (SA/V) changes with an increase in cell size?



10. *Refer to the diagram below of a plant cell to answer the question that follows.*

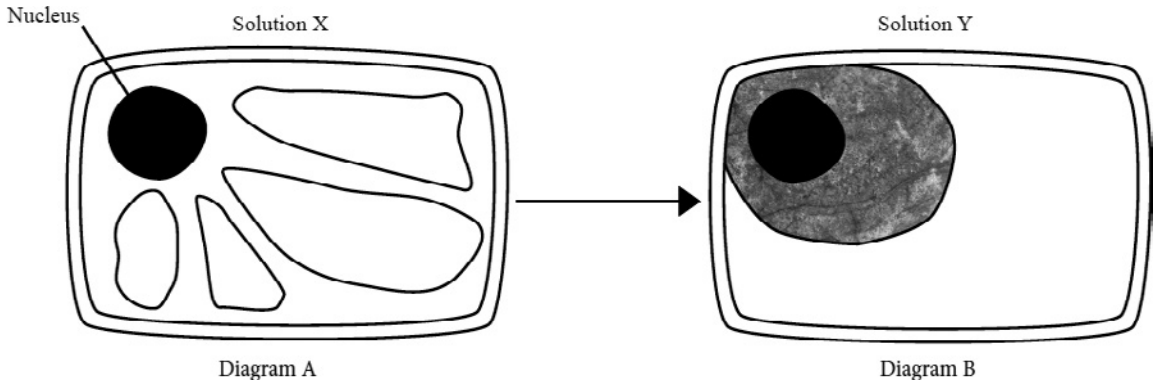


Diagram A represents the cell as it was observed after being placed in solution X for 10 minutes. The cell was then transferred to solution Y and observed after 10 minutes. The result is shown in Diagram B.

Which of the following is most likely to be true?

J Solution Y has a higher solute concentration than solution X

K there has been a nett influx of water into the cell after being placed in solution Y

L there has been a nett loss of salts from the cell in solution Y

M Solution X would eventually cause the cell to die

11. Which one of the following statements is true concerning the processes of endocytosis and exocytosis?

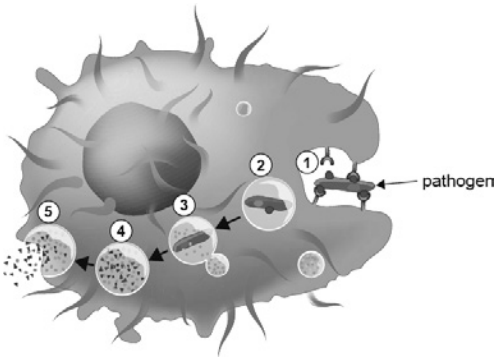
J There is no net loss or gain of the plasma membrane during endocytosis or exocytosis.

K During exocytosis there is a net loss in the size of the plasma membrane.

L During endocytosis there is a net loss in the size of the plasma membrane.

M During endocytosis there is a net gain in the size of the plasma membrane.

12. The diagram shows the process of phagocytosis (a form of endocytosis). This process is vital for immunity against pathogenic infections.



What is happening at position 1?

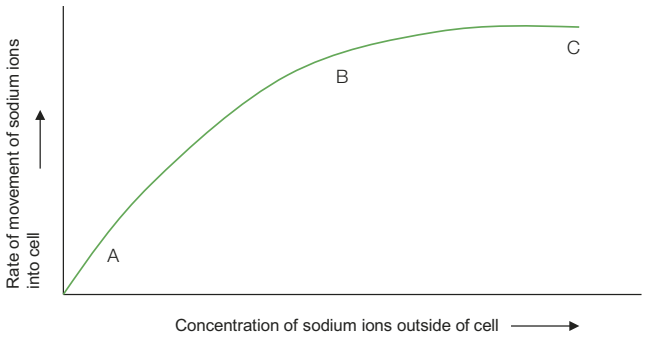
J The pathogen has been engulfed via endocytosis.

K Antigen recognition is occurring at the cell membrane.

L The cell is sampling the vesicle for antigen presentation.

M Intracellular microbes are attacking the microorganism.

13. *Refer to the graph below showing the effect of increasing the concentration of sodium ions in solution on the rate of uptake of sodium into the cell to answer the question that follows.*



The most likely reason for the plateau in the graph between points B and C is:

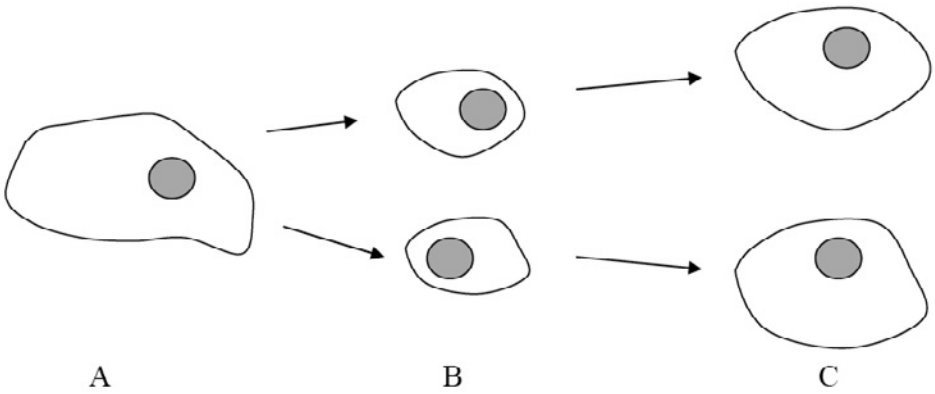
J the rate of active transport has slowed as energy is in short supply

K the rate of diffusion slows as the concentration of sodium ions inside the cell matches the concentration in solution

L the rate of active transport slows as the concentration of sodium ions inside the cell matches the concentration in solution.

M the rate of diffusion slows as the cell has an ample supply of sodium ions

14. *Refer to the diagram below which shows cell division and enlargement of cells in an organism.*



Which one of the following statements is correct?

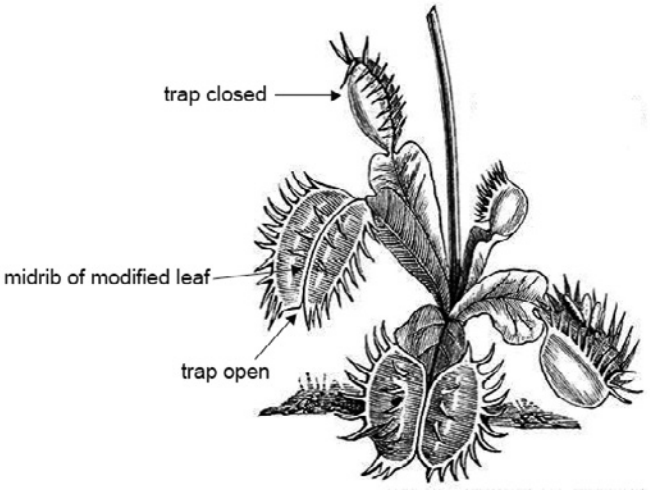
J cells at B would have a faster rate of osmosis than cell A as their surface area to volume ratio is smaller

K cells at B would have a faster rate of osmosis than cell A as their surface area to volume ratio is larger

L cells at C would have a faster rate of osmosis than cells at B as their surface area to volume ratio is larger

M cells at C would have a slower rate of osmosis than cells at B as their surface area to volume ratio is larger

15. *Refer to the diagram below to view the labelled parts of this plant and answer the following question:*



Some plants have modified forms of leaves, called traps. These traps can open and close to trap insects. The midrib of the modified leaf (see diagram) contains motor cells that are turgid at rest. When an insect enters the trap, potassium ions flow out of the motor cells along the concentration gradient through channels. This causes the motor cells to lose their turgidity, and the resultant pressure in surrounding cells causes the trap to close trapping the insect.

Which one of the following statements with regards to the opening and closing of the plants traps is correct?

J Water enters the motor cells by osmosis when the trap is closing

K Water enters the motor cells by active transport when the trap is opening.

L Potassium ions enter the motor cells by active transport when the trap is opening.

M Potassium ions flow out of the motor cells by osmosis when the trap is closing.

Free response questions

1. It is important for cells to carefully control the exchange of substances with the external environment.

   a) Describe why this is important, using examples to illustrate your answer.

   b) 'Inputs and outputs of substances differ in cells depending on whether they are from an autotrophic or a heterotrophic organism.' Explain the meaning of this statement, using examples to illustrate your answer.

2. Describe the two most important properties of cell membranes that influence the movement of molecules in and out of cells.

   a)

   b)

3. Diffusion and osmosis are both passive processes

   a) State what it means to say that diffusion and osmosis are passive processes.

b) Explain why, unlike diffusion, osmosis only occurs across a cell membrane.

4. Cells often maintain the concentrations of substances in the internal environment so that it differs from the concentration in the external environment. Describe why active transport is the most likely process responsible for this difference.

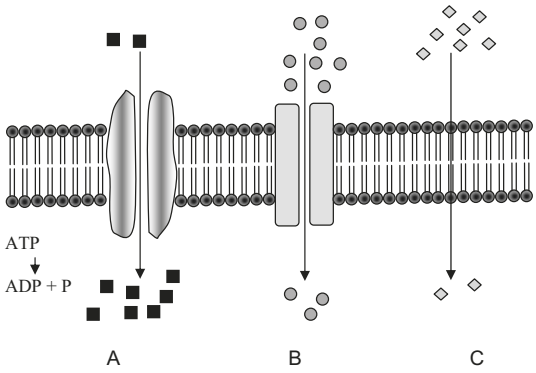
5. Carrier proteins are integral proteins in the cell membrane that can transport materials either into or out of cells.

   a) State the two processes by which the molecules or ions of substances move through carrier proteins.

   b) Explain how the two processes could be distinguished.

6. Explain why a larger cell exchanges substances less efficiently with the environment when compared to a smaller cell.

7. *Refer to the diagram below representing three types of movement across a plasma membrane.*

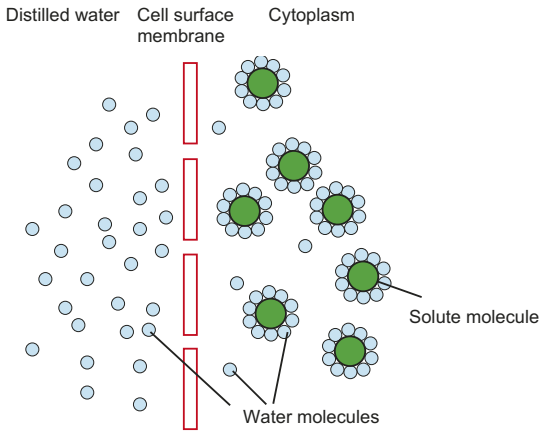


   a) State the type of movement represented by B and C.

   b) State the difference between the movements shown in B and C.

c) Explain why the breakdown of ATP into ADP is necessary for movement A to occur.

8. *Refer to the diagram below to answer the questions that follow:*



a) Explain why the nett movement of water molecules would be from the distilled water into the cytoplasm of the cell.

b) Explain why the impact of this movement is usually more significant for animal cells when compared to plant cells.

9. State how each of the following substances may be transported across the cell membrane in the situation outlined:

a) Water moving into a root hair cell from damp soil.

b) Nitrate ions moving into a root hair cell from soil that contains very low concentrations of nitrate ions.

c) Epithelial cells lining the small intestine absorbing lipid droplets.

d) A white blood cell, called a phagocyte, ingesting a bacterial cell.

e) CO_2 moving from muscle cells into the bloodstream.

f) Glucose moving from blood into a liver cell down the concentration gradient.

10. Endocytosis and exocytosis are types of movement of substances involved in what is often termed 'bulk transport'.

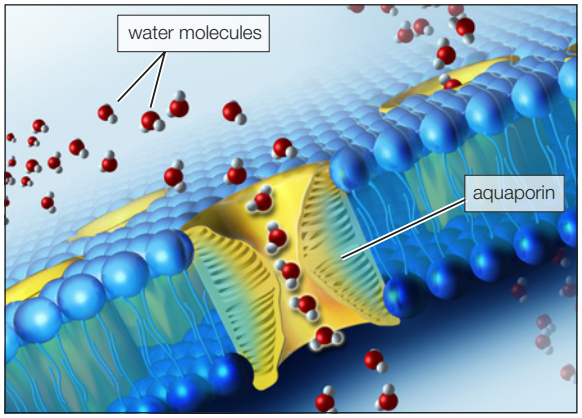
    a) Predict why the term 'bulk transport' might be appropriate here.

    b) Both of these processes are active means of moving molecules. Explain why this is the case.

    c) Describe the property of the cell membrane that makes endocytosis and exocytosis possible.

    d) 'Due to vesicles fusing with and particles being engulfed by the cell membrane, the actual size of the membrane temporarily changes during these processes.' Use your understanding of these processes to justify the above statement.

11. *Refer to the diagram below illustrating osmosis to answer the questions that follow:*



    a) Describe what situation is giving rise to the nett movement of water into the cell as depicted here.

    b) Propose the most likely reasons why the water molecules are moving through the aquaporin and not the phospholipid bilayer directly.

12. The SA:V ratio is an important factor determining the efficiency of the exchange of substances between the cell and its environment.

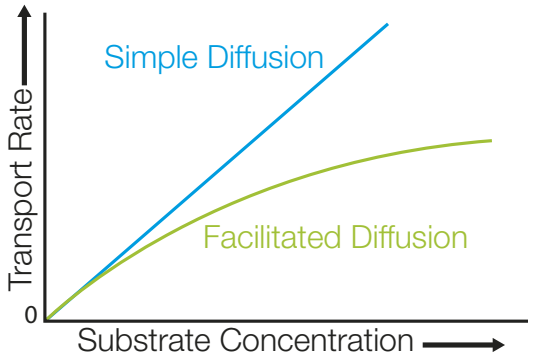
a) Complete the following table to calculate the SA:V for three different size cubes.

Edge length (cm)	Total area (cm^2)	Volume (cm^3)	SA:V
6			
2			
1			

b) Provide one conclusion relating the size of the cube compared to its SA:V.

c) Red blood cells are very small and have an extensive cytoskeleton to provide a bi-concave (flat and disc-like) shape. Explain why red blood cells have these structural features.

13. *Refer to the graph below to answer the question that follows:*



a) With reference to the graphs, describe the effect concentration gradient has on simple diffusion, compared to facilitated diffusion.

b) With reference to the graphs, explain why facilitated diffusion does not exhibit the same pattern of results as simple diffusion.

Chapter 2.5 Cell metabolism

Science Understanding

Cell metabolism is critical to the survival of cells.

Biochemical processes in the cell are influenced by the nature and arrangement of internal membranes and the presence of specific enzymes.

- Explain how the structure of internal membranes of mitochondria and chloroplasts facilitates some biochemical processes.
- Explain that in a metabolic pathway:
  - there are many regulated steps
  - each step loses some energy as heat
  - some steps produce intermediate compounds
  - specific enzymes are required at each step.
- Biochemical processes in the cell are influenced by environmental factors.

Chemicals can interfere with cell metabolism.

- Discuss possible benefits and/or harmful effects of chemicals that human beings use.

Metabolism and metabolic pathways

Enzymes and cell **metabolism** were studied in Chapter 1.4. This chapter focuses on factors that influence biochemical processes, as well as the effects of some substances that humans use. Nonetheless, a summary will be included here of the important points relevant to the required background knowledge.

Refer to Chapter 2.3 regarding energy transformations, particularly photosynthesis, aerobic respiration and fermentation.

Metabolism refers to all of the biochemical reactions occurring in an organism and is critical to the survival of cells and thus, to the organisms as a whole.

Most biochemical reactions in cells occur in what are termed **metabolic pathways,** where the substrate for the first reaction is converted to a product by the first enzyme. This product is the substrate for the second reaction and so forth. The sequence of chemical conversions of substrates into products continues until the end-product is made.

Each step in the pathway is catalysed by a **specific enzyme,** as each new substrate has its own specific shape and can only bind to the active site of its own enzyme.

Biochemical processes that take place as a result of many regulated steps in metabolic pathways provide a few important advantages for cells:

- The cell can exert a greater level of control of the reaction with a different enzyme at each step.
- Other substrates can ‘feed in’ at different points in the pathway, allowing cells to utilise other resources.
- Some steps produce **intermediate products** that are often essential molecules needed by cells.
- The cell can release energy more gradually, a portion of which which can be trapped in energy coupling processes, such as ATP synthesis.

During each step in a metabolic pathway some chemical energy is transformed into heat, which can be used to maintain stable body temperatures in many organisms, including humans.

Refer to *Figure 251* that is a representation of a simple metabolic pathway. There are three different shaped enzymes and two intermediate products and one end product at different stages along the pathway. The concept of end product inhibition has been studied previously in Chapter 1.4 but will be mentioned again later in this chapter.

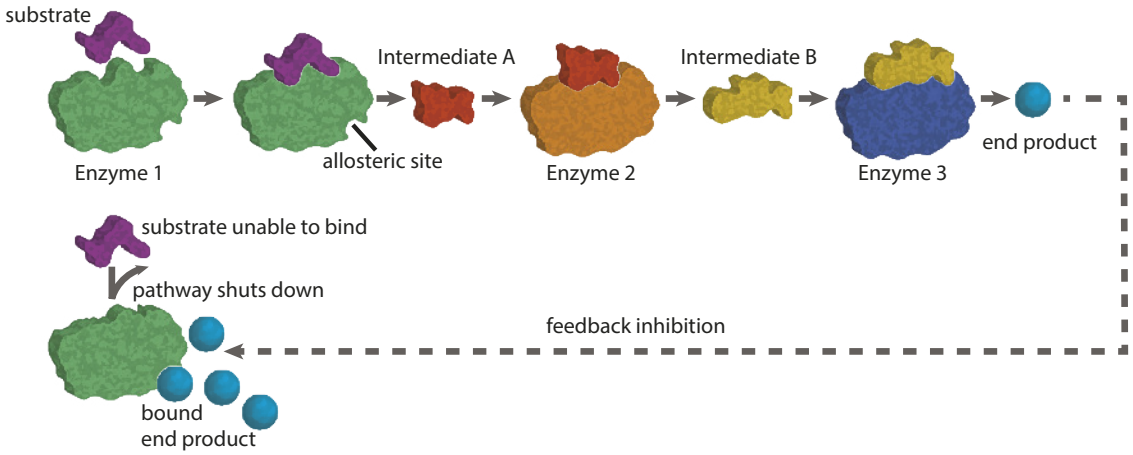


Figure 251 An example of a simple metabolic pathway

Two types of metabolic pathways

Some metabolic pathways release energy by breaking down complex molecules to simpler ones. Aerobic respiration is a good example of this.

Other metabolic pathways chemically build complex molecules from simple ones. Photosynthesis in plants is a good example.

As a result of metabolic pathways, cells are able to carry out work. This includes:

- mechanical work e.g. contraction of muscle cells or the movement of chromosomes during mitosis
- transport work e.g. active transport of molecules against the concentration gradient
- chemical work e.g. synthesising critical macromolecules, such as proteins and nucleic acids.

Cells maintain this work by energy coupling. Metabolic reactions link energy releasing pathways to those that require energy with the immediate source of energy to drive the work being provided by molecules of ATP.

Two of the most important metabolic pathways that have already been studied are photosynthesis and aerobic respiration.

Refer to *Figure 252* for a summary of these reactions.

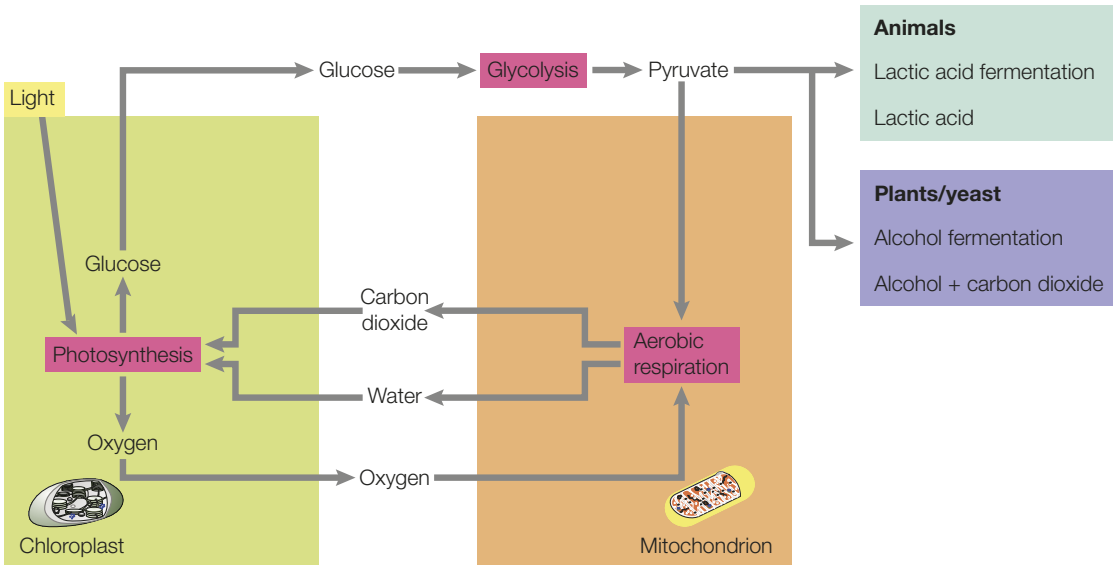


Figure 252 A summary of some important metabolic reactions

Figure 253 shows that glucose is converted into pyruvate during **glycolysis** prior to either entering mitochondria to carry out the rest of the aerobic respiration pathway (the **Krebs cycle** and the **electron transport chain**) or remaining in the cytoplasm and undergoing alcohol or lactic acid fermentation.

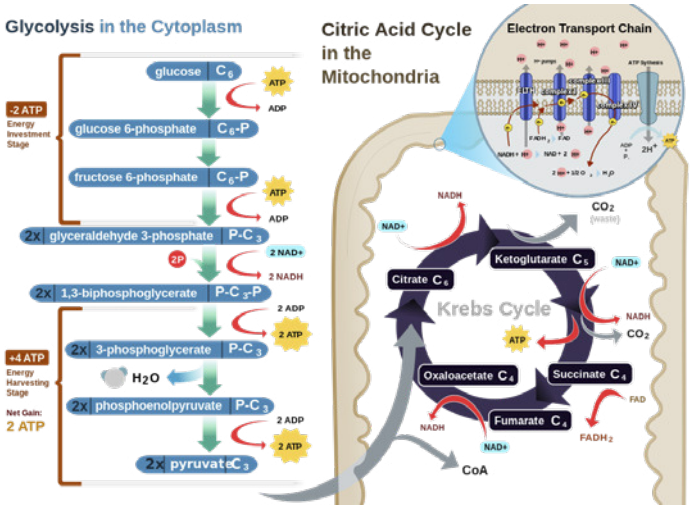


Figure 253 Glycolysis and other stages in aerobic respiration.

Note: The purpose of Figure 253 is not intended for student learning but merely to gain some appreciation of the complexity and multi-step nature of these metabolic pathways.

The usual word equation for glycolysis is as follows:

glucose → 2 pyruvate molecules

This reaction has a nett release of energy that enables two ATP molecules to be formed per molecule of glucose converted to pyruvate.

In reality, glycolysis is itself a metabolic pathway consisting of a series of reactions, some requiring ATP, others making ATP and each reaction with its own specific enzyme.

Helpful online resources

Stated Clearly: What is Metabolism?

<https://www.youtube.com/watch?v=nRq6N5NGD1U>

The site of aerobic respiration

The final two stages of cellular respiration i.e. Krebs cycle (also known as the Citric acid cycle) and the electron transport chain occur in the membrane-enclosed organelles called mitochondria.

Figure 254 shows a model representation of the internal structure of a mitochondrion. The Krebs cycle (refer to *Figure 253*) is a pathway of many steps which occurs in the **matrix** region of the mitochondrion. The electron transport chain occurs on folded inner membrane extensions embedded with enzymes called **cristae**. These provide the inner mitochondrial membrane a large surface area that facilitates aerobic respiration by enhancing its productivity of ATP. There are a number of key molecules, including enzymes, that are necessary for this final step and it is here that much of the energy release is used to make ATP.

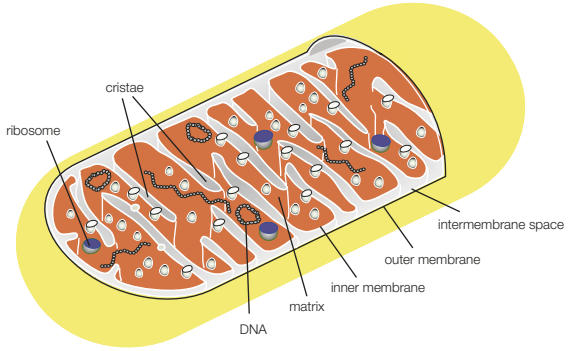


Figure 254 The internal structure of a mitochodrion

The site of photosynthesis

The nature and arrangement of internal membranes is important for photosynthesis in chloroplasts. The internal structure of a chloroplast, the site of photosynthesis in eukaryotic cells, is shown in *Figure 255*.

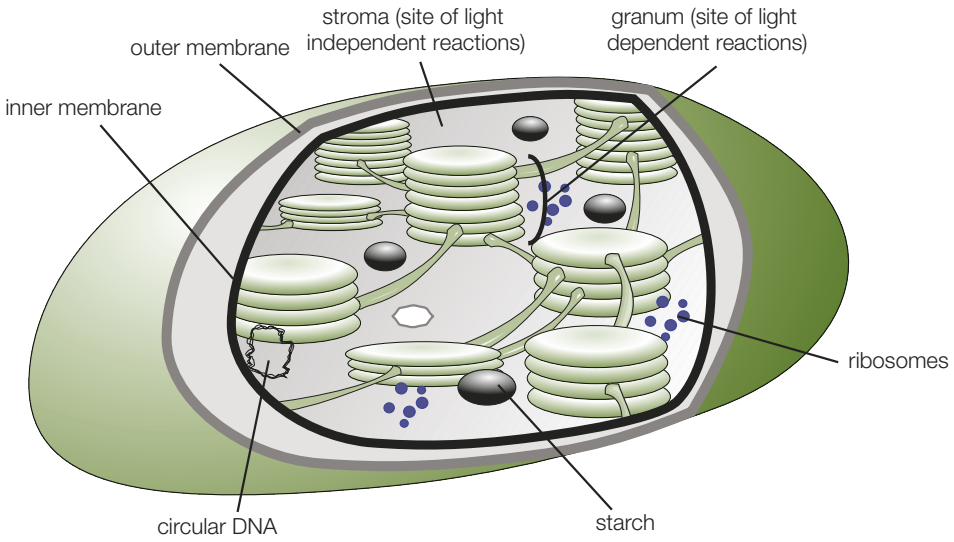


Figure 255 The internal structure of a chloroplast

Photosynthesis is also an example of a multi-step metabolic pathway, some of the reactions of which are dependent on light energy while others are not.

The **light-dependent reactions** occur on flattened sac-like membranes, called thylakoids, that contain chlorophyll and the enzymes that catalyse them. These are stacked like coins in a pile to form **grana**. Inside the grana, chlorophyll molecules are also stacked in many layers called lamellae. Lamellae are thought to facilitate photosynthesis by increasing the chance that light passing through a chloroplast will be absorbed by chlorophyll molecules.

The **light-independent stages** (not dependent on light) make up a pathway termed the **Calvin cycle**. This cycle occurs in the **stroma** and it is here that the organic molecule glucose is formed.

Importance of regulation of metabolic pathways

Aerobic respiration and photosynthesis are absolutely vital to the survival of organisms. These processes are tightly regulated to ensure they proceed efficiently without disruption. As both processes consist of many steps, each of which is catalysed by a specific enzyme, one way organisms achieve this efficiency is to keep the chemical composition and conditions within cells relatively constant.

Environmental factors influence metabolic pathways

Metabolic pathways in cells are influenced by specific enzymes and it is well-established that each enzyme works best at particular optimum conditions which will suit the active form of the molecule.

Some environmental factors that influence pathways are as follows:

- Temperature; as the temperature increases, kinetic energy increases as a molecules move faster and collide more frequently, increasing the chances of enzyme-substrate binding.
- At high temperatures the enzymes often denature, i.e. they lose their important three-dimensional shape, which is necessary for enzyme-substrate binding. Most human enzymes work best from 35-40°C.
- Each enzyme has an optimum pH, generally from pH 6-8, but some digestive enzymes in the stomach favour acidic conditions (pH = 2) and others in the intestines favour alkaline conditions (pH = 9)
- Some inorganic substances in the environment are **co-factors** for enzymes. These may bind to the active site or elsewhere on the enzyme, or with the substrate, and can include copper, iron and zinc ions. Organic molecules that are co-factors are called **co-enzymes,** with many vitamins acting in this way.
- Other molecules in the environment act as chemical inhibitors, either competitively or non-competitively, refer to Chapter 1.4 for examples.
- Many substances that are toxins and poisons have this effect because they act as chemical inhibitors of enzymes.

Other factors that influence metabolic pathways

The substrate concentration of individual metabolic reactions has a significant influence on any metabolic pathway. If the substrate concentration is too low, the overall efficiency of the whole pathway is affected. If the substrate concentration is too high, it may disrupt the internal environment of the cell, jeopardising the efficiency of the metabolic pathway by disrupting the progress of other metabolic reactions in the pathway.

Molecules that regulate metabolic pathways often bind in a reversible manner to what is termed an **allosteric site**; a region on the enzyme which is away from the active site. Binding of these molecules can stimulate or inhibit enzyme activity.

The concept of end-product inhibition (first discussed in Chapter 1.4) illustrates how a molecule that is an end-product of a metabolic pathway can bind to an allosteric site of an enzyme. This inhibits the reaction by changing the shape of the active site stopping the action of the particular enzyme. This is also referred to as feedback inhibition and a product acting in this manner (sometimes called an allosteric modulator) provides a way for metabolic pathways to be shut down when the product is no longer required. This is illustrated in *Figure 251*.

Helpful online resources

Jaqscimedia: Enzymes, Feedback Inhibition, and Allosteric Regulation":
<https://www.youtube.com/watch?v=LKiXfqaWNHI>

Photosynthesis

Photosynthesis is influenced by a number of environmental factors. *Figure 256* illustrates some summary graphs showing the effects of four environmental factors on the rate of photosynthesis.

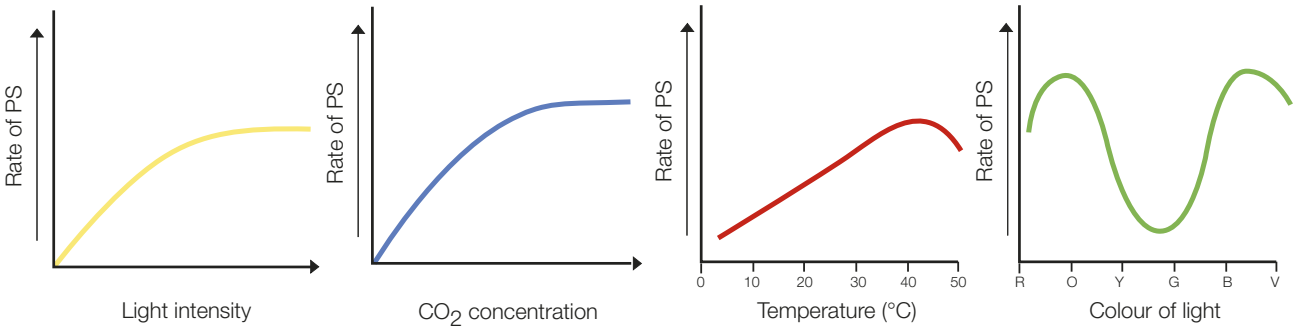


Fig 256 Factors affecting photosynthesis

Helpful online resources

Cognito: GCSE Biology - Factors Affecting the Rate of Photosynthesis
<https://www.youtube.com/watch?v=J0KxRX3fyol>

Chemicals can interfere with cell metabolism

A multitude of chemicals from the environment interact with metabolic pathways in all organisms, some of which benefit humans, whilst others are harmful. This section will briefly mention a few of these chemicals.

The concept of enzyme inhibition by chemical inhibitors has been discussed in this book and is one of the ways chemicals interfere with metabolic pathways. The binding of chemical inhibitors to enzymes can be reversible or irreversible. Irreversible inhibitors often react with an enzyme and can chemically alter the structure of individual amino acids that play a role in determining the precise shape and therefore functional activity of the enzyme. Many drugs are chemical inhibitors of enzymes and, as such, this is an important area of medical research.

Poisons

Substances that are harmful to organisms are called poisons. Many poisons work by inhibiting enzymes involved in metabolic pathways e.g. mercury and lead.

Cyanide

Potassium cyanide is an irreversible inhibitor of a key enzyme in the electron transport chain of aerobic respiration called, **cytochrome c** oxidase (complex IV). Cyanide competitively inhibits this enzyme by preventing the binding of oxygen at the active site. The poison binds to iron in the 4th complex of the electron transport chain of aerobic respiration and stops electron transport to oxygen. ATP production is a severely limited and usually results in death.

Malonate

Malonate is a poison that binds to the active site of the enzyme succinate dehydrogenase and acts as a competitive inhibitor of its substrate succinate. This enzyme is essential for both the Krebs cycle and the electron transport chain so its inhibition rapidly brings about cell death.

Herbicides

A chemical that is used to kill or greatly slow the growth of a plant pest is called a **herbicide**. In Chapter 1.4 a good example of a herbicide was presented in 'An agricultural application'. It was noted that glyphosate acts as a competitive inhibitor of an enzyme that catalyses a step in the important metabolic pathway that produces substances that plants need to grow. As a result of being sprayed with glyphosate, the plants die, usually within a couple of weeks. *Figure 257* illustrates the novel use of a herbicide to create a path through a crop.

Figure 257 Use of a herbicide

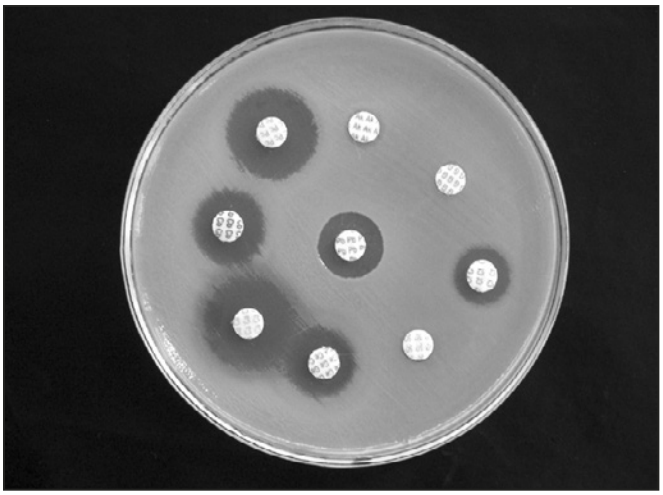


Figure 258 The effect of antibiotics

Medicines

Some enzyme inhibitors can be used for medicinal reasons. Enzyme inhibitors to the viral enzyme protease can act to slow or stop viral growth by preventing them building new protein coats.

The antibiotic penicillin works by inhibiting a bacterial enzyme, called transpeptidase, which is necessary for the proper development of the cell walls of new bacteria. In the pathway, penicillin is accepted as a substrate and irreversibly binds to the active site. Bacteria subjected to penicillin cannot form effective cell walls during binary fission and thus cannot reproduce or survive. See *Figure 258* which shows bacterial growth being inhibited by antibiotics on an agar plate.

Helpful online resources

HCVNEWDRUGS: How HCV protease inhibitors work
<https://www.youtube.com/watch?v=Gk143LIYYmE>

Insecticides

Chemicals that are used to kill insect pests are called **insecticides**. Many plants secrete naturally occurring insecticides that help them repel attack from insects. Humans use both naturally occurring and synthetic insecticides, as well as genetically modifying organisms (GMO) to produce insecticides to improve productivity in agriculture or assist in reducing the spread of disease. One of the best known insecticides, DDT, was introduced in 1944 and brings about its action by disrupting the transmission of nerve impulses by opening sodium channels in an insect's nerve cells. Today, however, the use of DDT is banned in many countries due to its tendency to accumulate to toxic levels in the cells of many types of animals, including humans. *Figure 259* illustrates spraying with an insecticide.

Figure 259 Using an insecticide to kill insects in a wood pile

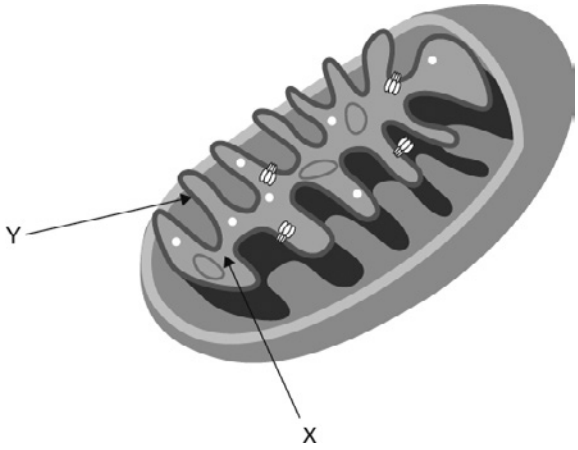
Helpful online resources

TED-Ed: Do we really need pesticides? - Fernan Pérez-Gálvez
<https://www.youtube.com/watch?v=GLIlZ-qiXJA>

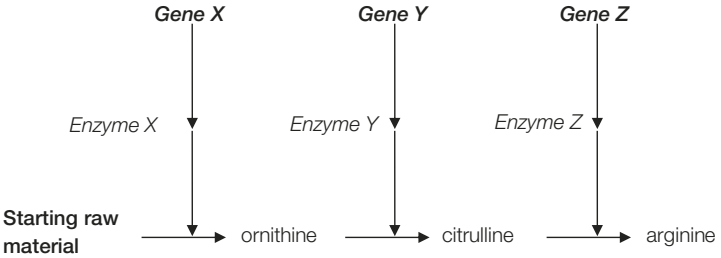
2.5 Review questions

Multiple choice questions

Refer to the following diagram of an organelle found in eukaryotic cells to answer Questions 1 and 2.



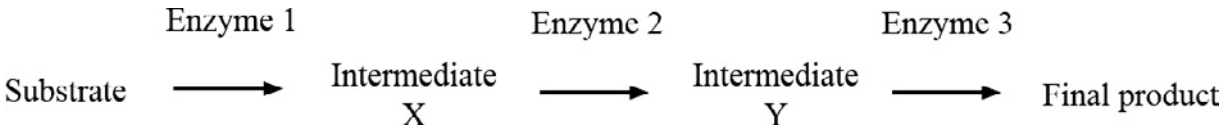
1. The region identified by X is named the:
   - J granum
   - K matrix
   - L stroma
   - M cristae
2. The structure identified by Y is where:
   - J light dependent reactions occur
   - K glucose enters glycolysis
   - L pyruvate is broken down into lactic acid
   - M the majority of ATP is produced in the cell.
3. Which of the following is not an advantage of having many small, regulated steps in a metabolic pathway?
   - J Intermediate products are formed which can be essential molecules to cells.
   - K Energy in the molecule is not all released at once.
   - L Cells have greater control over the reaction.
   - M The metabolic pathway cannot be inhibited by a competitive inhibitor.
4. *Refer to the diagram below showing a metabolic pathway involved in the production of the amino acid arginine in a mould named Neurospora.*



If a mutation occurred in gene X which prevented the formation of enzyme X, which substance(s) would be required to be present in the culture for the mould to survive?

- J starting material and ornithine
- K ornithine
- L arginine
- M all 4 substances

5. A substrate undergoes a series of enzyme-catalysed reactions to form intermediate substances X, Y and then the final product.



What effect would adding a **competitive** inhibitor to enzyme 2 have on this series of reactions?

J The activity of enzyme 3 would increase.

K The substrate would not react to produce intermediate X.

L The concentration of intermediate X would increase.

M No final product would be produced.

Free response questions

1. Explain the role of each of the following in metabolic reactions.
   a) Nucleus

   b) Mitochondria

   c) Enzymes

2. State three advantages for cells if metabolic pathways occur in many, regulated steps.
   a)
   b)
   c)
3. Name two medicines/chemicals that impact metabolic pathways and have beneficial outcomes for human use:
   a)
   b)
4. Describe three environmental factors that can impact biochemical processes.
   a)
   b)
   c)
5. Heat energy is released as a by-product of each step in metabolic pathways.
   a) Describe one reason why this occurs.

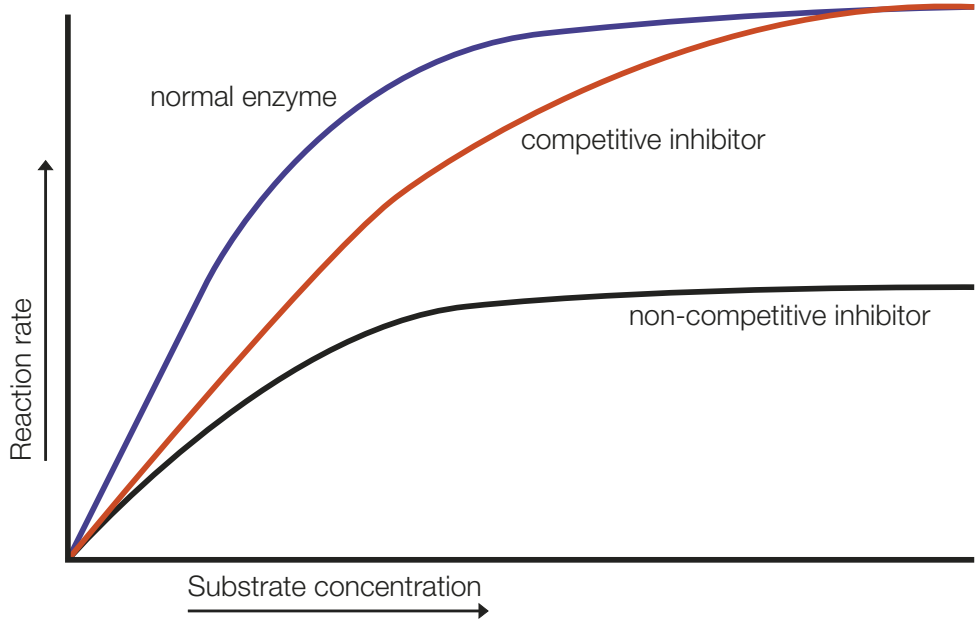
   b) Describe one advantage of this release for humans.

6. Important metabolic processes and, as a result, energy transformations, occur in the mitochondria and chloroplasts.

   a) Name the main internal membrane in each of these organelles.

   b) Explain why the internal membranes are important for the metabolic pathways occurring here.

7. *Refer to the graph below to help answer the question that follows:*

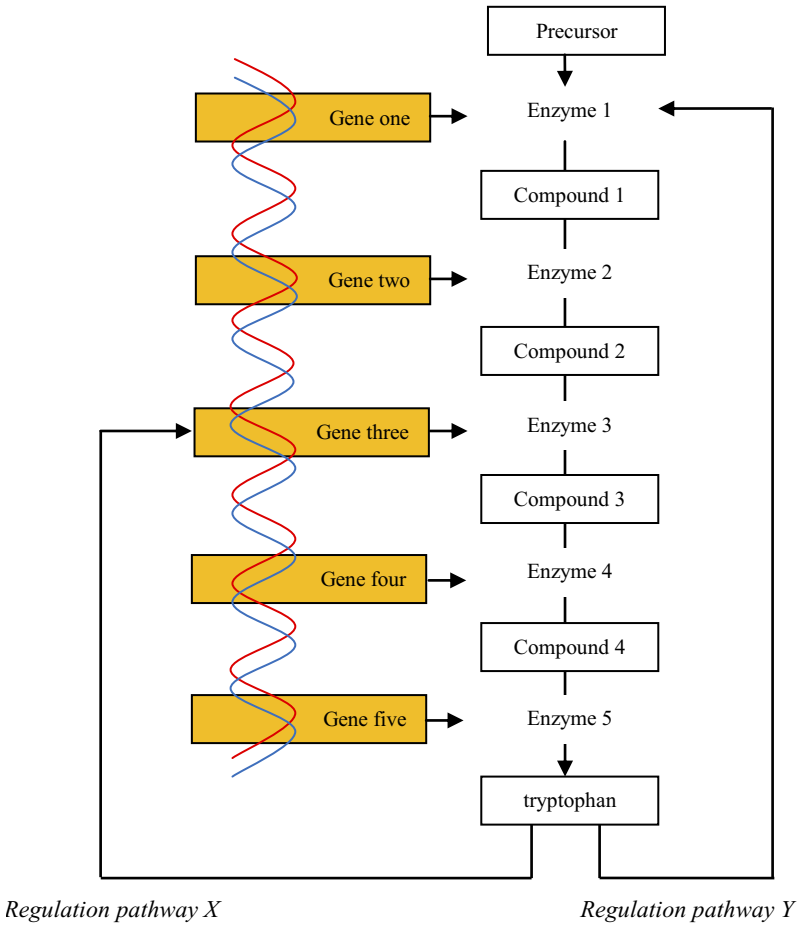


The graph indicates the effect of substrate concentration on the rate of reaction under three different conditions.

   a) Describe the pattern of results for the normal enzyme with no inhibitor present.

   b) With reference to the graphs, explain the results observed when the same enzyme was subjected to competitive and non-competitive inhibitors.

8. Bacteria in the human small intestines normally absorb amino acids from digested food. The diagram below illustrates how bacteria have the capacity to produce tryptophan if it is in short supply in the body. *Refer to the diagram below of a metabolic pathway showing the production of tryptophan and a series of intermediate compounds in a bacterial cell.*

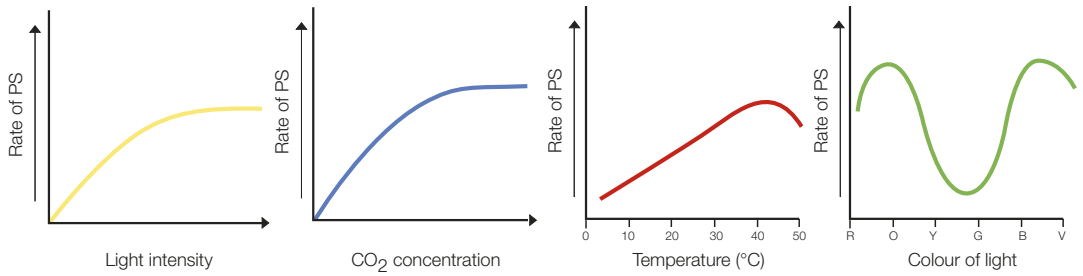


a) Explain why a different gene is required for each enzyme-catalysed steps in a metabolic pathway.

b) When tryptophan levels rise, this acts to slow the production of tryptophan. With reference to the flow diagram, describe two possible modes of action for this enzyme.

c) Describe one possible advantage to humans of this metabolic pathway having regulation pathways.

9. *Refer to the diagrams of environmental factors affecting photosynthesis to assist in answering the questions below.*



a) Explain the pattern of results observed in the carbon dioxide graph.

b) Provide one conclusion about the effect of temperature on the rate of photosynthesis.

10. Co-enzyme A is an important molecule in aerobic respiration. As a result, it is synthesised by the cells of all living organisms. It appears that it is a "potent allosteric modulator".

a) Explain the difference between an enzyme and a co-enzyme.

b) Describe the likely mode of action of co-enzyme A, if it is a potent allosteric modulator.

11. Cyanide is an inhibitor of an important enzyme in the mitochondria called cytochrome C oxidase.

a) Explain why cells poisoned with cyanide would only be able to produce around 2 ATP molecules for each molecule of glucose that is used for aerobic respiration.

b) This poison is often an irreversible chemical inhibitor. Describe what this means and explain why cyanide poisoning is often fatal.

Chapter 2.6 Binary fission and mitotic division

Science Understanding

Cells arise from pre-existing cells, and cell division leads to an increase in cell number.

Cell division in somatic cells is different from the cell division that produces gametes from germ-line cells.

Continuity of life requires the replication of genetic material and its transfer to the next generation through processes including binary fission, mitosis, meiosis, and fertilisation.

- Explain why the amount of DNA in a cell doubles before division.

The products of binary fission and mitotic division have the same number and type of chromosomes as the parent.

- Recognise, describe, and represent the process of binary fission in prokaryotic cells.
- Recognise, describe, represent, and name the process of mitosis in eukaryotic cells.
- Compare the products of binary fission and mitotic division.

Continuity of life

Cells and organisms function efficiently for a finite period of time. The continuity of life therefore requires new cells to be produced. This involves:

- The replication of the genetic material of pre-existing cells. This is called **DNA replication.**
- The transfer of replicated DNA to the next generation. This is called cell division.

Cell division that does not involve germline cells (in testes and ovaries) dividing to produce gametes (sperm or ova) is called meiotic division.

DNA replication - Review

The process of DNA replication was presented in Chapter 1.1. In summary, the main points are:

- DNA is a unique and special molecule that has the ability to make copies of itself.
- DNA replicates prior to mitotic division, binary fission and another form of cell division called meiotic division, which will be studied in Chapter 2.7.
- DNA strands are directional and are synthesised in the 5' to 3' direction.
- The process is termed semi-conservative as each molecule of DNA formed in the process consists of one 'old' or original strand and one 'new' strand (see *Figure 261*).
- Although the amount of DNA doubles during the process, the number of chromosomes does not double.
- DNA replication occurs to ensure that the products of mitotic division and binary fission have the same number and type of chromosomes as the original parent cell.

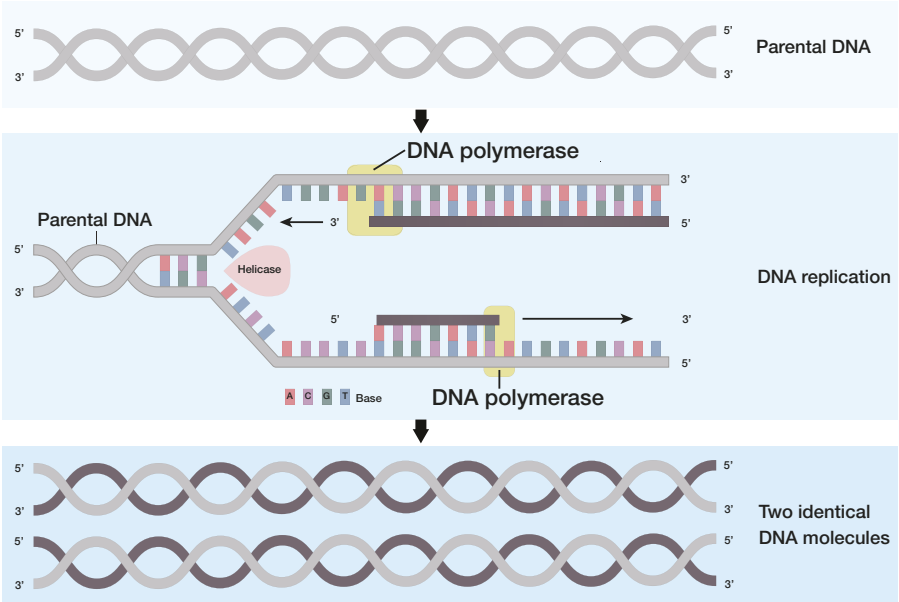


Figure 261 The process of DNA replication

Binary fission

Binary fission is a type of asexual cell division that results in **reproduction in prokaryotic cells**; one cell divides to form two genetically identical daughter cells (offspring). It has already been noted that prokaryotic cells are simpler and less specialised than eukaryotic cells; they do not have a nucleus and only have one circular chromosome consisting a double-stranded DNA (no histones). They may also have other smaller circular molecules of DNA that are referred to as plasmids. It is the process of DNA replication that makes it possible for the circular chromosome to be copied and thus for two new identical cells to be formed.

Figure 262 illustrates a transmission electron micrograph (TEM) of a single gut bacterium dividing into two cells using the process of binary fission.

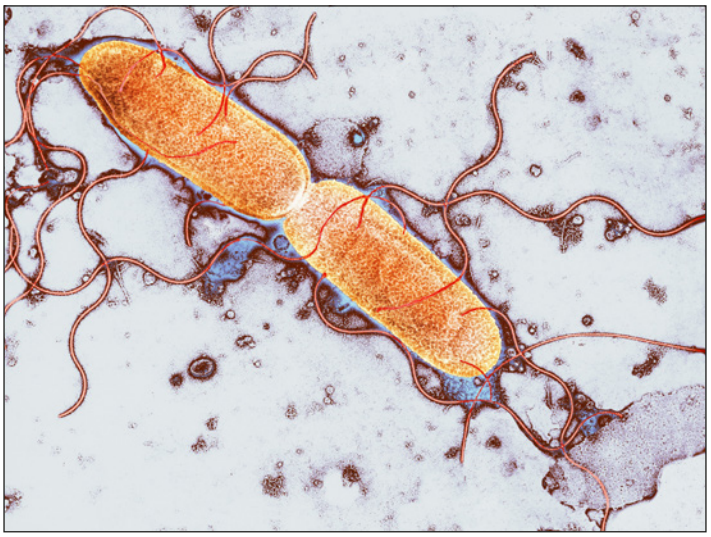


Figure 262 A bacterium undergoing binary fission

The main steps in binary fission	
1.	Just prior to the process, DNA replication occurs, resulting in two identical DNA molecules.
2.	Condensation of the cell's DNA occurs to form two identical circular chromosomes.
3.	Both chromosomes attach to the inside of the cell membrane.
4.	The size of the cell increases length-ways (elongates,) which separates the two chromosomes.
5.	The separated chromosomes are moved to the opposite ends of the original (parent) cell as the cell elongates.
6.	A new cell wall and cell membrane form and the cell divides into two daughter cells, each one with one circular chromosome.

This process can produce enormous numbers of prokaryotes in a very short time period. In optimum conditions, bacteria divide approximately every 20 minutes, doubling their numbers each time this occurs (see *Figure 263*). The very rapid increase in numbers of cells (or organisms) like this is called **exponential growth**.

Figure 264 (a) and (b) illustrates how binary fission in bacteria can lead to exponential growth.

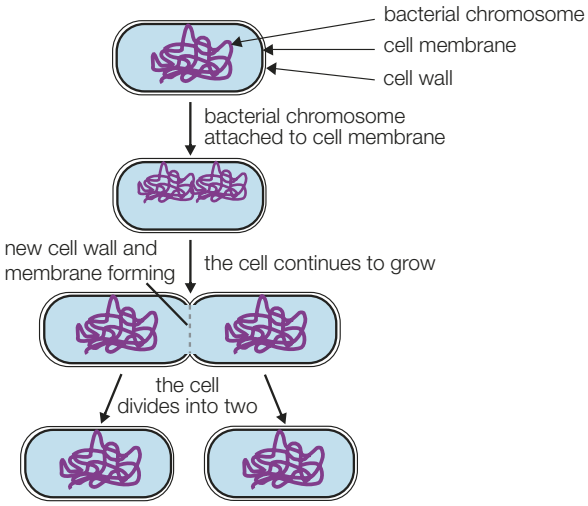


Figure 263 The process of binary fission

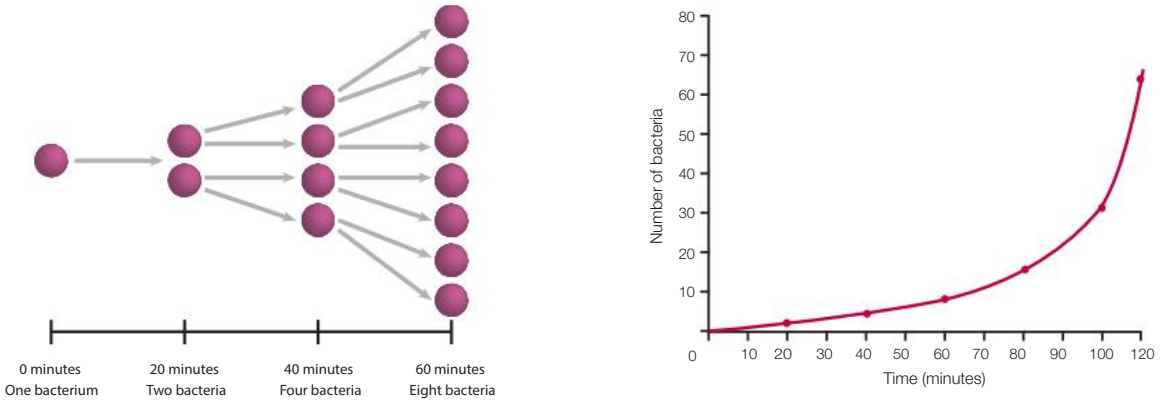


Figure 264 (a) The process and (b) the result of exponential growth

Helpful online resources

Cognito: Binary Fission - How Do Bacteria Divide?
<https://www.youtube.com/watch?v=kKiz8Wzcfc8>

Mitotic division

One part of the cell theory states that 'cells arise from pre-existing cells.' It is the process of binary fission that is responsible for this in prokaryotic cells; but in eukaryotic cells mitotic and meiotic division produces new cells (meiotic division is covered in Chapter 2.7). **Mitotic division** involves **both** the process of **mitosis** (nuclear division) and **cytokinesis** (division of the cytoplasm). Mitotic division is necessary for the following reasons:

- it enables the new **zygote** (sperm and egg) to grow into a fully formed adult
- for the repair and replacement of damaged cells and tissues it is the form of reproduction in eukaryotic and unicellular organisms and some other forms of asexual reproduction in eukaryotes.

Mitosis

Prior to mitosis, the DNA in the nucleus of the cell is present in uncoiled long loose strands called **chromatin.** This allows the DNA to be accessed more easily for transcription or DNA replication. After DNA replication has occurred (in interphase) there are two sets of chromatin (sister chromatids joined at the centromere). These **sister chromatids are separated** in the process of mitosis (see *Figure 265*).

Mitosis refers to the **division of the nucleus** and is a continuous process. During mitosis the nucleus of the parent cell divides to give rise to two **identical daughter nuclei**. There are **four phases** in this process where recognisable changes occur to the visibility and location of chromosomes in cells undergoing mitosis.

The four phases of mitosis are:

- **Prophase**
- **Metaphase**
- **Anaphase**
- **Telophase**

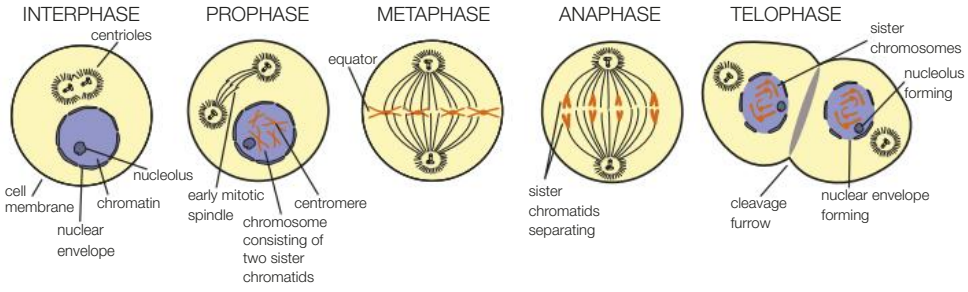


Figure 265 A summary of the process of mitosis

The following table provides the name, a visual representation and a description of what happens during each phase of mitosis and during cytokinesis.

Prophase

At the beginning of prophase, DNA in the nucleus condenses (coils up around histones) and the **chromosomes become visible**. This condensation is necessary so that DNA can easily be moved around the cell and sister chromatids can be separated as necessary.

At this stage the nucleolus disappears, and the **nuclear membrane breaks down**, resulting in the chromosomes temporarily residing in the cytoplasm. Spindle fibres, made of microtubules, begin to be assembled into a structure called the **spindle apparatus**. In animal cells, pairs of structures called **centrioles also move towards the poles** of the cell. The tubules and centrioles are components of the cell's cytoskeleton.

Metaphase

In the cytosol, the microtubules radiate from the poles towards the cell's equator. They attach to the chromosomes, which are moved by spindle fibres to **align vertically along the equator of the cell** or the 'metaphase plate', which is an imaginary line midway through the cell. Spindle fibres from opposite poles are attached to either side of the centromere. This is important to ensure that both sister chromatids do not end up at one pole of the cell.

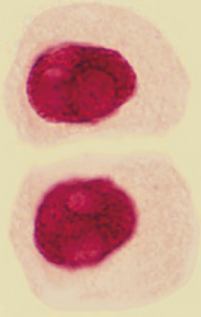
Anaphase

This phase is characterised, when the centromeres separate and the pairs of **sister chromatids of each chromosome are drawn apart** by the spindle fibres. Each chromatid is now considered to be an identical daughter chromosome and they are moved towards the opposing poles by the spindle fibres. At the end of anaphase, **identical sets of genetic information** are located at opposite poles of the cells.

Telophase

After the daughter chromosomes are moved to the opposite poles, **new nuclei begin to form**, each one complete with a nucleolus. The chromosomes now **decondense (uncoil) into chromatin** and no longer appear as visible structures (signalling the end of mitosis). The spindle apparatus is also broken down.

Cytokinesis



Cytokinesis is considered separate to mitosis and is the **division of the cytoplasm** (not the nucleus). Cytokinesis starts in either anaphase or telophase (depending on the type of cell) and finishes after telophase. In animal cells, the cytoskeleton constricts the cell membrane forming a cleavage furrow and the cell 'pinches' to form two **genetically identical daughter cells**. In plant cells new cell wall and cell membranes need to be made as well.

Helpful online resources

Amoeba Sisters: Mitosis: The Amazing Cell Process that Uses Division to Multiply! (Updated)
https://www.youtube.com/watch?v=f-ldPgEfAHI

Comparing mitotic division and binary fission

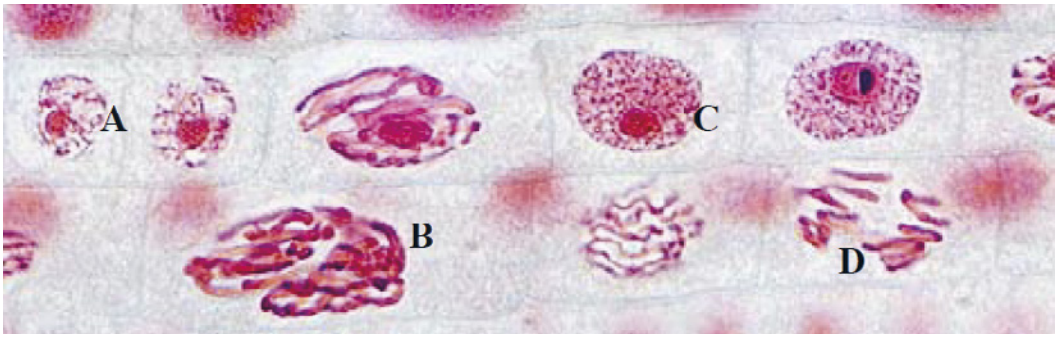
Area of comparison	Binary fission	Mitotic division
Type of cell	Prokaryotic	Eukaryotic
Replication prior to division	Yes	Yes
Nuclear division	No	Yes
Type of chromosome(s)	Single, circular	Many, linear
Number of cells produced	Two	Two
Daughter cells	Clones of parent cell	Clones of parent cell
Spindle fibres involved	No	Yes
Growth if no restrictions	Exponential	Exponential

2.6 Review questions

Multiple choice questions

1. Which one of the following statements is true concerning the process of binary fission?
   - J The DNA replicates in a semi-conservative manner prior to the process.
   - K It is a type of division used by cells that have a primitive form of sexual reproduction.
   - L It is the process used by prokaryotes to replicate their DNA.
   - M During the process, the circular DNA attaches to the cell wall prior to the cell splitting into 2 cells.
2. The cytoskeleton of a cell is not involved in which of the following processes?
   - J mitosis
   - K endocytosis
   - L binary fission
   - M movement of cell organelles
3. Mitosis is the division of the nucleus of a cell into 2 daughter nuclei. Which one of the following statements is true concerning mitosis?
   - J The 2 daughter nuclei each have one half of the number of chromosomes as the original nucleus.
   - K The DNA in each of the 2 daughter nuclei is not an identical copy of the DNA in the original nucleus.
   - L Each daughter nuclei has half the amount of DNA as the nucleus immediately before division.
   - M Each daughter nuclei has twice the number of chromosomes as the nucleus immediately before division.

4. *Refer to the diagram below of a group of cells, some of which are dividing by mitosis.*



The cells labelled A, B, C and D are at different points in their mitotic division. Which of the following indicates the correct sequence of events?

J C, B, D, A

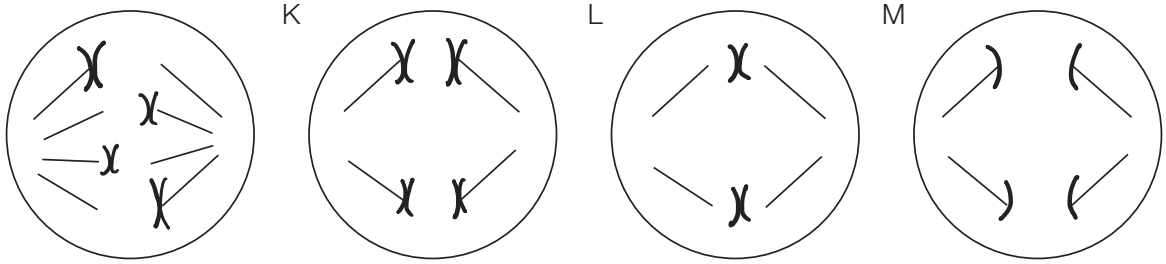
K A, B, C, D

L B, C, A, D

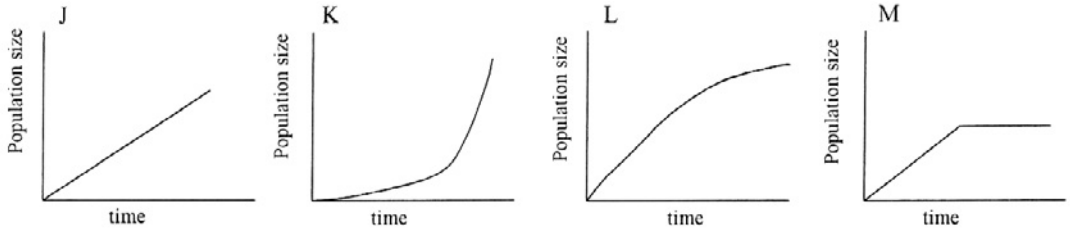
M C, B, A, D

5. Which one of the following diagrams represents a possible stage of mitosis in a cell with a haploid number of 2?

J K L M



6. Bacteria are prokaryotic cells that divide by the process of binary fission. If a single bacterium was placed in a culture medium with adequate nutrients, which one of the following graphs would best illustrate the increase in numbers of bacteria over a period of time?



7. Microtubules form part of the cytoskeleton of a cell. A particular toxin when placed in cultured cells prevents the formation of the microtubules. In a cell treated with the toxin you would expect that cell division would:

J proceed normally.

K not proceed as the chromatids in the cell would fail to separate.

L proceed but the daughter cells produced would lack a nucleus.

M not proceed as DNA replication would be unable to occur.

8. Which of the following options is not a phase of mitosis?

J prophase

K metaphase

L anaphase

M cytokinesis

9. During prophase the chromatin condenses into chromosomes. A major reason this occurs is:
   J So that RNA polymerase can access the genetic code more easily.
   K To initiate and contribute to the breakdown of the nucleus.
   L To protect the genetic code during mitosis.
   M To ensure the DNA can be replicated.
10. Which of the following options is a likely result of a spindle fibre only attaching to one side of a chromosomes centromere during mitosis of a human epithelial cell.
   J Two genetically identical daughter cells are likely to be produced.
   K Two daughter cells with 47 and 45 chromosomes are likely to be produced.
   L The daughter cells will likely lose their ability to differentiate and become specialised.
   M The two daughter cells are likely to both have 46 chromosomes but contain different chromosomes and be genetically variable.

Free response questions

1. Binary fission occurs in a prokaryotic cell. Explain the reason for the following processes occurring with the circular chromosome.
   a) Condensation prior to binary fission.

   b) Attachment to the cell membrane prior to new cells being formed.

2. In a 'dot-point format', outline the main processes that occur to the condensed chromosomes during mitosis.

3. State two examples where mitotic division is used in each of the following cases:
   a) As a form of asexual reproduction
   b) Growth
   c) Repair of tissue
4. Describe two roles of the cytoskeleton during mitotic division in eukaryotic cells.
   a)

   b)

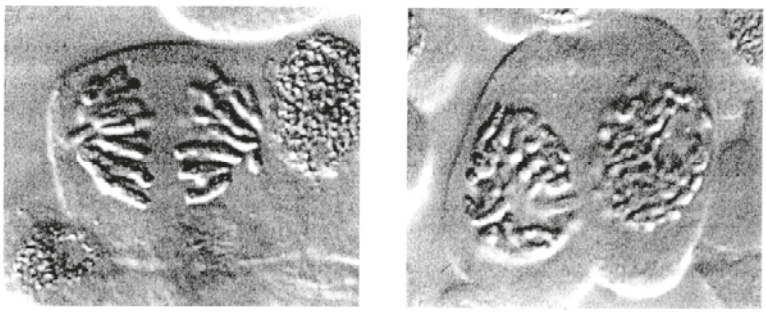
5. Summarise the main processes occurring in a prokaryotic cell that are responsible for ensuring that the two daughter cells produced have the same number and types of chromosomes as the parent cell.

6. Describe the differences between chromatin, a chromatid and a chromosome.

7. Compare cell division in prokaryotic and eukaryotic cells.

8. Explain how it is possible that the amount of DNA in a cell doubles prior to cell division, but yet the chromosome number remains the same.

9. *Refer to the following photographs A and B which show two stages in mitosis.*



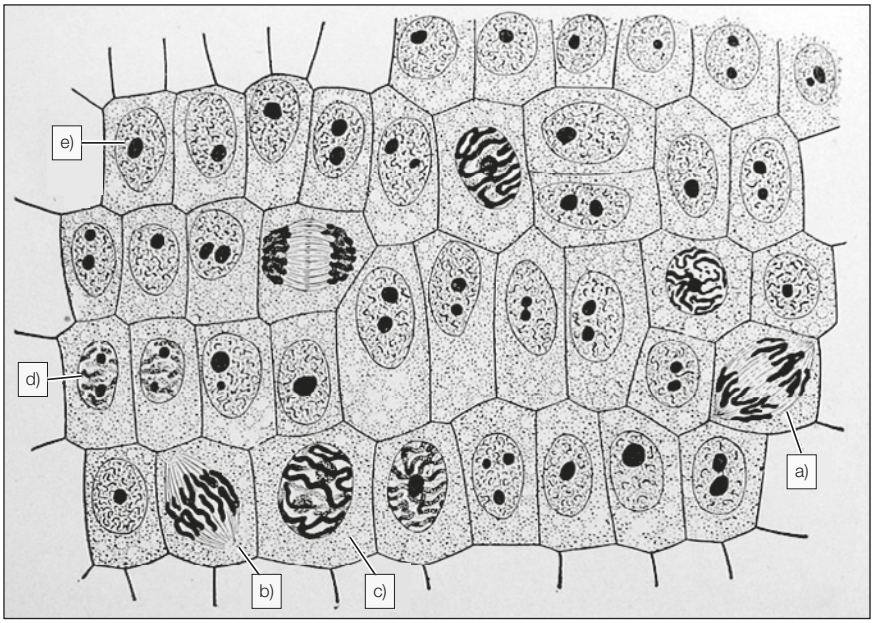
A **B**

a) State whether the two photographs are displaying a prokaryotic or eukaryotic cell and justify your answer.

b) Describe what is happening to the chromosomes in each photograph.

c) Explain how it is possible that cells produced by mitotic division are clones of the original cell.

10. *Refer to the diagram below representing cells in various stages of the cell cycle.* Cells that appear normal (i.e. as though they are not undergoing division) are said to be in interphase.

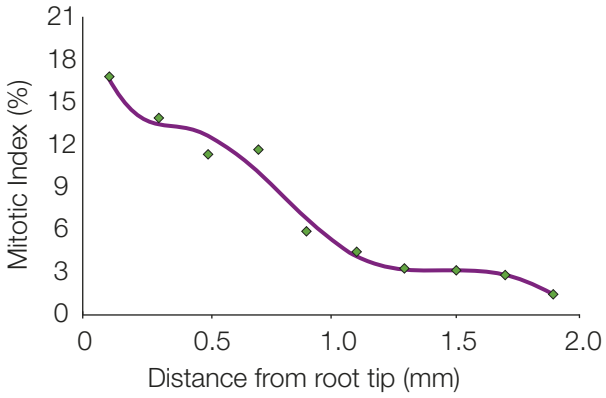


a) State the phase that each of the labelled cells is in:

b) Using the letters a) to e), determine the correct sequence of events as they would occur during mitosis.

11. Refer to the graph below regarding mitotic index. The mitotic index is a measurement of how much mitotic division is occurring in a tissue at a given time. It can be formulated as indicated below:

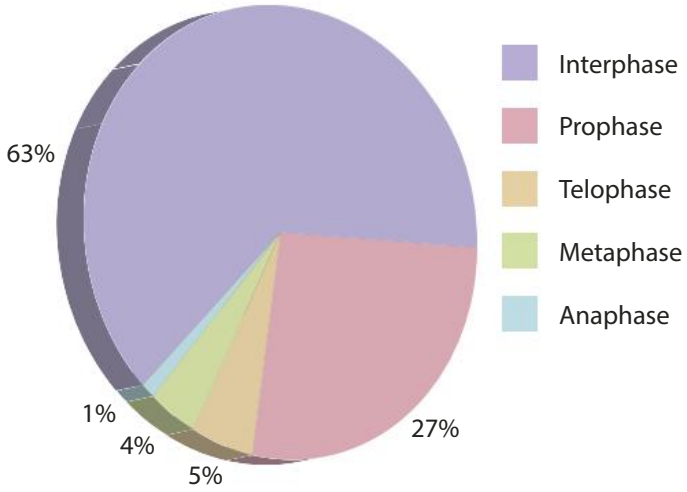
$$\text{Mitotic index} = \frac{\text{number of cells with visible chromosomes}}{\text{total number of cells}} \times 100$$



a) Describe the pattern of results indicated by the data.

b) Provide one conclusion based on the data.

12. *Refer to the pie chart below showing the time spent in various phases of the cell cycle, to answer the questions that follow:*



a) Describe why cells spend the most time in interphase.

b) Describe why prophase is longer than all of the other phases of mitosis put together.

Science as a Human Endeavour 2.6 – Telomerase and anti-aging

The ends of eukaryotic chromosomes have sequences of non-coding DNA called telomeres. Like the plastic tips on shoe laces, telomeres stop chromosome ends from breaking apart and sticking to each other which otherwise would alter the genetic information of an organism.

In human cells, each time DNA replication occurs the telomeres shorten slightly. After a certain number of divisions, the telomeres become too short for DNA replication to occur. The effect of this is to prevent cell division and thus the production of more daughter cells.

An Australian scientist, *Professor Elizabeth Blackburn*, helped to discover an enzyme called telomerase that catalyses a biochemical reaction that makes telomere DNA. It was then found that in cells with high telomerase activity, like germline and cancer cells, the shortening of telomeres is greatly slowed or stopped, letting them divide indefinitely. The discoveries led to *Elizabeth Blackburn* being awarded the Nobel Prize for Medicine or Physiology in 2009 (*see photo*).

In early 2017 *Elizabeth Blackburn* co-authored a book called *The Telomere Effect* that proposed individuals can have more control over aging than previously imagined. One of its central points is cell telomerase activity varies, and is enhanced in cells exposed to molecules called antioxidants or if organisms are subject to low stress.

Please refer to the online resources below to help answer the questions that follow.

1. Using the information in the text above, explain why performing meditation has been linked with slowing ageing.

2. Use your understanding of science as a human endeavour to discuss how unanticipated variables or insufficient data may limit the possible applications of this discovery.

Helpful online resources

Joe Fullarton: The Action of Telomerase:
<https://www.youtube.com/watch?v=qQCecSuPa1w>

FOX 2 St Louis: The Telomere Effect:
<https://www.youtube.com/watch?v=FxvfZOkcnt4>

ASAP Science: The Scientific Power of Meditation
<https://www.youtube.com/watch?v=Aw71zanwMnY>

Chapter 2.7 Meiotic division

Science Understanding

Diploid cells contain pairs of homologous chromosomes. Haploid cells have one chromosome from each homologous pair.

- Recognise, describe, represent, and name the process of meiosis in eukaryotic cells.
- Explain why the products of meiosis are haploid cells and contain a single set of chromosomes.
- Explain the importance of crossing over and independent assortment in meiosis.
- Explain that fertilisation restores the diploid number.
- Compare the products of mitotic and meiotic cell division.
- Compare the sources and degree of genetic variation of the products of asexual and sexual reproduction.

Haploid and diploid cells

"Ploidy" is a term used to describe the number of sets of chromosomes (represented by the symbol 'n') within a cell. Diploid cells contain two sets of chromosomes (2n), one set from each parent; whereas haploid cells contain one set of chromosomes (n) (see *Figure 271*).

Meiotic division produces haploid cells called gametes (sex cells), for example, sperm and egg cells in humans. During fertilisation, two haploid cells (n) fuse together to restore the diploid number (2n) producing a zygote. The zygote undergoes multiple mitotic divisions maintaining the diploid number throughout all somatic (body) cells.

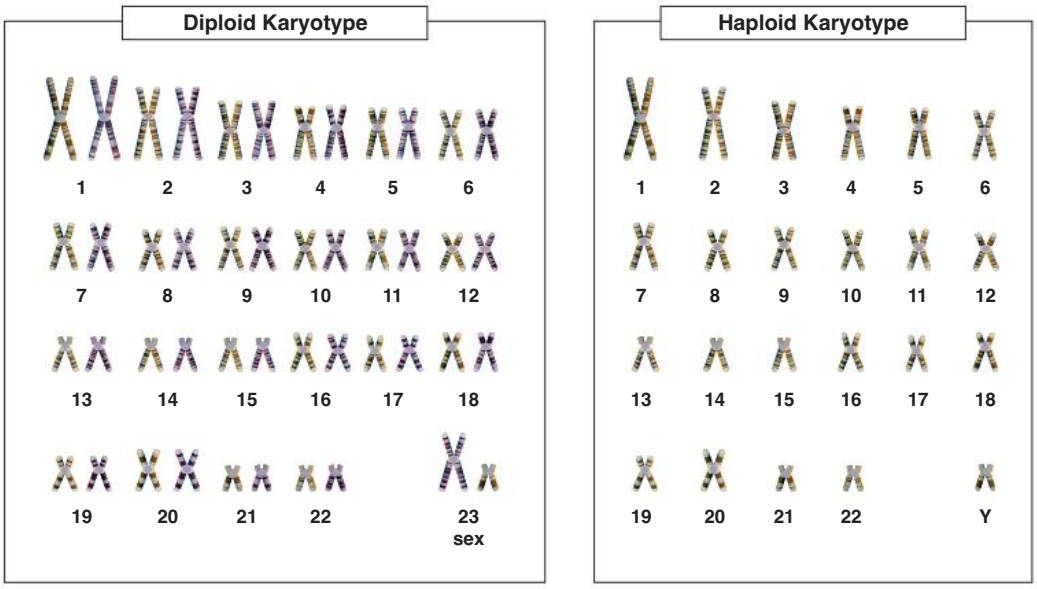


Figure 271 A comparison of a human diploid karyotype (two sets of chromosomes -2n) and haploid karyotype (one set of chromosomes - n)

Helpful online resources

Stated Clearly: What is a Chromosome?
<https://www.youtube.com/watch?v=lePMXxQ-KWY>

Nucleus Biology: What are Haploid and Diploid Cells?
<https://www.youtube.com/watch?v=NR9zTvMg-pE>

Homologous chromosomes

Human diploid cells contain 46 chromosomes and on closer inspection it is revealed that these cells actually contain 23 pairs of chromosomes. These pairs are termed **homologous chromosomes**, one of each pair was derived from the maternal (mother's) side of the family and one from the paternal (father's) side.

Homologous chromosomes are characterised by the following:

- One of each pair comes from the mother and one from the father
- Each member of the homologous pair look similar in length (except sex chromosomes)
- The **centromere** of each chromosome is located in a similar position
- They have the same banding pattern after being stained with a particular dye
- At corresponding positions on each member of the pair, genes code for the same characteristic. Although they code for the same characteristic, they may be different forms (**alleles**) of the same gene. An example to illustrate this is that an individual may have a maternal chromosome with alleles that codes for brown eyes but the paternal chromosome has alleles that codes for blue eyes. The combined expression of both the maternal and paternal alleles in the individual will determine his or her eye colour. In this case, the eyes will usually be brown. Refer to *Figure 272* which illustrates a homologous pair.

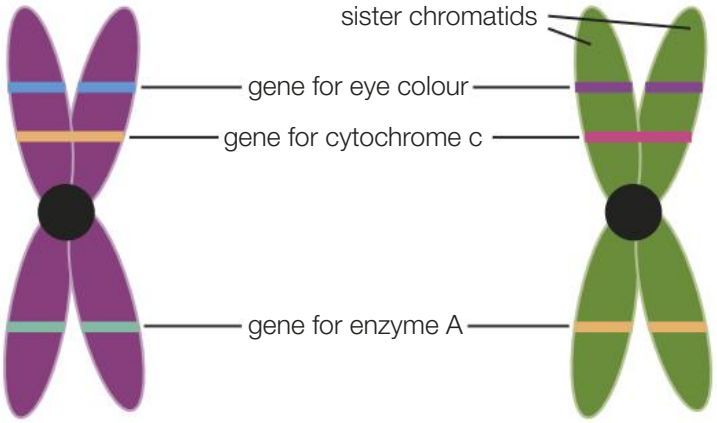


Figure 272 A homologous pair of chromosomes

Helpful online resources

Amoeba Sisters: Alleles and Genes

<https://www.youtube.com/watch?v=pv3Kj0UjiLE>

Meiotic division

Meiotic division involves both the process of **meiosis** (two nuclear divisions) and **cytokinesis** (two divisions of the cytosol).The main purpose of meiotic division, is to produce sperm in males and eggs in females that are **haploid cells.** These haploid cells will only have **half** the number of chromosomes as the **somatic cells**; only one member of each homologous pair. The diploid number is restored in the process of **fertilisation** where a sperm fuses with an egg cell (ovum). Meiotic division occurs in the testes and ovaries of humans and most other animals and in the flowers or cones of most plants.

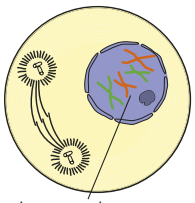
Sperm +	Egg →	Zygote
		
haploid (n)	haploid (n)	diploid (2n)
only one of each pair of homologous chromosomes		both pairs of homologous chromosomes

The term '**germline cell**' is often used to describe cells that have the capacity to divide by meiotic division and give rise to gametes. Any cells along this pathway are said to be on the 'germline'. Any mutations or epigenetic changes that occur to germline cells can be passed on to future generations.

Prior to the onset of meiosis, the chromatin undergoes DNA replication resulting in two identical sister chromatids attached at the centromere. The meiosis part of meiotic division can be divided into two main stages called Meiosis I and Meiosis II. Each of these two stages is then subdivided into four phases, so that a complete meiotic division results in four haploid cells. Refer to the following tables on meiosis I and meiosis II, which provides the name, a visual representation and a description of what happens during each phase.

Prophase I

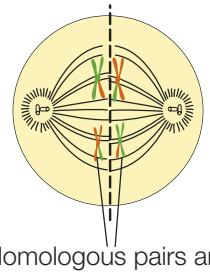
Starting cell is diploid (2n = 4)



Homologous chromosomes pair up and exchange fragments (crossing over)

The chromatin condenses (coils up), and chromosomes become visible, each consisting of identical sister chromatids. The **homologous chromosomes pair up**, forming a bivalent. **Fragments of chromatids are exchanged forming new combinations of maternal and paternal genes** in a process called **crossing over** occurs. The nucleolus disappears and the nuclear membrane breaks down, resulting in homologous pairs moving into the cytoplasm. Spindle formation also begins, and spindles radiate towards equator of cell.

Metaphase I

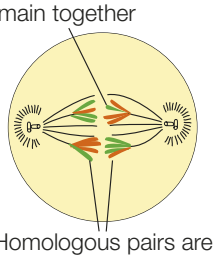


Homologous pairs are aligned either side of metaphase plate

The pairs of the homologous chromosomes (bivalents) are moved to the equator of the cell by spindle fibres. **Homologous chromosomes line up next to each other** (i.e. either side of the metaphase plate). The side of the metaphase plate a chromosome lines up on is completely random and is known as **independent assortment.** This results in the **random assortment of maternal and paternal genes** in the resulting haploid cells.

Anaphase I

Sister chromatids remain together

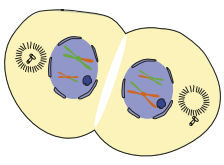


Homologous pairs are seperated to opposite poles of cell

The homologous pairs have been randomly arranged at the equator and are now separated by the spindle fibres that pull each homologous chromosome to the opposite pole of the cell. The sister chromatids are not separated during anaphase I, only the homologous pairs are.

Telophase I and Cytokinesis

Daughter cells are haploid (n = 2)



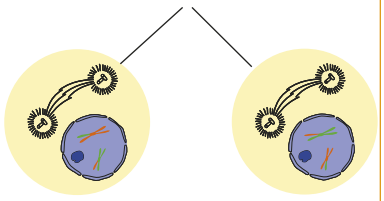
Each chromosone has two non-identical sister chromatids

Chromosomes arrive at the poles of the cell. In some organisms, the chromosomes decondense into chromatin and nuclei form around the two haploid sets of chromosomes. However, some organism's cells skip this step and proceed straight into prophase II.

Cytokinesis divides the cytoplasm of the parent cell into two daughter cells. The result of meiosis I is **two haploid cells** with only one set of chromosomes; however, both cells **still have their sister chromatids**, and a further division is required (meiosis II).

Prophase II

Starting cells are the two haploid cells from end of meiosis I



The two haploid cells produced from meiosis I do not require DNA replication prior to meiosis II (because sister chromatids are already present). If required, the chromatin condenses into chromosomes, and the nucleolus and nucleus break down. The chromosomes will therefore be in the cytoplasm. Note: they cannot form homologous pairs in prophase II as these pairs were separated in meiosis I. A new spindle apparatus also starts to form.

Metaphase II

Chromosomes are aligned on top of each other at metaphase plate

The spindle fibres from opposite poles attach to the centromeres of chromosomes, each consisting of two identical sister chromatids, and move them to the metaphase plate where they align vertically (on top of each other).

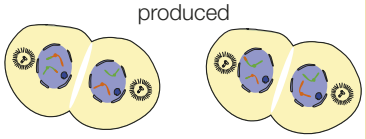
Anaphase II

Sister chromatids are separated to opposite poles of cells

The sister chromatids of each chromosome are separated and move to opposite poles.

Telophase II and cytokinesis

Four haploid gametes with single chromosomes are produced



During telophase II a nuclear membrane forms around each of the four sets of chromosomes and the nucleolus for each cell also becomes visible. The chromosomes elongate (de-condense), forming chromatin and are no longer visible as separate structures.

Cytokinesis then follows for both cells, dividing each cytoplasm. The result is **four genetically variable haploid cells.**

The overall result of meiosis is that from one diploid germline cell, **four** haploid cells are produced, either male or female gametes. Whilst all cells in mature male animals can develop into sperm, usually only one of them develops into a mature ovum, or egg cell, in mature females.

The chromosome number of a sexually reproducing species is kept constant from one generation to the next. In summary: meiotic division is the reduction division; from diploid to haploid and then, if fertilisation occurs, the diploid state is restored.

Helpful online resources

Biologica com Sanabria: Stages of Meiosis HD Animation
<https://www.youtube.com/watch?v=EPBSsGqTC8I>

Cognito: Meiosis
<https://www.youtube.com/watch?v=micUPynqx9k>

Sources of genetic variation in sexual reproduction

The offspring of organisms that reproduce sexually look different from both parents even though they share certain features.

The main sources of variation are:

- crossing over during Prophase I of meiosis.
- the independent assortment of the homologous chromosomes at Metaphase I.
- fertilisation, which restores the diploid number when a sperm and its unique genetic profile fuses with an ovum.

Crossing over

In Prophase I of meiosis, the homologous chromosomes, each consisting of two identical sister chromatids, lie next to each other (synapsis). The non-sister chromatids are in contact at a number of points called **chiasmata**. See *Figure 276(a)* for an electron micrograph and *Figure 276(b)* for a matching a diagram of the chiasmata. Enzymes cut identical sites on non-sister chromatids and sections of DNA swap between them.

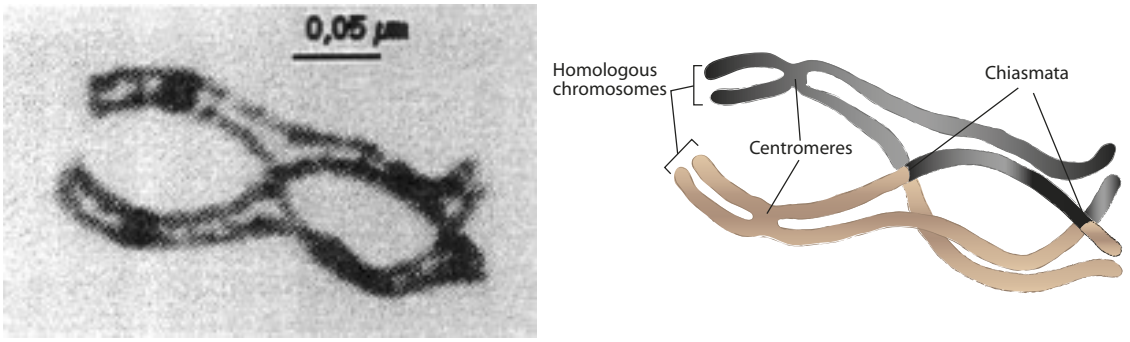


Figure 276 (a) A SEM and (b) Corresponding illustration of crossing over

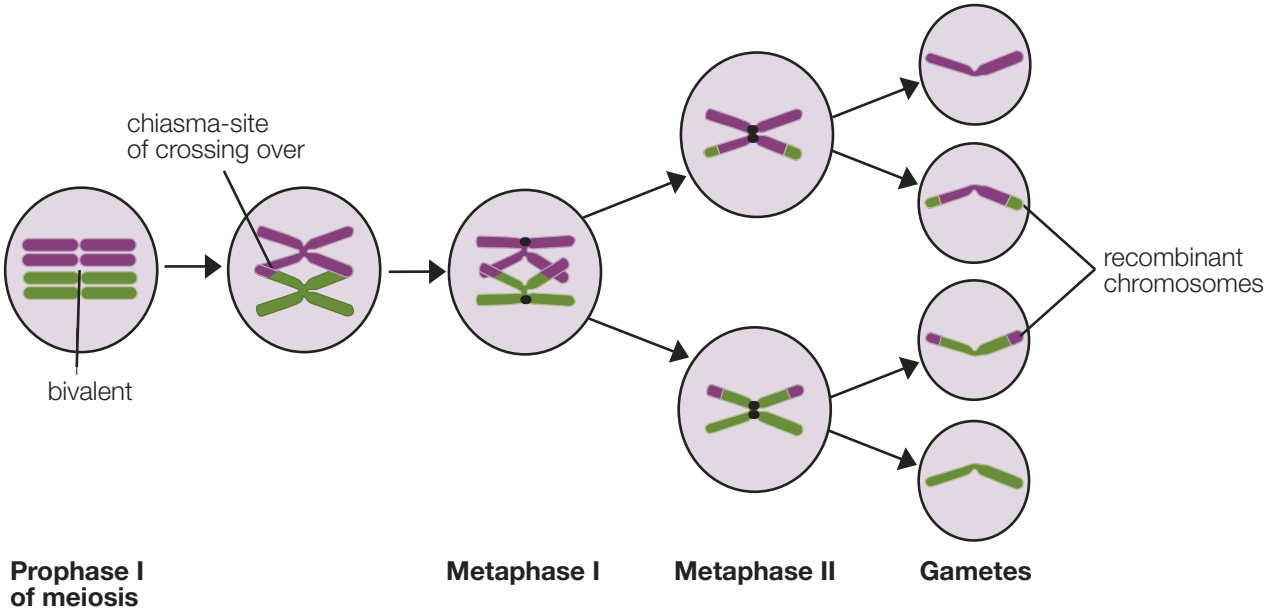


Figure 277 The results of crossing over

Figure 277 illustrates the process of crossing over between one homologous pair and the resulting gametes.

The chromosomes that show different combinations of genes as a result of crossing over are called **recombinant chromosomes**, or simply recombinants. Crossing-over produces **new combinations of maternal and paternal genes** and thus greater genetic diversity in the possible gametes formed. *Figure 278* illustrates how new combinations of maternal and paternal genes can occur as a result of crossing-over.

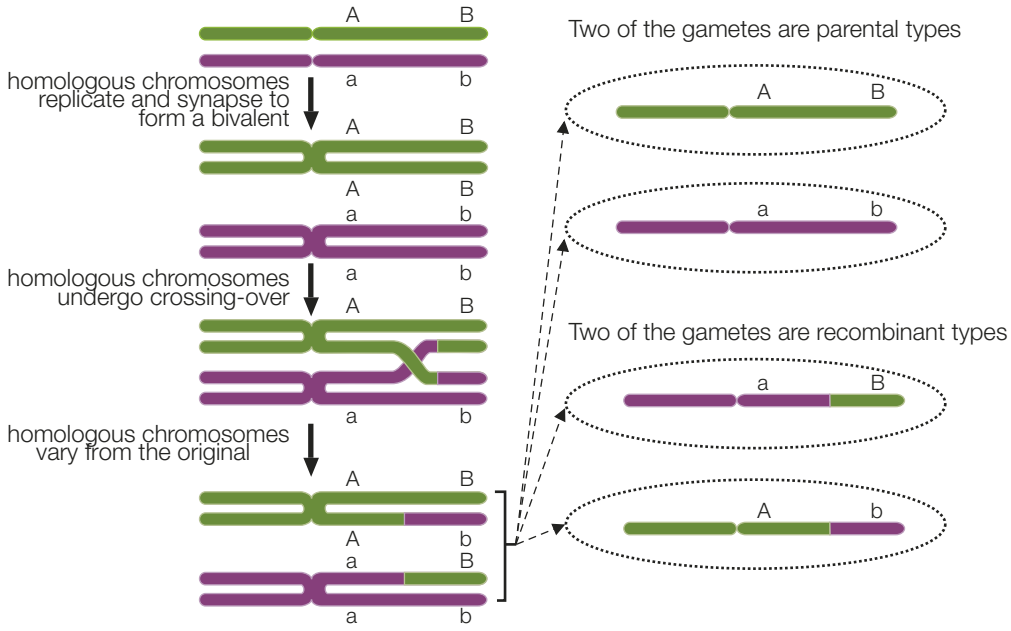


Figure 278 How crossing over can produce new combinations of alleles of genes

Independent assortment

Independent assortment is a process that occurs in meiosis and results in the **random assortment of genes**. This process occurs during Metaphase I, where the homologous **maternal and paternal chromosomes randomly line up on either side of the equator of the cell**. There is an equal chance for a chromosome to be on the left or right side.

Figure 279 shows an example of a hypothetical organism where the diploid number (2n) = 4. There are two possibilities for the homologous pairs to arrange themselves on the equator and each will result in the formation of different gametes.

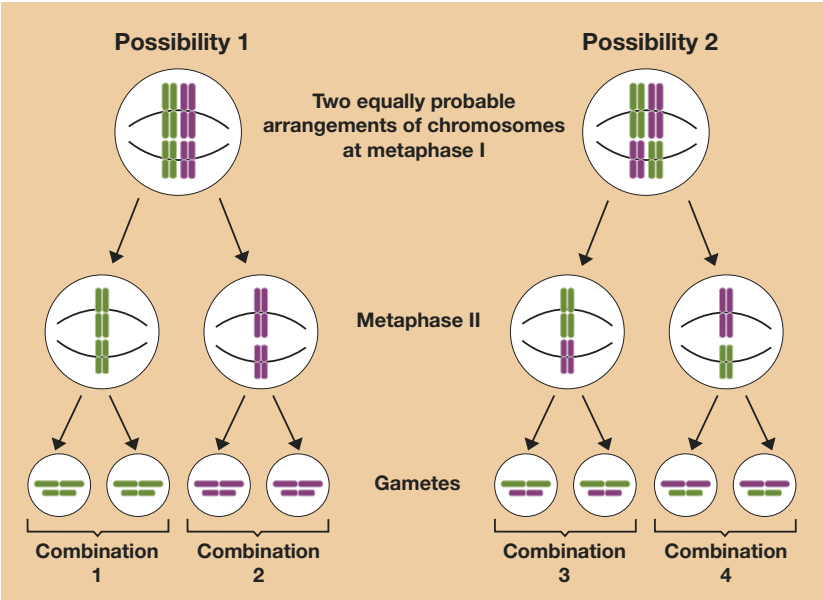


Figure 279 The process of independent assortment

Possibility 1 and possibility 2 represent the two ways that are possible for the chromosomes to line up and as a consequence, which combinations of chromosomes will end up in the final gametes (assortment). It can be seen here that there are ($2^2 = 4$) possible combinations in total.

The mathematical representation for the number of possible combinations is 2^n where 'n' equals the number of homologous pairs in the organism. As such, humans with 23 pairs of chromosomes can produce 2^{23} (about 8 million) different types of gametes, due to independent assortment alone. Independent assortment makes it possible to have different combinations of maternal and paternal chromosomes in the gametes.

Fertilisation

Fertilisation refers to the fusion of the two gametes which restores the diploid number of chromosomes. *Figure 2710* illustrates the sperm trying to penetrate the membrane and fertilise an ovum or egg cell.

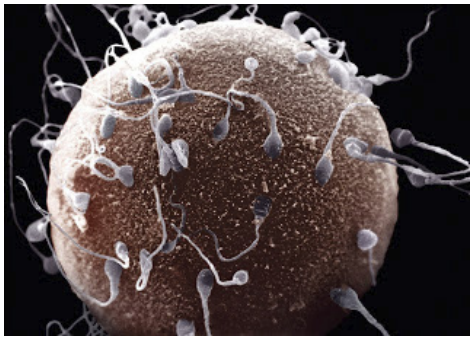


Figure 2710 Sperm and egg

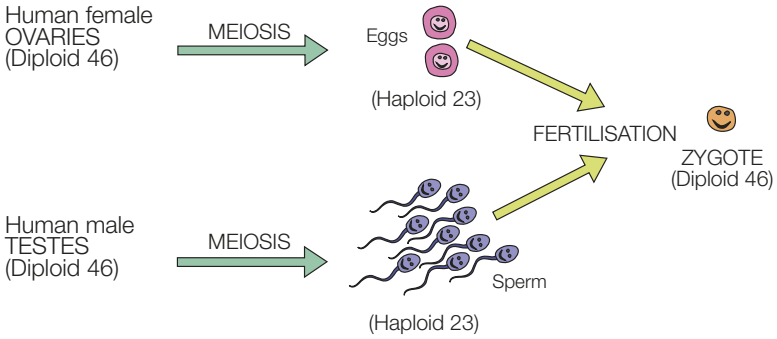


Figure 2711 Fertilisation of sperm and egg

Fertilisation introduces variation into a sexually reproducing species as the new zygote formed has genetic material from two different parents. Refer to *Figure 2711* showing fertilisation.

A comparison of mitotic and meiotic division

Refer to *Figure 2712* below comparing mitotic and meiotic cell division and their respective products:

Mitosis	Meiosis
In somatic cells	In cells in the sexual cycle
One cell division, resulting in two daughter cells	Two cell divisions, resulting in four products of meiosis
Chromosome number per nucleus maintained (e.g., for diploid cell)	Chromosome number halved in the products of meiosis
One premeiotic S phase per cell division (e.g., for diploid cell)	One premeiotic S phase for both cell divisions
Normally, no pairing of homologs	Full synapsis of homologs at prophase I
Normally, no crosssovers	At least one crossover per homologous pair
Centromeres divide at anaphase	Centromeres do not divide at anaphase I but do at anaphase II
Conservative process: daughter cells' genotypes identical with parental genotype	**Promotes variation among the products of meiosis**
Cell undergoing mitosis can be deploid or haploid	Cell undergoing meiosis is diploid

Figure 2712 The differences between mitotic and meiotic division

Helpful online resources

Amoeba Sisters: Mitosis vs. Meiosis: Side by Side Comparison
<https://www.youtube.com/watch?v=zrKdz93WlVk>

Amoeba Sisters: Chromosome Numbers During Division: Demystified!
<https://www.youtube.com/watch?v=gcz1FOWw0Cg>

A comparison of asexual and sexual reproduction

Organisms generally reproduce by sexual or asexual means but some organisms are capable of both of these methods at different times. Reproduction is sexual if, at any stage in the life-cycle, fertilisation occurs. Meiotic division produces the sex cells or gametes needed for this to occur.

In asexual reproduction, there is no fertilisation. In unicellular eukaryotic cells this normally occurs by mitotic division whereas prokaryotic cells use binary fission.

Asexual reproduction generally produces clones of the parent. Sexual reproduction, through crossing over, independent assortment in meiosis and fertilisation, introduces enormous variation into the offspring compared to the parents.

Mutations can also introduce variation in the DNA of **germline cells** which can be passed on to the offspring of species that reproduce by either sexual or asexual reproduction. Additionally, **epigenetic changes** that occur to **germline cells** can also be passed on to offspring, influencing the gene expression.

Asexual reproduction is not particularly common in the animal kingdom but an example is shown in the photograph of an aquatic organism called a hydra. This organism is using mitotic division in the process termed **budding** to give rise to new hydra which are clones of the parent. Refer to *Figure 2713 (a) and (b)* showing a hydra budding.

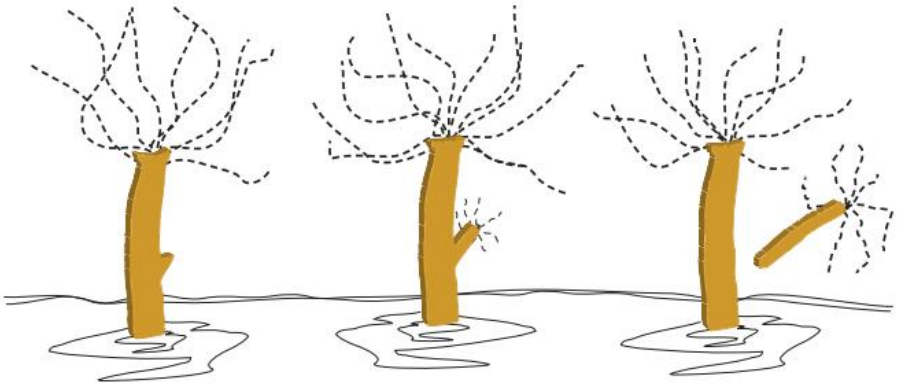


Figure 2713 (a) A photograph and Figure 2713 (b) A diagram to illustrate the process of budding

Refer to the following table which summarises some advantages and disadvantages of asexual and sexual reproduction:

	Advantages	Disadvantages
Sexual Reproduction	• Almost no individuals of a species are the same • Very high survival rates in most species • Populations are more resilient to changes in environment and disease	• Slow process • Requires lots of energy at cellular level • Generally, only have one to a few offspring at a time resulting in slow population growth)
Asexual Reproduction	• Very fast process • Requires little to no energy • Able to quickly reproduce and make a large population quickly	• All individuals of the species are virtually identical • High mortality rate in offspring • Population more susceptible to widespread disease deaths and environment change deaths

Helpful online resources

Cognito: GCSE Biology - Sexual vs Asexual Reproduction - What is Asexual Reproduction?
<https://www.youtube.com/watch?v=LgLkt02Hl9s>

Cognito: GCSE Biology - Pros and Cons of Sexual and Asexual Reproduction
<https://www.youtube.com/watch?v=mtYCd2LAr_w>

SciShow: Bananas Are Losing the War on Fungus
<https://www.youtube.com/watch?v=9H0dy8fv33M>

2.7 Review questions

Multiple choice questions

1. Which one of the following correctly describes when DNA replication occurs in the formation of gametes?
   - J During crossing over.
   - K Directly after the gamete is formed.
   - L Prior to the start of meiosis.
   - M At the end of the first meiotic division.
2. A new form of a gene could arise in a sexually reproducing species by:
   - J Random fertilisation of gametes.
   - K Independent assortment of homologous chromosomes during meiosis.
   - L A mutation in a DNA sequence prior to meiosis.
   - M Crossing over between sister chromatids in the process of meiosis.
3. If the haploid number of a species is 24, how many chromatids will there be in a germline cell undergoing meiosis at metaphase I?
   - J 96
   - K 24
   - L 48
   - M 12
4. Which one of the following would not give rise to genetic variation in gametes?
   - J Independent assortment
   - K Fertilisation
   - L Crossing over
   - M Mutation
5. You have the same mitochondrial DNA as your:
   - J Maternal grandfather.
   - K Maternal grandmother.
   - L Paternal grandfather.
   - M Paternal grandmother.

6. A child is born with an extra chromosome in each of its cells. This condition is usually the result of which one of the following?

   J Paired chromosomes failing to separate during meiosis.

   K Crossing over

   L A failure of DNA replication to occur normally.

   M A failure of the cells to divide during mitosis.

7. Which of the following options best describes why cloning is used in agriculture?

   J To preserve genetic variability in a population.

   K To increase the gene frequency of recessive traits.

   L To preserve favourable traits in the offspring.

   M To increase combinations of alleles in a population.

8. In a species of ant, it has been observed that the males develop from unfertilised eggs but females develop in the usual manner involving fertilisation.

   Which of the following is true concerning these ants?

   J the unfertilised eggs are produced by mitosis.

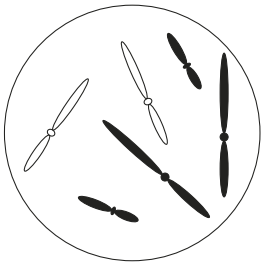
   K all males are identical.

   L males contain homologous pairs of chromosomes.

   M sperm produced by an individual male are made by mitosis.

9. *Refer to the diagram to the right to answer the following question.*

   How many homologous pairs of chromosomes does this cell have?

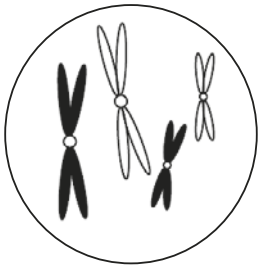
   J 6

   K 12

   L 3

   M 2

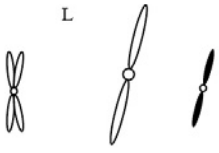
10. Refer to the diagram below of the chromosomes in a cell in an early stage of meiosis.

    Which one of the following diagrams represents the possible chromosomes in a gamete formed at the end of meiosis?

    J 

    K 

    L 

    M 

11. Ignoring the effect of crossing over, what is the possible number of different haploid cells that could arise by the meiotic division of a diploid cell containing 12 chromosomes?

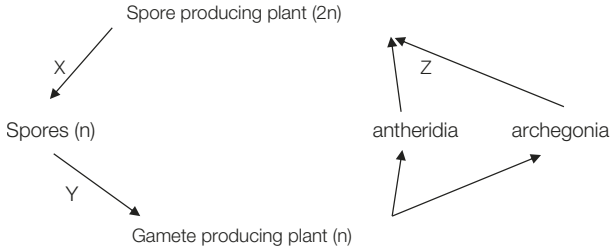
    J 128

    K 64

    L 24

    M 12

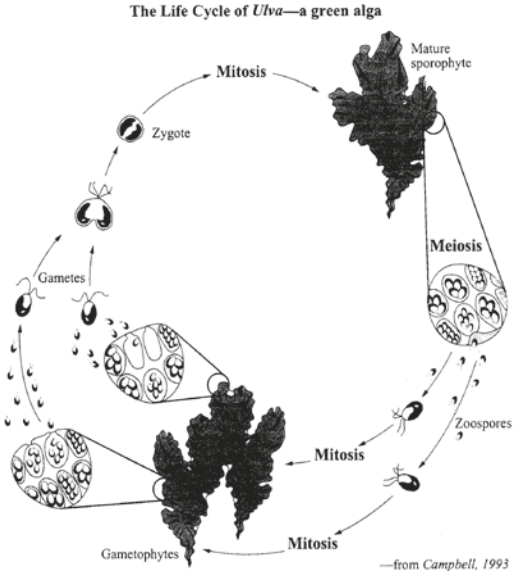
12. *Refer to the following diagram which shows the processes X, Y, and Z in the reproductive cycle of a typical fern.*



Which one of the following combinations correctly identifies the processes **X, Y** and **Z**.

	X	Y	Z
J	mitosis	meiosis	fertilisation
K	meiosis	fertilisation	mitosis
L	mitosis	differentiation	fertilisation
M	meiosis	mitosis	fertilisation

13. *Refer to the following diagram and then answer the question beneath.*



Which structures in the life cycle of the *Ulva* are diploid?

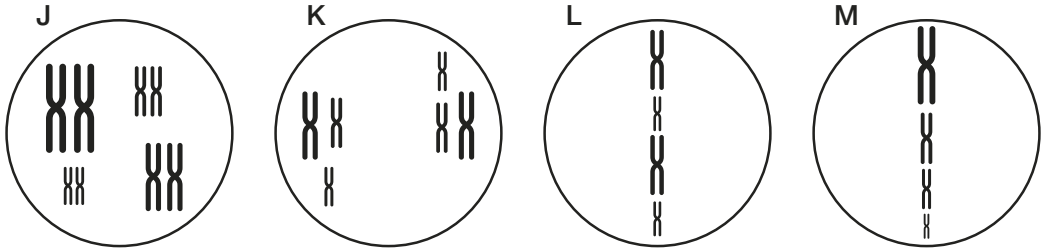
J zoospores and the zygote

K the sporophyte and the zygote

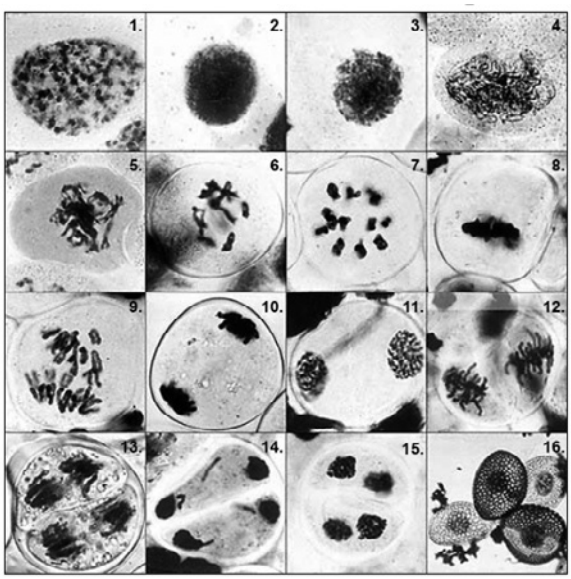
L zoospores and the gametophytes

M The sporophyte and the gametophytes

14. Which one of the following cells is undergoing mitosis?



15. The following images show stages in meiosis in the order in which they occur.



Which one of the following statements is incorrect?

J Crossing over occurs during the process shown in image 8.

K Image 3 shows chromatin condensing into chromosomes.

L The separation of homologous pairs is shown in image 9.

M Four haploid cells are shown in image 16.

Free response questions

1. In a homologous pair of chromosomes one is said to be of 'maternal' origin and the other 'paternal'. Explain what this means.

2. Genes code for the same characteristic at the same position on a pair of homologous chromosomes, but they may code for a different polypeptide, or be an allele that does not code for a polypeptide. Describe how this is possible.

3. Explain why somatic cells contain homologous chromosomes but gametes do not.

4. Mutations in DNA are the only way that variation is introduced from parent to offspring in those species that reproduce by asexual means.

   a) State the process during the (asexual) life-cycle when a DNA mutation is most likely to occur.

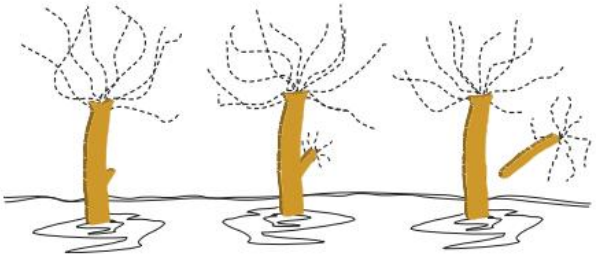
   b) Describe why the offspring are clones.

5. Meiotic division is often referred to as a 'reduction division'.

   a) Describe what is happening to the chromosomes to achieve this reduction.

   b) State the phase of meiosis when the homologous chromosomes are separated to opposite poles of the cell.

6. Use the following diagram of a hydra to answer the questions that follow.

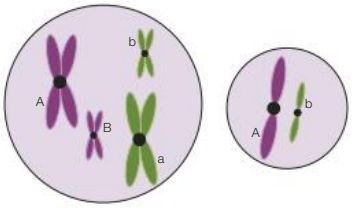


a) State whether this diagram shows sexual or asexual reproduction and justify your answer.

b) Name the type of cell division involved and justify your choice.

7. Explain how the process of fertilisation ensures that brothers and sisters in the one family are all different in their appearance and other characteristics.

8. This is a diagram of a primary spermatocyte (a cell involved in sperm formation) showing two pairs of homologous chromosomes. The letters represent two pairs of genes found on the chromosomes. The primary spermatocyte (left side) divides by meiotic division to form a secondary spermatocyte and eventually sperm cells. One sperm cell (right side) was found to contain the two chromosomes shown.

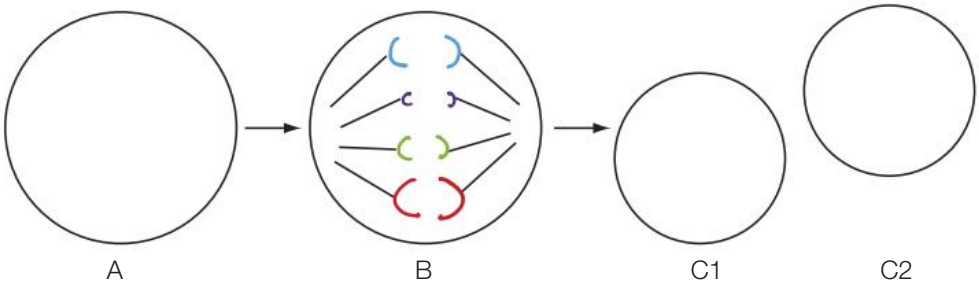


a) State the name of the organ in males where this process would occur.

b) State the diploid number and haploid number of this species?

c) Draw the original arrangement of homologous chromosomes during meiosis that would have occurred to produce the primary spermatocyte shown in the diagram above. Ignore the effects of crossing over.

9. *Refer to the diagram below of a sketch of a cell (labelled B) undergoing a form of cell division.*



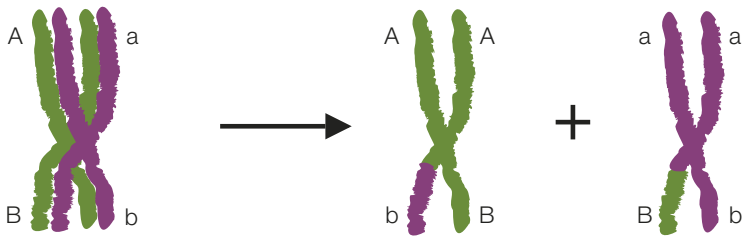
a) State the type of cell division and justify your answer.

b) Draw the chromosomes in the cells (circles) provided above to show the position and structure of the chromosomes immediately prior to B (in cell A), and the products of the division (cells C1 and C2).

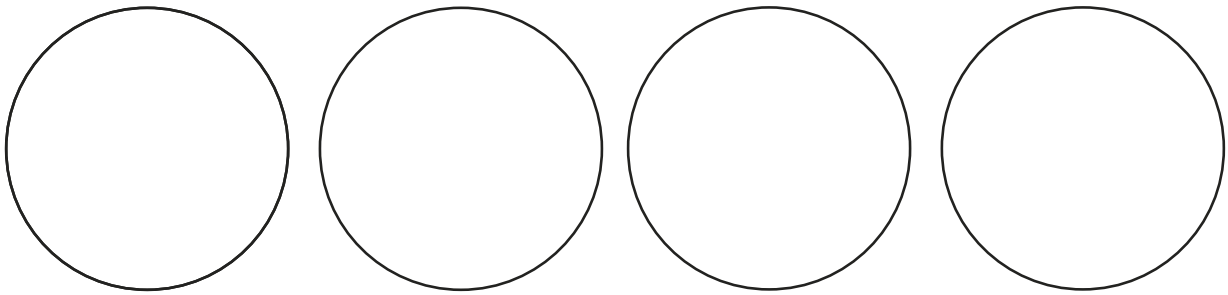
c) State the diploid and haploid numbers of this species.

10. In some species of bees the females are diploid but the males develop from unfertilised eggs. If the females have 36 chromosomes:
    a) State how many chromosomes the males will have in each cell.
    b) Explain why the male bees of this species would not be able to produce sperm by meiotic division.

11. a) Explain how crossing over and independent assortment increase genetic diversity in gametes.

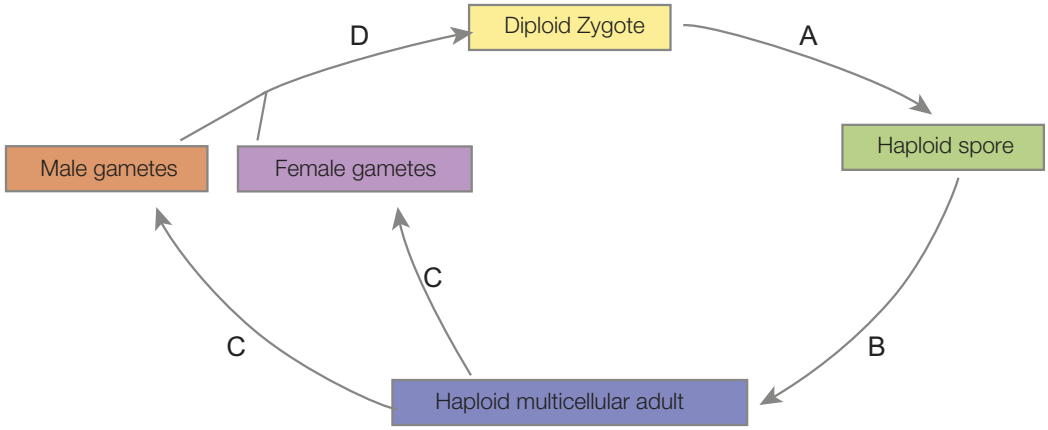


b) With reference to the diagram above, draw the four possible chromosomes in the circles provided that would result from this crossing over event.



12. Market gardeners often grow strawberry plants from cuttings rather than using seed which has been produced by sexual reproduction. Using your understanding of sexual and asexual reproduction, discuss why this might be the preferred method to propagate new strawberry plants.

13. Some species alternate in their life-cycle between diploid and haploid forms, as shown in the diagram below.



a) Name the processes occurring at A, B, C and D.

A

B

C

D

b) Name the parts of the life-cycle which represent sexual and asexual phase(s) and explain, giving reasons:

- sexual phase(s)

- asexual phase(s)

Science as a Human Endeavour 2.7 – Gene editing and genetic disorders

An inherited medical condition caused by a mutated or faulty gene or set of genes is called a genetic disorder. About 6000 human genetic disorders have been discovered and described. Common examples include cystic fibrosis, sickle cell anaemia and Huntington's disease.

In recent years, the number of inheritable disorders that can be prevented by using a form of genetic test or screening has greatly increased. This includes sophisticated newborn screening and testing IVF embryos (pic) before implantation, e.g. pre-implantation genetic diagnosis (PGD). Another emerging way to do this is gene therapy. As discussed in Chapter 1.6, hundreds of gene therapy trials are underway that aim to replace a faulty gene with a fully functional one. In March 2017, it was reported a gene therapy had cured a teenage boy of sickle cell anaemia, the first time the procedure had been used to successfully treat a common genetic disorder.

Today the world has CRISPR. The way this new procedure makes it possible to cheaply, and easily, 'edit' genes was detailed in Chapter 1.7. Now, fixing faulty genes, means a future where children are born free from inherited genetic disorders is closer than ever before.

Please refer to the online resources below to help answer the questions that follow.

Use your understanding of Science as a Human Endeavour to answer the following questions:

1. Discuss how science informs public debate about the use of gene editing (CRISPR) to stop children inheriting genes for disorders.

2. Explain how issues raised by public debate might impact on scientific progress and possibilities; for example, whether CRISPR should not only be used for gene editing of somatic (body) cells, but used for germline cells and/or human embryos as well.

Helpful online resources

Future of Medicine: DNA editing (CRISPR-Cas9) will cure/treat incurable diseases

<https://www.youtube.com/watch?v=O0usd9IZVCg>

Helpful online resources

New Scientist: Can gene editing fix genetic mutations in embryos?

<https://www.youtube.com/watch?v=zmlyYXFchKA>

Chapter 2.8 Control of cell division

Science Understanding

Cell division may be regulated by internal and external factors.

The cell produces gene products that regulate the cell cycle.

- Describe the stages in the cell cycle (including checkpoints).
- Explain that hormones may regulate cell division.

Carcinogens upset the normal controls of cell division by causing mutations in key regulatory genes.

Human beings culture cells for a variety of purposes.

- Describe techniques of cell culture, and discuss the applications and limitations of contemporary examples.

The cell cycle

All cells, from the time they are first formed, go through a **cell cycle** (see *Figure 281*). One cycle is the time it takes to go from one cell division to the next.

There are three stages of the cell cycle:

- Mitosis - the division of the nucleus
- Cytokinesis – the division of the cytoplasm and the formation of two new cells
- **Interphase** - the time in between cell divisions

Interphase is a very active phase in the life of a cell, during which many processes and biochemical reactions occur; including transcription, translation and DNA replication. Scientists have named three stages in interphase: Gap 1 (G1), Synthesis (S) and Gap 2 (G2). Another stage, G0, is when cells are not dividing; these cells may be in this stage permanently if they will never divide again (e.g. nerve cells), or temporarily if they enter the cell cycle only after a particular trigger, e.g. damage to tissue.

The time it takes for a cell to pass through the cell cycle varies due to a range of factors but as an example, intestinal cells take about 12 hours and cells growing in culture in a laboratory often take about 22 hours.

Refer to the table below which summarises the main events of the cell cycle.

Stage	Events
G0	cells are removed from the cycle and are not dividing, though functioning
G1	cell growth, ribosome synthesis, protein synthesis
S	DNA replication, histone synthesis, phospholipid synthesis
G2	developing and preparing organelles for division
M	mitosis; division of the nucleus
Cytokinesis	division of the cytoplasm and the cell divides

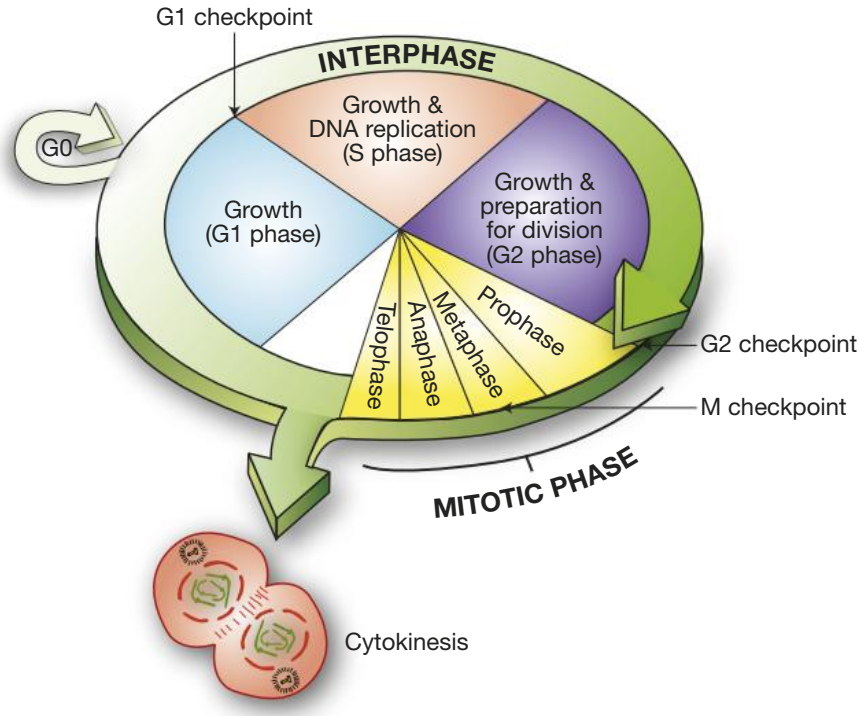


Figure 281 The stages of the cell cycle

Note in *Figure 281* the labelling of '**checkpoints**' in the cell cycle:

- G1 checkpoint
- G2 checkpoint
- M checkpoint.

Helpful online resources

Nucleus Biology: The Cell Cycle

https://www.youtube.com/watch?v=e6N9_RhD10Q

The cell cycle needs to be a carefully controlled and regulated process for organisms and as such, the cell cycle is characterised by the following:

- the ability to respond to extracellular and intracellular signals
- a system that only allows a cell to move on in the cycle when its current requirements are met
- a control system to switch processes and chemical reactions on and off at precise moments in the cell
- a DNA detection system which looks for completion of and faults during DNA replication
- a series of checkpoints (i.e. G1, G2, M) that act as a molecular surveillance system.

Cell cycle checkpoints

The checkpoints, seen in *Figure 281*, are points in the cell cycle where the cell checks, at the molecular level that the cell is ready to proceed further in the cycle and that essential processes and reactions have been completed satisfactorily. The checkpoints are characterised by the following:

- a sensor or detector
- the ability to send a message
- an effector to bring about a response.

G1 checkpoint

At this checkpoint the cell carries out a check on its DNA to ensure that it is ready to proceed into the S phase and replicate. The gene 'p53' is often referred to as the 'guardian of the genome' and is responsible for checking if the cell cycle can proceed. In some cases repair of the DNA may occur and in others, where the damage is more severe, cell death (**apoptosis**) may be triggered by the p53 gene. Other checks may be performed here to ensure that the cell has available other pre-requisites for cell division.

A 'go-ahead' signal at the G1 checkpoint triggers DNA replication. Without such a signal, DNA replication does not start and the cell does not divide.

G2 checkpoint

The G2 checkpoint is after G2 phase; as such the cell enters mitosis immediately following this point.

The checks here include:

- ensuring that the DNA has replicated accurately and that there is no molecular damage to the DNA
- an overall check to ensure the cell is suitable to enter mitosis, for example, the cellular energy required is available to the cell for division to occur

A go-ahead signal at the G2 checkpoint triggers mitosis to occur up to the end of metaphase. Without a go-ahead signal, mitosis does not start.

M checkpoint

This checkpoint is in metaphase of mitosis. It will check that the spindle apparatus is in place and that the chromosomes are lined up correctly, ready to separate the chromatids during anaphase (this ensures that each daughter cell receives an identical set of chromosomes).

A go-ahead signal at the M checkpoint triggers the completion of mitosis. Cytokinesis then takes place and two daughter cells are produced. Without a go-ahead signal here, the cell does not complete mitosis, and thus does not divide.

External and internal factors

It is important that cells exert careful control over when and how often they divide and move through the cycle. This control is exerted by both external and internal factors.

External factors controlling the cell cycle

External factors can be both physical and chemical in nature and these impact on the internal molecular controls or gene products inside the cell. Some examples of such factors are as follows:

- ***Nutrient dependence***: the cells need particular nutrients in their extracellular fluid to divide.
- ***Anchorage dependence***: many cells will only divide if they are attached to a substrate or surface.
- ***Density dependence:*** cells that are in close contact with one another will usually not divide. See *Figure 282*. Note that cancer cells do not respond in the same manner as normal cells.
- ***Large cell size***: large cells have a relatively low Surface Area to Volume ratio (SA:V) and this acts to stimulate cell division to give two smaller cells that will have a higher SA:V ratio and be more efficient at exchanging substances with their environment.

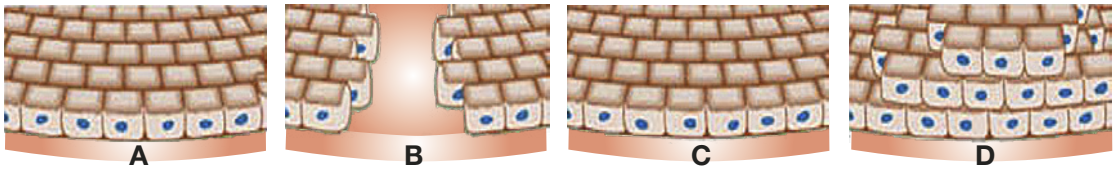


Figure 282 How density dependence affects cell division

Chemical factors involved in the control of the cell cycle include hormones binding to specific target cells and tissues that possess receptor molecules with a complementary shape to the hormone. Refer to *Figures 136* and *216* in previous chapters, indicating the action of molecules binding to complementary receptors.

Examples are numerous and include: growth hormone (GH), sex hormones such as follicle stimulating hormone (FSH) and cytokinins in plants.

Often hormones stimulate cells to express specific genes that result in the production of molecules called **growth factors,** such as proteins or hormones. If cells are deprived of growth factors, they generally will not divide.

Figure 283 illustrates the binding of a growth factor and the subsequent **signal transduction** causing gene stimulation. This illustrates how an external factor (growth factor) can impact on an internal molecular control factor.

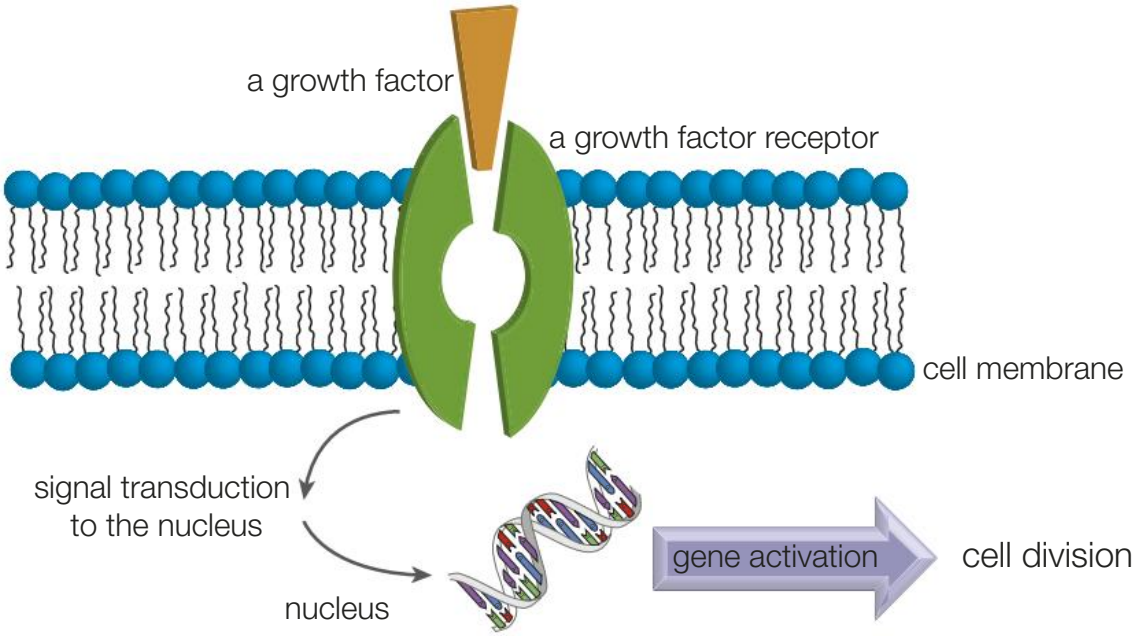


Figure 283 The process of binding of a growth factor and signal transduction

Internal factors controlling cell cycle

The cell produces gene products (proteins)that regulate the cell cycle and **cyclins** are the most important regulators of these gene products. There are several basic types of cyclins and each cyclin is associated with a particular phase of the cycle and helps to drive what happens in that phase.

M cyclin promotes the events of mitosis, such as the breakdown of the nuclear membrane and the condensation of the chromosomes. Typical cyclins are present at low levels for most of the cycle but increase strongly when required. Cyclins operate by binding with enzymes, called **cyclin-dependent kinases (Cdks)**, which activates the enzyme and forms **mitosis promoting factor (MPF)**. MPF can also be called maturation promoting factor or M-phase promoting factor. Refer to *Figure 284*.

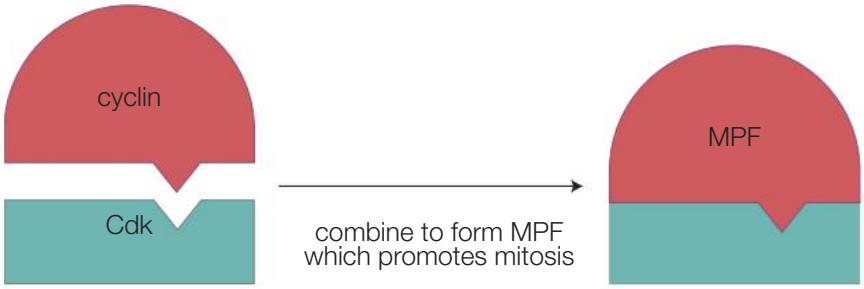


Figure 284 The mechanism of cyclin, Cdk and MPF

Refer to *Figure 285* which shows the concentrations of mitosis promoting cyclin and the resulting complex **MPF** which is formed when the cyclin binds to Cdk. High concentrations of MPF stimulate the onset of mitosis but it subsequently breaks down to allow completion of the process.

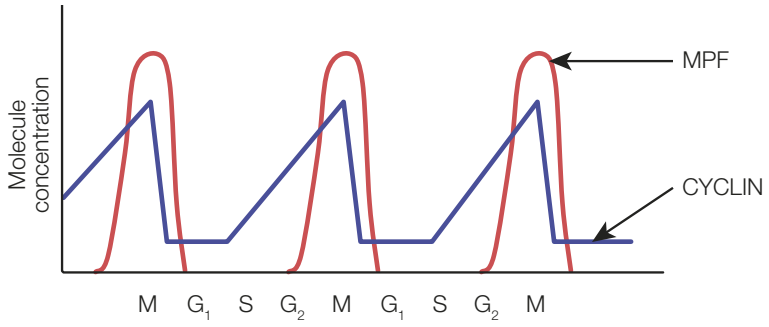


Figure 285 The role of MPF and cyclin

Therefore, external factors like growth factors typically increase the activity of Cdks and cyclins, whereas others like DNA damage may slow or decrease the activity.

Helpful online resources

Maria C.Edwards: Cell Cycle Regulation

<https://www.youtube.com/watch?v=Jmqd9Qj_PTA>

Carcinogens

Carcinogens can be physical or chemical factors that induce mutations in genes and give rise to uncontrolled cell growth or cancer.

Chapter 1.6 presented a range of different types of mutations, along with a range of factors (**mutagens**) like ionising radiation, mutagenic chemicals, high temperatures and viruses, which can increase mutation rates and thus increase the likelihood of cancer.

Cancer is a disease caused by **uncontrolled cell division**, leading to tumour formation. Cancer will occur as a result of factors that upset the normal controls of the cell cycle.

Helpful online resources

Amoeba Sisters: Cell Cycle (and Cancer) Updated

<https://www.youtube.com/watch?v=QVCjdNxJreE>

In Chapter 1.5, it was established that there are three types of genes associated with cancer:

Oncogenes

These are genes that are called tumour genes and when the function of the normal gene is altered,(e.g. by single mutation) the resulting **oncogene** may over activate the cell cycle; for example, by the overproduction of a growth factor.

DNA repair genes

These DNA repair genes produce products that repair DNA that has been damaged by factors, such as X-rays or mutagenic chemicals. If the normal DNA repair processes do not function as they should, the cell cycle may allow faulty cells to move through the cell cycle.

Tumour suppression genes

The p53 gene, mentioned earlier in this chapter, is a tumour suppression gene that produces a p53 tumour suppressor protein that prevents the production and proliferation of cells with damaged DNA. It does this by binding to specific sequences in the DNA and stopping the cell cycle. Once the cell cycle has been stopped, the p53 protein activates gene expression of other proteins involved in **DNA repair**. It is important that these genetic alterations are not passed on to daughter cells. However, if the DNA cannot be repaired, p53 further activates the gene expression of proteins involved in **apoptosis**, which is the process of programmed cell death. It has been found that p53 is inactive in almost 50% of all cancers. *Figure 286* summarises the action of p53.

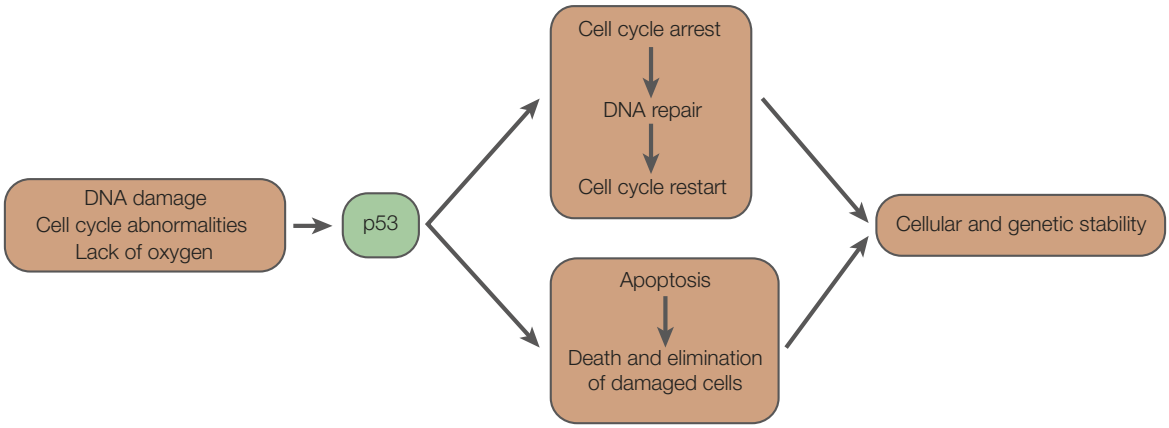


Figure 286 A summary of some of the regulatory actions of p53

Helpful online resources

Nature Video: p53: Guardian of the Genome
<https://www.youtube.com/watch?v=_lsvd01XvSs>

TED-Ed: The cancer gene we all have - Michael Windelspecht
<https://www.youtube.com/watch?v=pOyKFgGKmHE>

TED-Ed: How do cancer cells behave differently from healthy ones? - George Zaidan
<https://www.youtube.com/watch?v=BmFEoCFDi-w>

TED-Ed: Why is it so hard to cure cancer? - Kyuson Yun
<https://www.youtube.com/watch?v=h2rR77VsF5c>

Metastasis

Cancer may begin in any organ or tissue. If tumour cells evade the destruction by the immune system a lump of non-invasive tissue forms called a tumour. Subsequent division of these tumour cells may lead to a malignant tumour; a lump of invasive tissue. Cells from an invasive tumour are able to break away from the tumour mass and enter the circulatory (or lymphatic) system which transports them to other parts of the body, where they continue to divide. Tumour cells that divide at locations distant from the original tumour site, grow to form secondary tumours, a process called metastasis (see *Figure 287*).

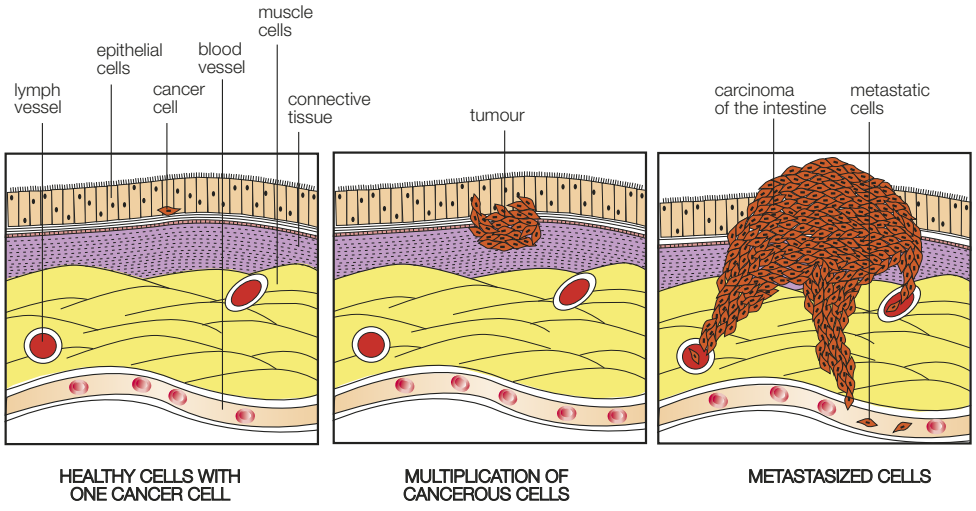


Figure 287 The process of metastasis

Helpful online resources

TED-Ed: What happens when your DNA is damaged? - Monica Menesini
https://www.youtube.com/watch?v=vP8-5Bhd2ag&t=64s

TED-Ed: How does cancer spread through the body? - Ivan Seah Yu Jun
https://www.youtube.com/watch?v=OcigJn8UJNQ

Culturing cells

Scientists have developed methods where they can successfully grow cells in the laboratory; these are referred to as cell-culture techniques.

There are a range of cell types that can be used and, in its simplest form, techniques involve the dispersal of cells in an artificial environment.

This environment needs to provide ideal conditions for cellular growth, including:

- nutrients, including sugars, amino acids and mineral ions
- a suitable medium for growth: a plate or suspension
- optimal temperature, pH, gases
- a sterile environment
- growth factors.

Sugars like glucose (and the gas oxygen) need to be supplied for cells to perform aerobic respiration and amino acids enable them to synthesise proteins. Using the optimal temperature (about 37ºC in human cell culture) and keeping it constant, maximises the growth rate of the cultured cells. Selecting and maintaining the optimal pH level minimises disruption to the activity of enzymes. Ensuring the culture medium is sterile can be achieved by using antibiotics and is necessary to prevent infection of the cultured cells due to the growth of unwanted microorganisms. Growth factors are added to stimulate division of the cells to be cultured.

Applications

A variety of applications of cell culturing were briefly explained in Chapter 1.8. The list below gives some contemporary examples that illustrate where cell culturing is used extensively throughout the scientific world:

- manufacturing vaccines
- to test the effect of antibiotics on bacterial infections to determine which antibiotics the species is not resistant to and can therefore be used to treat the infection for an individual
- to culture embryos to implant into expecting mother or surrogate mother through in vitro fertilisation (IVF)
- culturing human stem cells for scientific research and differentiation into specific somatic cells
- use of biotechnology and recombinant DNA to manufacture a range of critical products; including enzymes, hormones, monoclonal antibodies and anti-cancer agents
- a key process in cellular agriculture is the production of transgenic organisms with targeted genes, e.g. for herbicide resistance
- improving the techniques of food production e.g. producing cell-cultured meat
- growing human tissue for drug testing, e.g. to study the effects on human cells before release, or for reconstructive surgery e.g. growing skin to treat the victims of serious burns.

Figure 288 illustrates general cell culture techniques.

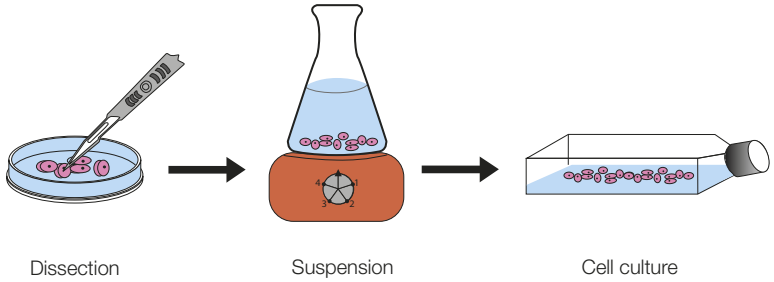


Figure 288 The process of tissue culturing

Helpful online resources

Business Spectator: Dr Fiona Wood on spray on skin

<https://www.youtube.com/watch?v=mrxLBpy0_10>

The profile of a medical scientist - *Dr Lauren Thurgood*

Cancers can be separated into two main types, solid tumours and blood cancers. Solid tumours affect tissues such as the lung, breast, colon and liver, whereas blood cancers (also called haematological malignancies) affect the blood, bone marrow or lymphatic system. Blood cancers include leukaemias, lymphomas and myelomas.

Haematological malignancies are the third most common cancer in Australia and depending on the type, have very diverse survival rates. My work focus on leukaemia, which is typified by the rapid production of white blood cells, these cells are not able to carry out their usual tasks of fighting infection and also impair the formation of red blood cells (anaemia) and platelets (thrombocytopenia) within the bone marrow.

Leukaemia can be classified as two types; lymphocytic, where the abnormal cell growth affects a type of white blood cell called lymphocytes and myeloid, which affects cells that mature into red blood cells, platelets or a group of white blood cells called granulocytes, monocytes or platelets. Further classifications can be made based on whether the leukaemia is chronic or acute. Therefore, the four types of leukaemia are acute lymphocytic (ALL), acute myeloid (AML), chronic lymphocytic (CLL) and chronic myeloid (CML).

Leukaemia occurs in both adults and children, with ALL being the most common form of childhood leukaemia, in fact leukaemia is the most common cancer in people aged 0-24. My work focuses on CLL, which is the most common form of adult leukaemia in the western world. In CLL, there is a accumulation of a type of white blood cell called a B-cell, which is pivotal in the immune response. CLL is usually diagnosed incidentally after a routine blood test returns a result showing high levels of lymphocytes. Diagnosis is confirmed by looking for particular markers on the surface of the B-cells obtained from a blood test using a technique called flow cytometry. This technique uses antibodies against proteins on the cell membrane which are known to be present on CLL cells, such as markers called CD5, CD19 and CD23. The antibodies are tagged with a fluorescent marker which can be detected by a machine called a flow cytometer producing a pattern called an immuno-phenotype. This is important, as each type of leukaemia has a different immuno-phenotype and therefore this step is pivotal to determine which type of leukaemia is present.

The cause of CLL is not known, but often patients have mutations in particular chromosomes. To determine the patients karyotype, a genetic test called fluorescent in situ hybridization (FISH) is used. In FISH, special fluorescent probes are used which hybridize to specific regions of DNA within the chromosome, either on the long arm (q) or short arm (p). In patients with no mutations, two fluorescent dots can be seen under the microscope in every cell, representing both copies of that particular chromosome region. In patients with deletions, the fluorescent probes can't hybridize resulting in either one dot (a deletion in one of the chromosomes) or no dots (a deletion in both chromosomes). Common regions which are deleted in CLL include the long arm of chromosome 13 (del13q), the long arm of chromosome 11 (del11q) and the short arm of chromosome 17 (del17p). Results of the genetic testing can predict how quickly the disease will progress and what treatment options will have the best outcomes.

My research looks at CLL patients with differing disease outcomes, for example, patients with del17p progress rapidly and often respond poorly to treatment and people with del13q often have a slow disease course which may never require treatment. My work is to generate a protein expression profile in the CLL cells taken from these patients using a technique called mass spectrometry. I then compare the proteins from patients with differing clinical outcomes to work out how the cells are different, why some grow much more rapidly and some are less prone to death by chemotherapy. I have found differences in pathways that are responsible for cell metabolism, in particular differences in the generation of a cell component called lipids. Lipids provide important energy to cells but are also imperative structural components, particularly in cell membranes. They play pivotal roles in intracellular signalling and in the response to chemotherapy. Lipids are now emerging as an important aspect in cellular transformation, tumour development and tumour progression. My work will continue to investigate the role of lipids in CLL and whether manipulating lipid levels within cells could represent a therapeutic target to drive the cells towards death, or whether agents that manipulate lipid levels could be used with current chemotherapy agents to promote a better response, called drug synergy.

This article was kindly contributed by Dr. Lauren Thurgood, who is a graduate of Flinders University and a researcher at Flinders University, College of Medicine and Public Health in South Australia.

Limitations

As with most developments and technologies, there are many areas that are unknown, require further research or provide current limitations to the progress and applications available.

Chapter 1.8 explained a few of these more common issues associated with advances in biotechnology and many of these apply or are relevant to culturing cells.

There are also practical limitations including:

- accumulation of toxins and/or dead cells
- it is hard to culture meat that consists of the correct types and ratios of the different types of tissues as naturally produced meat
- changes in pH of the growth media
- **contact inhibition** i.e. density dependence
- genetic and epigenetic changes perhaps leading to culture-adapted cells with changed capacities
- most primary cells tend to stop dividing after about 50 divisions (referred to as the *Hayflick limit*).

Helpful online resources

TED-Ed: How in vitro fertilization (IVF) works - Nassim Assefi and Brian A. Levine
<https://www.youtube.com/watch?v=P27waC05Hdk>

WIRED: Inside the Quest to Make Lab Grown Meat | WIRED
<https://www.youtube.com/watch?v=QO9SS1NS6MM>

2.8 Review questions

Multiple choice questions

1. Specific plant hormones (auxins) are added when plant tissue is cultured.

   These hormones are added to:

   J enable energy provision to the tissue which is essential for growth.

   K sterilise the tissue destroying fungi and bacteria.

   L provide specific nutrients essential for growth.

   M stimulate cell division and promote rapid growth.

2. Which one of the following statements about cell culturing is not correct?

   J A gene of interest can be transferred into bacteria by cell culture.

   K The temperature of the cell culture is critical because important proteins could denature at high temperatures.

   L Sterile conditions are required in a cell culture to prevent the growth of undesirable microorganisms.

   M A cell culture can be used to create genetically identical human skin cells.

3. Ataxia telangiectasia (AT) is a disease caused by a mutation in the DNA which causes several defects including a significant increase in cancer susceptibility. AT patients' cells in culture show susceptibility to spontaneous and radiation induced chromosome breaks.

   The most likely reason these patients suffer from an increase in cancer susceptibility is a mutation affecting:

   J the rate of meiosis

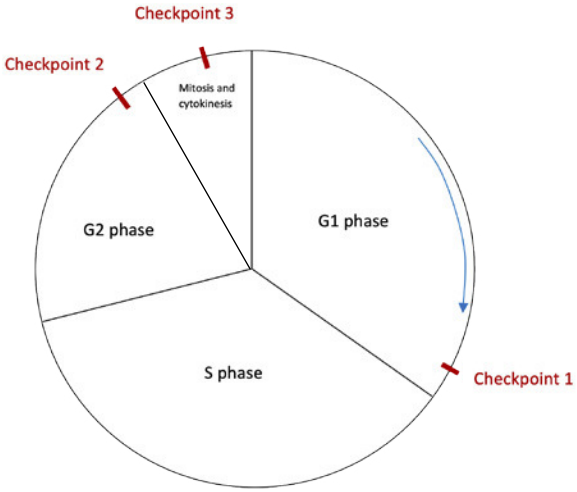
   K a gene which regulates the cell cycle

   L tissue cells leading to a suppression of DNA replication.

   M the rate of mitosis in reproductive cells

4. A checkpoint in the cell cycle is a control point where stop and go-ahead signals regulate the cycle.

Refer to the following diagram of a cell cycle control system to help you answer the question that follows.



Which one of the following most likely describes what might happen at one of the checkpoints?

J At checkpoint 3 the cell is checking to see that DNA replication has occurred successfully.

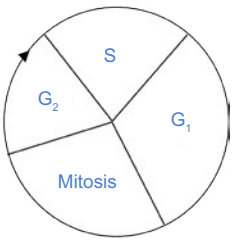
K At checkpoint 1 the cell will not proceed further if environmental conditions are not adequate for cell division.

L At checkpoint 2 the cell is checking to see that the chromosomes are successfully attached to the spindle apparatus.

M At checkpoint 2 the cell checks that the spindle fibres are in place ready for cell division.

5. 'p53' is the name of a tumour suppressor protein known to regulate the cell cycle and thus is involved in the prevention of cancer.

Refer to the diagram of the cell cycle below to help you answer the question that follows.



Which one of the following is a possible mode of action for p53 protein in helping to prevent cancer?

J Holding the cell cycle at the G_1/S checkpoint to allow DNA repair to occur

K Reducing the impact of mutations that have occurred during the mitotic phase

L Preventing the impact of carcinogens during the G_2 phase

M Promoting the correct transcription and translation processes during the S phase

6. There are many factors both chemical and physical that can influence the rate of cell division. Which one of the following is **not** true concerning the control of cell division?

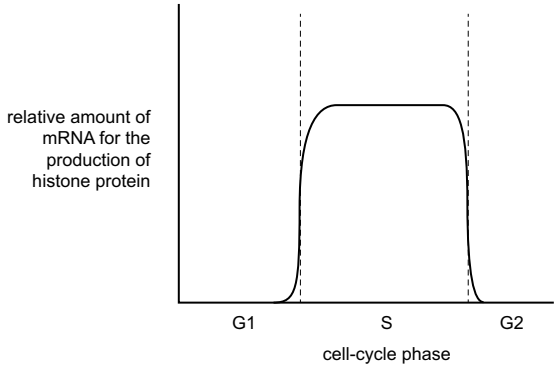
J Certain cells release proteins that stimulate other cells to divide.

K The SA: V ratio is a physical factor influencing cell division.

L Factors that control cell division are always external to the cell.

M Cancerous cells may make a required growth factor themselves and consequently not divide normally.

7. Refer to the graph below which shows different phases of the cell cycle and the relative amount of mRNA for the production of histone protein at varying times throughout a cell cycle.



With reference to the graph, which of the following statements is likely to be true?

J Histone proteins are only present in the cell during the S phase of the cell cycle.

K The gene expression for histone proteins occurs throughout the whole cell cycle.

L The expression of histone protein relies on the cell progressing through checkpoint at end of G2.

M Protein synthesis of histone proteins occurs concurrently with semi-conservative DNA replication.

8. Changes to cellular apoptosis (cell death) function can cause cells to become cancerous.

Which one of the following changes to cellular apoptosis could result in a cancer?

J An increase in apoptosis, resulting in increased inflammation.

K An increase in apoptosis, which increases the activation of white blood cells that target cancer cells.

L A decrease in apoptosis, which results in the death of surrounding cells.

M A decrease in apoptosis, resulting in increased survival of pre-cancerous cells.

9. Carcinogens are substances that:

J decrease the rate of cell division by causing beneficial mutations to onco genes.

K decrease the rate of cell division by causing harmful mutations to onco genes.

L increase the rate of cell division by causing beneficial mutations to onco genes.

M increase the rate of cell division by causing harmful mutations to onco genes.

10. Which of the following is true concerning mutagens and carcinogens?

J All mutagenic substances have the potential to cause cancer.

K Mutagens may lead to cancer by disrupting metabolic processes in cells.

L Carcinogens are always chemicals that induce changes in DNA.

M Anything that can lead to a change in the DNA of an organism is termed a carcinogen.

Free response questions

1. Cells that are not dividing are said to be in the G0 phase.

a) Give examples of the types of cells found in this phase, both permanently and temporarily.

Permanent example:

Temporary example:

b) Suggest a possible trigger that may induce a cell in G0 temporarily to move into the cycle in G1.

2. Molecular checks of cells and molecules occur at regular points in the cell cycle and these occur at 'checkpoints'.
   a) State the location of the three checkpoints in the cell cycle.

   b) Using an example to support your answer, explain the role of checkpoints in the cell cycle.

3. Describe the two ways that MPF helps regulate cell division.

4. Name three types of genes that if they are faulty (e.g. mutated) may lead to cancer. For each type of gene, describe how the malfunction could lead to tumour formation.

5. The cell cycle can be controlled by both external and internal factors.
   a) Name three external factors that can influence the cell cycle and, for each, describe how they would influence cell division.

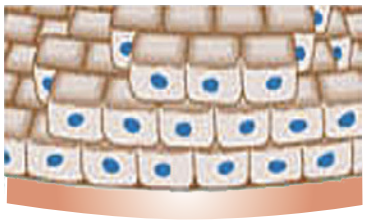
   b) Hormones can influence cell division; explain why a hormone such as human growth hormone (hGH) may stimulate certain cells to divide but not others.

6. Describe how the action of the p53 protein in causing apoptosis may prevent cancer from starting.

7. State why each of the following would be required for the successful culturing of cells:
   a) sugars
   b) growth factors
   c) suitable pH
8. Humans culture cells for a variety of purposes.
   a) Describe one contemporary application in the medical fields of cell culturing.

   b) Outline two possible limitations associated with this application.

9. *Refer to the diagram to answer the questions that follow:*

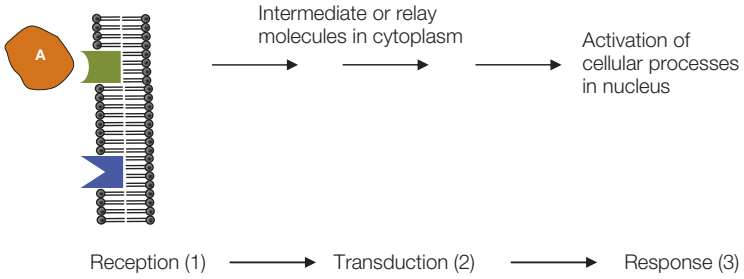


a) Name the mechanism that ensures that normal cells stop dividing upon contact with other cells.

b) Describe one reason why the cancer cells shown in the diagram above continue to divide even though they are in contact with other cells.

c) Explain why the activity of the p53 gene increases when cells undergo damage by UV radiation.

10. *Refer to the diagram below showing what is termed a transduction pathway.*



This pathway is involved in regulating the cell-cycle by transmitting signals from the cell membrane through the cell to influence critical control points in the cycle called checkpoints.

a) Name the molecule represented in the diagram as 'A'.

b) The initiation of such a signal is very specific. State the feature that ensures this specificity.

c) Explain an example of how fluctuations in the concentration of molecules inside the cell can initiate mitotic division.

11. Explain a possible causative link between overexposure to the sun and cancers of the skin, such as melanoma.

12. Cell culturing is associated with several bioethical issues. Stem-cell culturing is one such technique.

a) Explain a possible application of stem cell culturing.

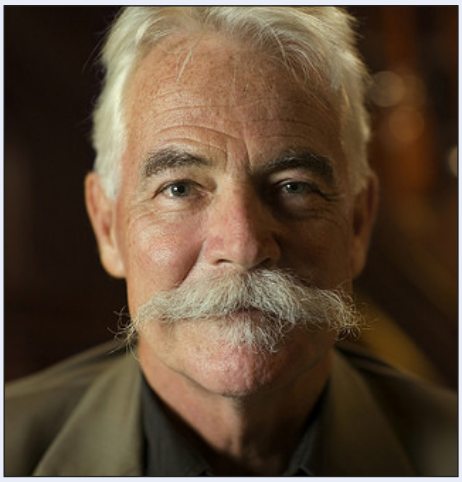
b) Describe two bioethical issues that arise from such a technique.

13. Herbicides are chemicals that destroy weeds and are often sprayed on crops to improve agricultural production. The mode of action of herbicides is often based around disruptions to the cell cycle. Some affect microtubule proteins and others affect cytokinases. Predict two ways in which disruption to the microtubule production and function may disrupt the cell cycle in plant cells.

Science as a Human Endeavour 2.8 - Stem cell research

Since the discovery of stem cells there has been a great deal of interest in their possible use for medical purposes. Human stem cell cultures are providing stem cells for research into treating conditions ranging from Parkinson's disease to multiple sclerosis, heart disease, and Type I diabetes. Recently, work headed by Australia's 2017 Australian of the Year *Alan Mackay-Sims* concluded that properly trialled treatments for spinal injuries are now possible and safe.

The medical use of stem cells, however, is not without its risks. Transplanted stem cells can lead to the wrong cells developing, cells derived from them may be rejected by the patient's body, and tumour formation is a possibility. Various untested stem cell treatments are available in other countries, and there is a small but steady flow of people who seek them out. The risks these 'stem cell tourists' face are considerable.



For these reasons stem cell research is regulated. In Australia, this includes by bodies such as the Australian Government's Therapeutic Goods Administration (TGA) and the Australia New Zealand Clinical Trials Registry. Countries like England have a comprehensive and well-established framework to guide stem cell research, as do nations like Spain, Sweden and The United States. Collaboration between these agencies is essential to ensure that research is properly reviewed and validated internationally to ensure the promise of new stem cell therapies is properly balanced with the reality of their safety, cost and long-term effectiveness.

Use your understanding of the interactions between science and society to answer the following questions.

1. Discuss why international collaboration between teams of stem cell researchers is important for the potential discovery of new stem cell based treatments.

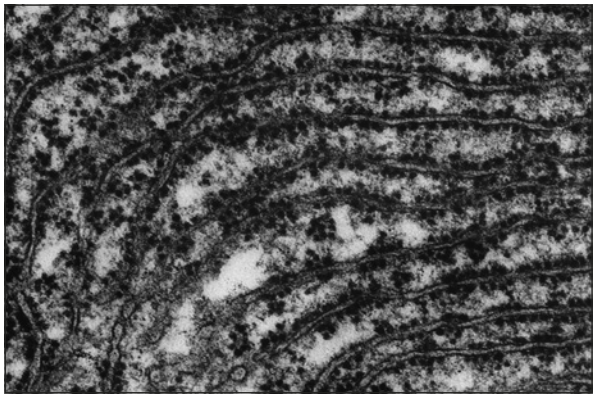
2. Discuss one unexpected consequence of a potential increase in 'stem cell tourists' to society..

Topic 2 Review Test

Allocate 90 minutes to complete this Test. These are all SACE exam-style questions. Indicate your choice for each of the multiple choice questions (each worth one mark) and answer all of the other questions in the spaces provided. The number of marks for each free response question is shown in brackets. It is recommended that you compare your answers to the suggested answers section as part of your revision. Please note that the suggested answers are not extensive or exclusive.

Section 1: Multiple choice questions (15 marks)

1. *Refer to the electron micrograph showing cellular structures to answer the question* that follows.



Which one of the following is NOT correct regarding this structure?

J Membrane bound vesicles move between it and the Golgi apparatus.

K The transcription of proteins occurs on its surface.

L The structure can be continuous with the nuclear membrane.

M The structure is held together by cytoskeleton.

2. Which one of the following is correct concerning the cell membrane?

J Protein molecules are found in fixed positions embedded in the lipid-bilayer.

K It is relatively permeable to large water-soluble molecules.

L It allows molecules to pass through only by active processes.

M It is relatively impermeable to ions and many molecules.

3. Which of the following does NOT involve the cytoskeleton?

J Active transport of glucose against the concentration gradient.

K Uptake of extracellular material by endocytosis.

L Cell division.

M Moving vesicles inside a cell.

4. Which of the following statements is true of autotrophic organisms?

J They may obtain energy for cellular processes from aerobic respiration.

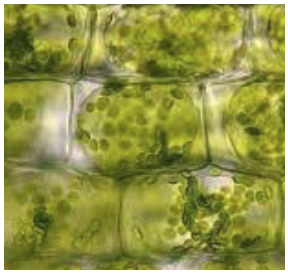
K They all use photosynthesis to make carbon compounds.

L They use energy from the breakdown of organic molecules to synthesize all of their requirements.

M They rely on existing molecules for their nutrition.

5. *Refer to the images below to answer the question that follows (magnifications not shown):*

Cell A



Cell B

Cell C

Which of these statements is true regarding these cells?

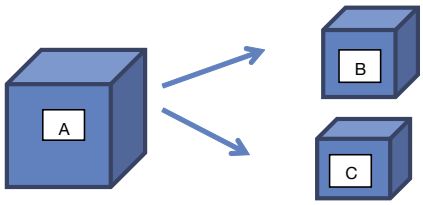
J Cell A has no organelles.

K Cells A and B both have cell walls and membranes.

L Cell B is a plant cell with chloroplasts and circular DNA.

M Cell C is a prokaryotic cell that would divide by binary fission.

6. *Refer to the diagram to the right showing division of a cell to answer the question that follows.*



Which one of the following is a true statement?

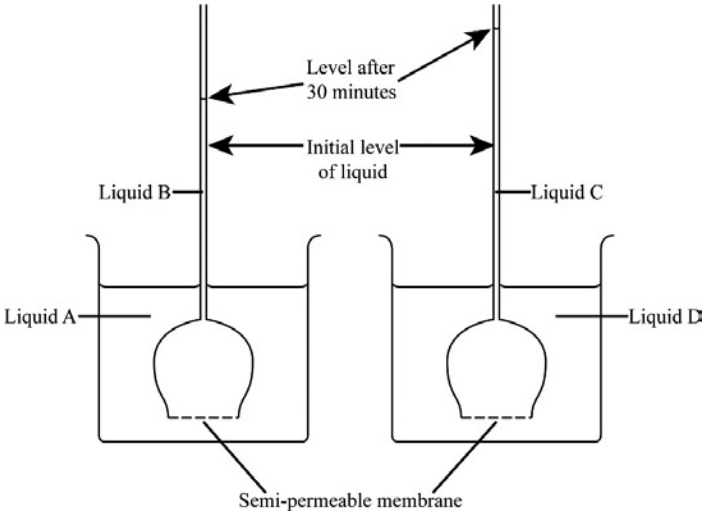
J Cell B has a greater surface area than cell A.

K Cell C has a smaller SA:V ratio than cell A.

L A trigger for cell A to divide could be its reduced ability to exchange materials with the external environment.

M As cell B grows, its efficiency in exchanging materials with the environment will increase.

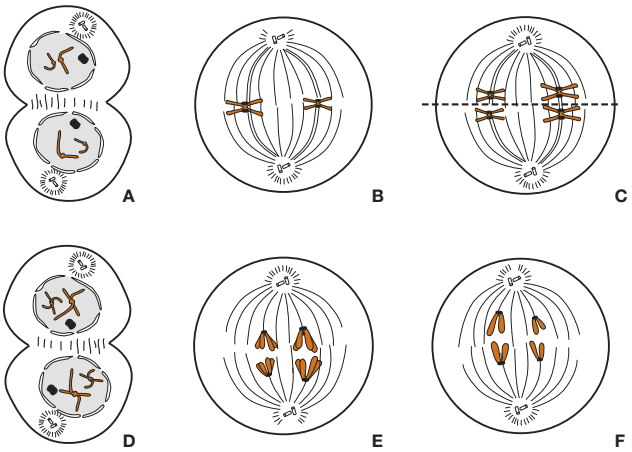
7. *Refer to the diagram below of an experimental set-up with four liquids, A,B,C&D.*



Which one of the following combination of liquids could give rise to the results observed?

	A	B	C	D
J	water	concentrated sucrose solution	dilute sucrose solution	water
K	water	dilute sucrose solution	concentrated sucrose solution	water
L	concentrated sucrose solution	water	water	dilute sucrose solution
M	dilute sucrose solution	water	water	concentrated sucrose solution

8. Refer to the diagram to the right showing a cell undergoing the process of meiosis to answer the question that follows.

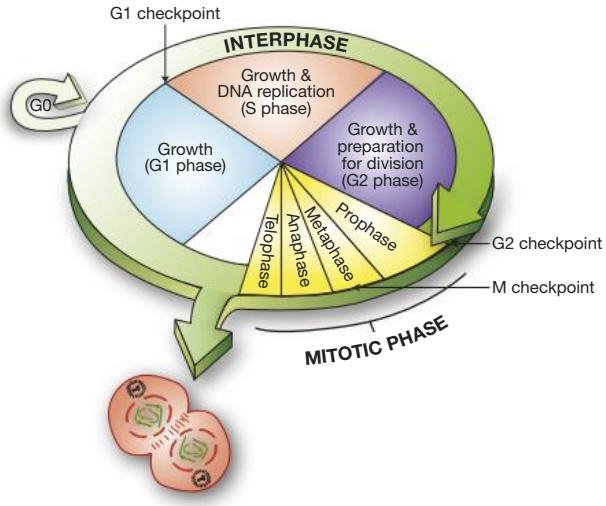


Which one of the following options identifies the stages of meiosis in the correct sequence from start to finish?

	Stages					
J	C	F	A	B	D	E
K	C	E	D	B	F	A
L	C	F	D	E	A	B
M	C	E	F	D	B	A

RT

9. *Refer to the following diagram of a typical cell cycle.*



Checkpoints are points in the cell cycle that ensure that proper division of the cell will occur. Which one of the following is correct concerning one of the checkpoints?

J At checkpoint G2 the cell checks for the proper attachment of the DNA to spindle fibres.

K Before progressing past checkpoint G1 the cell needs to respond to external factors or signals.

L At checkpoint M the cell checks for damage to the DNA.

M At checkpoint G1 the cell checks that the DNA has been replicated without errors.

10. Which of the following statements is correct?

J Only one measurement is required to have precise data.

K Results can be consistently and reliably accurate but not precise.

L Precision is how closely results agree with the accepted value.

M Results can be precise without being accurate.

11. Which one of the following characteristics applies to prokaryotic cells?

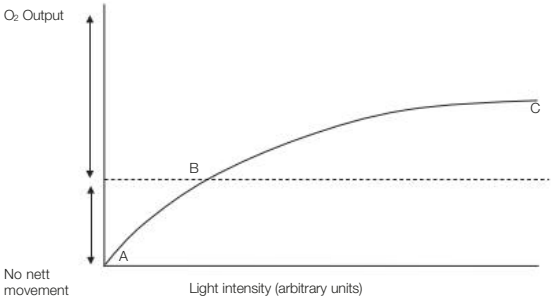
J They ingest materials by endocytosis.

K Translation occurs on ribosomes.

L They have single stranded DNA.

M They divide by mitosis.

12. *Refer to the graph below* showing the rates of O_2 uptake/output in a plant (Y axis) with changing light intensity (X axis).



Which of the following is a correct statement?

J At point B the plant begins photosynthesizing.

K Point C is the maximum rate of photosynthesis that can be achieved by the plant.

L The rate of respiration is constant for A-C.

M From A-B the rate of respiration is greater than the rate of photosynthesis.

13. Red blood cells have an internal salt concentration of approximately 1% salt solution. If red blood cells are placed in a solution that is 3% salt concentration, the blood cells would show:

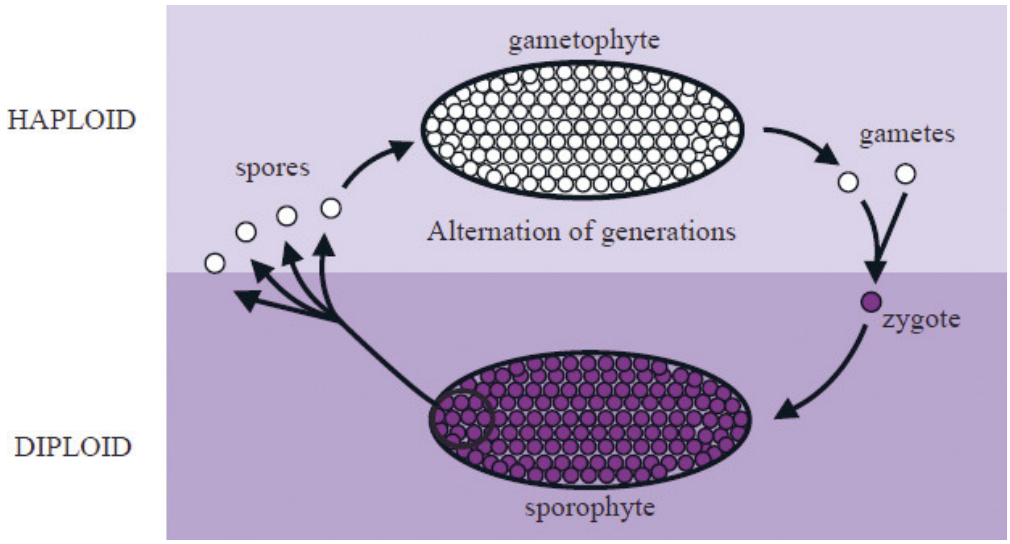
J An increase in mass and each cell would increase its surface area to volume ratio.

K A decrease in mass and each cell would increase its surface area to volume ratio.

L An increase in mass and each cell would decrease its surface area to volume ratio.

M A decrease in mass and each cell would decrease its surface area to volume ratio.

14. *Refer to the diagram below as an example of 'alternation of generations' to answer the question that follows.*



Which of the following statements is correct?

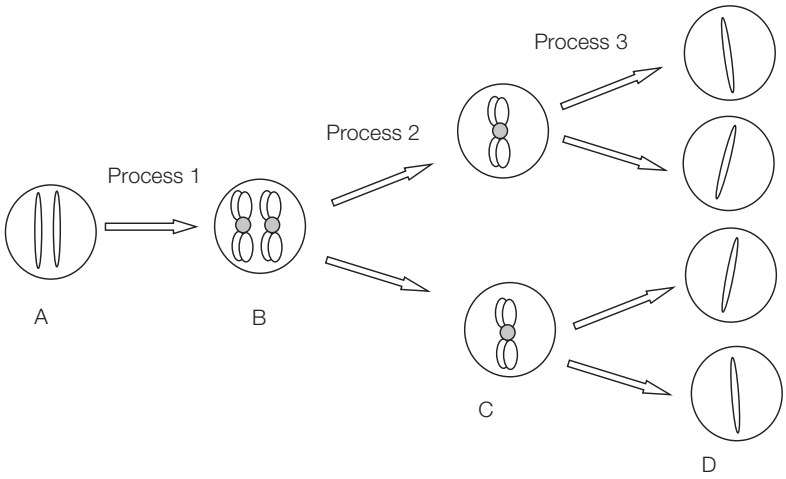
J The sporophyte produces spores by mitosis.

K The gametophyte produces gametes by meiosis.

L Fertilisation does not occur in this alternation of generations.

M The gametophyte grows from a spore by mitosis.

15. *Refer to the flow diagram below which represents one pair of homologous chromosomes in a cell during meiosis to answer the question that follows.*



Which one of the following is correct concerning the processes listed above?

J Process 1 is transcription.

K Process 2 involves separation of the chromatids.

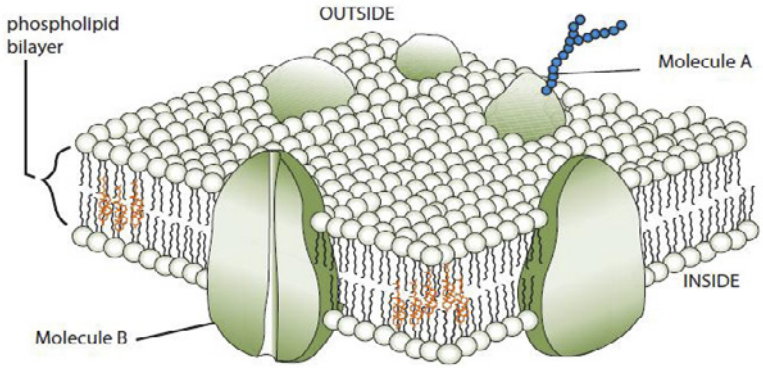
L Process 3 involves the separation of a homologous chromosome.

M Process 2 involves the formation of haploid cells.

RT

Section 2: Free response questions (75 marks)

16. *Refer to the diagram below of a model of the cell membrane.*



a) State the name of this model that represents the current understanding of the structure and function of the cell membrane.

(1 mark)

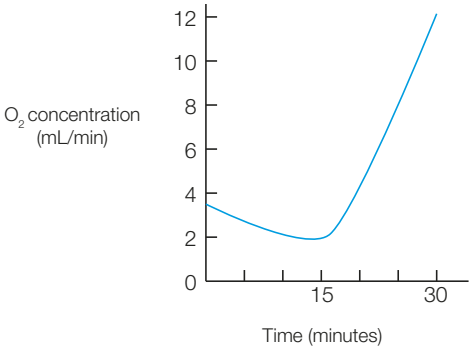
b) Explain the characteristics of structure A that might enable the molecule to be involved in cellular communication.

(3 marks)

c) Explain how the protein labelled B might function to actively move molecules into the cell against the concentration gradient.

(3 marks)

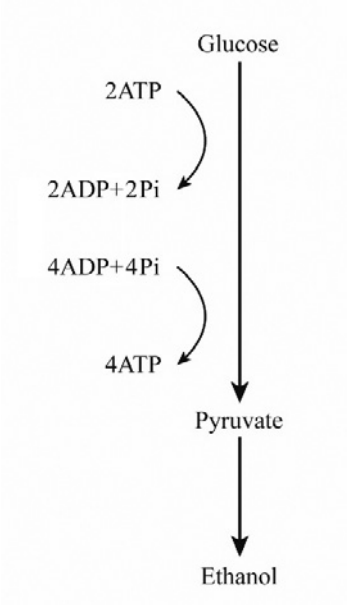
17. *Refer to the diagram below which shows data obtained in measuring the rate of photosynthesis in bean seedlings.* The plants were kept in the dark for 15 minutes and then exposed to light.



Explain the results obtained.

(4 marks)

18. The adjacent diagram summarises the process of alcohol fermentation in yeast cells. *Refer to this diagram to assist in answering the questions that follow.*



a) State where in the cell this reaction occurs.

(1 mark)

b) Using evidence from the diagram on the right, explain how scientists know that when glucose breaks down to pyruvate there is a nett release of energy.

(4 marks)

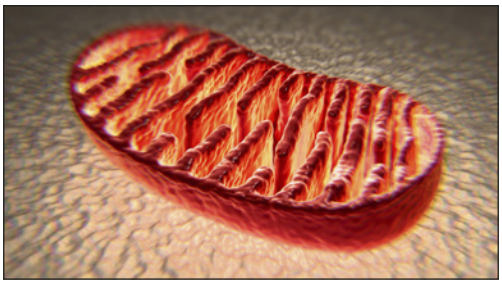
c) Write the chemical equation that represents this process of alcohol fermentation.

(2 marks)

d) State two advantages in using ATP as an energy molecule in cells.

(2 marks)

19. *Refer to the image below to answer the questions that follow.*



a) Name the cellular process that occurs in this organelle.

(1 mark)

b) Name the inner membrane extensions.

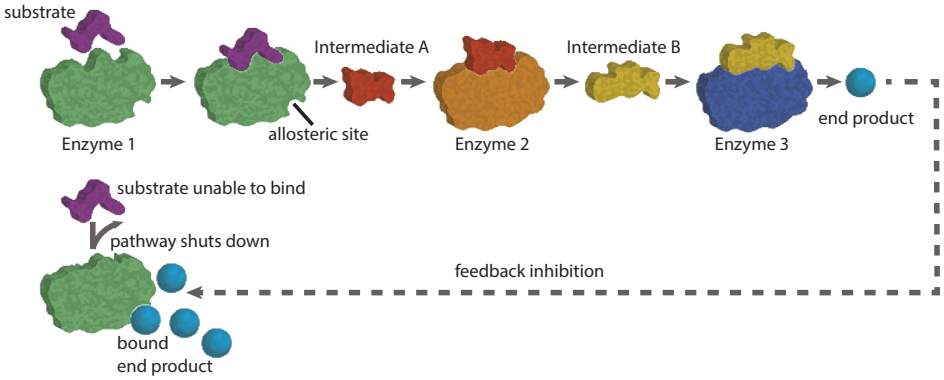
(1 mark)

c) Describe how the structure of these membranes contributes to the function of the organelle.

(2 marks)

RT

20. *Refer to the diagram below which is a representation of a simple metabolic pathway to answer the questions that follow*:



a) State two reasons why most biochemical reactions occur in pathways such as this.

(2 marks)

b) The pathway shown above is an example of end-product inhibition. Explain how the production of the end product acts as a mechanism to slow the reaction.

(3 marks)

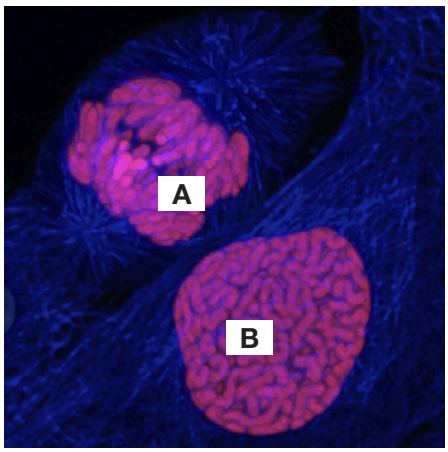
c) Describe one advantage of end-product inhibition to organisms.

(2 marks)

21. *Refer to the photograph below showing plant cells in two stages of mitosis to answer the questions that follow.*

a) State what is happening to the chromosomes and describe the significance of these processes for both cells A and B.

Photograph A



(2 marks)

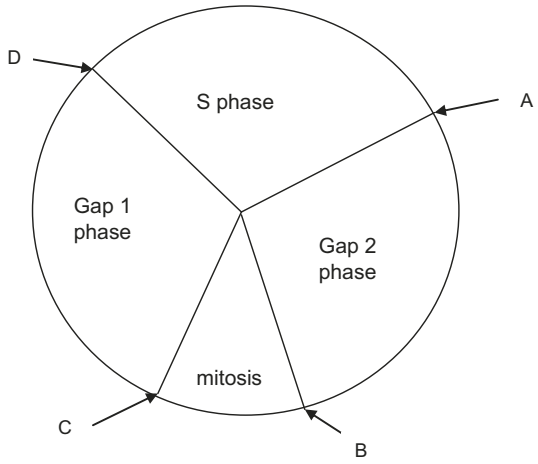
Photograph B

(2 marks)

b) State one advantage to a population in reproducing using mitotic division.

(1 mark)

22. *Refer to the diagram below of the cell cycle to answer the questions that follow:*



a) State the difference in the amount of DNA per cell between points D→A when compared with C→D.

(1 mark)

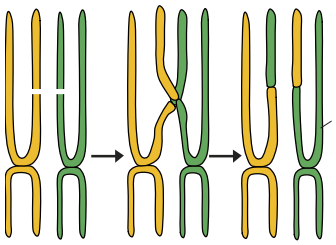
b) The cell cycle has defined checkpoints at specific points in the cycle. Describe a likely function of a checkpoint located near point B.

(2 marks)

c) Describe an example to explain how a gene product could influence how a cell progresses through the cycle.

(2 marks)

23. *Refer to the diagrams below showing a process that occurs during meiotic division, to answer the questions that follow.*



a) The chromosomes shown are homologous. State one similarity and one difference between homologous chromosomes.

Similarity

(1 mark)

Difference:

(1 mark)

b) Explain how the process above contributes to genetic variation in populations that reproduce sexually.

(3 marks)

RT

c) Explain another process that occurs during meiosis I which can give rise to genetic variation between parents and their offspring.

(3 marks)

24. Human infertility clinics perform IVF procedures for couples wishing to have children but are unable to conceive naturally.

A typical procedure might involve the following steps:

- Removing 20 mature ova (eggs) from the ovaries of the woman
- Use sperm from either the husband or a donor to fertilise the eggs
- Incubate the fertilised eggs to produce embryos
- Select the best few embryos for implantation into the woman's uterus
- Discard the remaining embryos
- Extract stem cells from the discarded embryos for use in stem cell research.

a) State two important techniques/factors that would be required in culturing the fertilised eggs.

(2 marks)

b) Discuss two potential limitations or concerns associated with the above procedure.

(4 marks)

25. *Refer to the photo and information below to answer the questions that follow.*

Paramecium is a unicellular organism that lives in fresh-water and possesses a structure known as a contractile vacuole. This vacuole fills with fresh water and periodically contracts to expel water from the cell.

A researcher conducted an investigation to observe the effect of changing the external solute (dissolved substances) concentration on the rate of contraction of the vacuole. The data is shown below. Refer to this data to answer the questions that follow.

External solute concentration (arbitrary units)	Number of contractions per minute
0.00	7.1
0.02	7.0
0.04	5.3
0.06	5.2
1.00	4.9

a) Describe the aim of this research.

(1 mark)

b) State two factors that need to be controlled during this investigation.

(2 marks)

c) Suggest a possible hypothesis that could be tested in this research.

(1 mark)

d) Name the dependent variable.

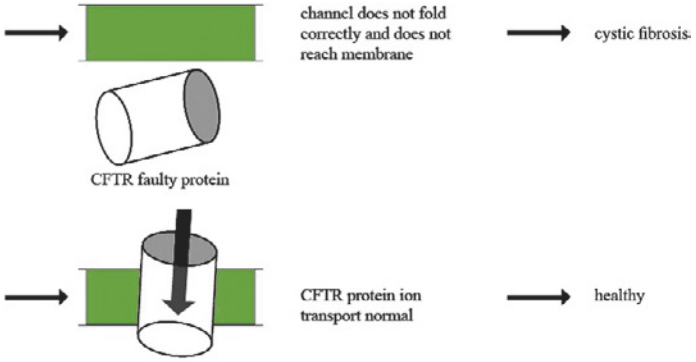
(1 mark)

e) Name one variable that might be difficult to control in the research and the effect it could have on the results collected.

(2 marks)

26. Cystic fibrosis is a genetic disorder caused by a mutation to the Cystic Fibrosis Transmembrane Conductance Regulator (CFTR) gene located on human chromosome 7. The symptoms of the disease include abnormal transport of sodium and chloride ions across cell membranes leading to thick viscous secretions that affect lungs, pancreas, liver and intestines.

Changes in the CFTR gene can affect the structure and function of the CFTR protein located in the cell membrane (refer to diagram below).



The most common mutation is a deletion of three DNA nucleotides leading to the absence of the amino acid phenylalanine at position 508 in the CFTR protein.

Use the information and diagram above to answer the following questions.

a) Explain why the 'normal' structure and function of the CFTR protein contributes to the transport of sodium and potassium ions across the membrane in a healthy individual.

(5 marks)

RT

b) Explain how the absence of the amino acid phenylalanine may alter the normal function of the cell membrane and lead to cystic fibrosis.

(4 marks)

27. Cell culturing has many beneficial applications for society. A current area of research and development is using cell cultures to print biological tissues and organs.

*Refer to the video link below and u*se your understanding of Science as a Human Endeavour to *answer the following questions.*

Helpful online resources

TED-Ed: How to 3D print human tissue–Taneka Jones

<https://www.youtube.com/watch?v=uHbn7wLN_3k>

a) Discuss how society has influenced research into the bioprinting of tissues and organs.

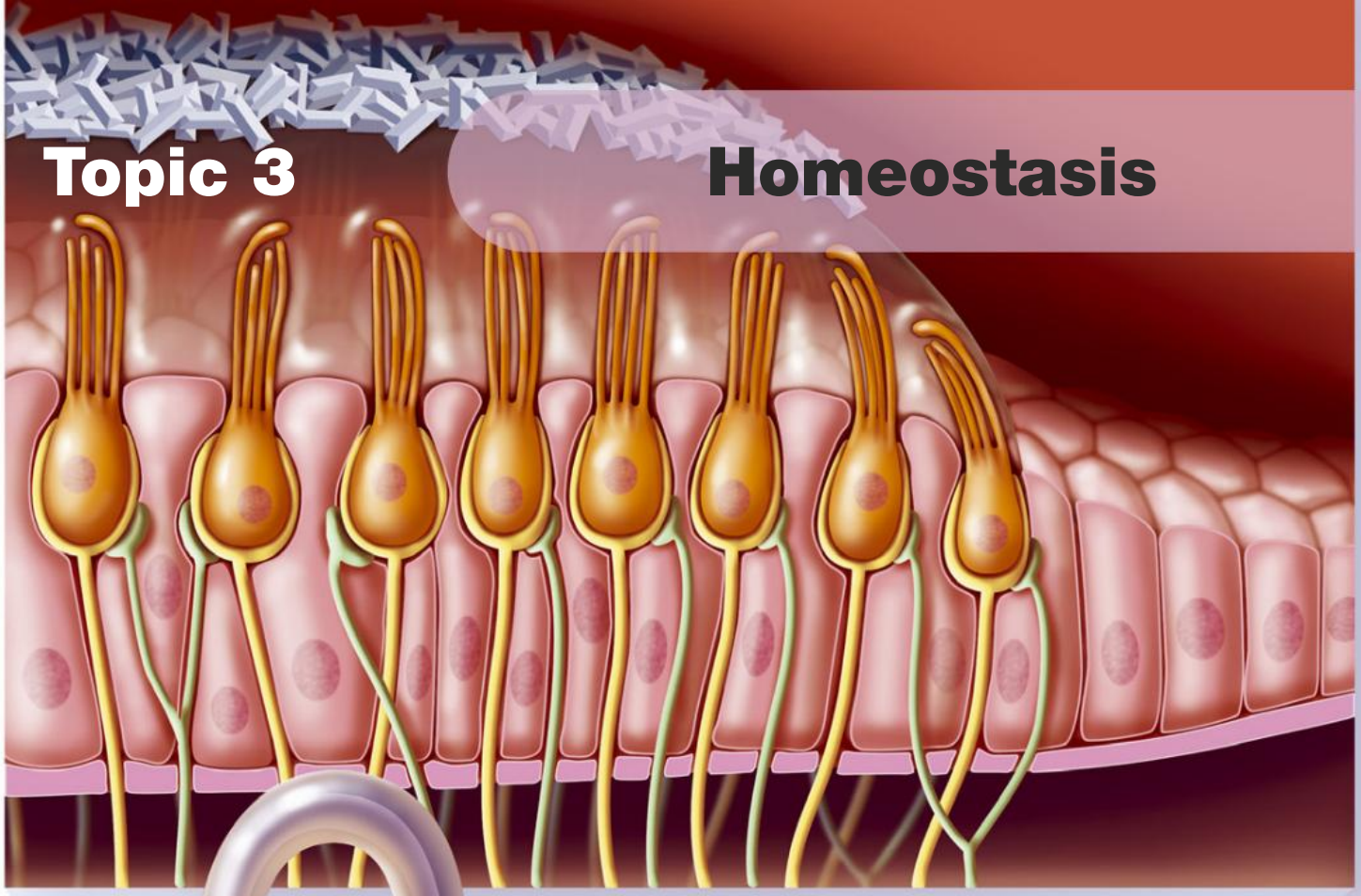
(2 marks)

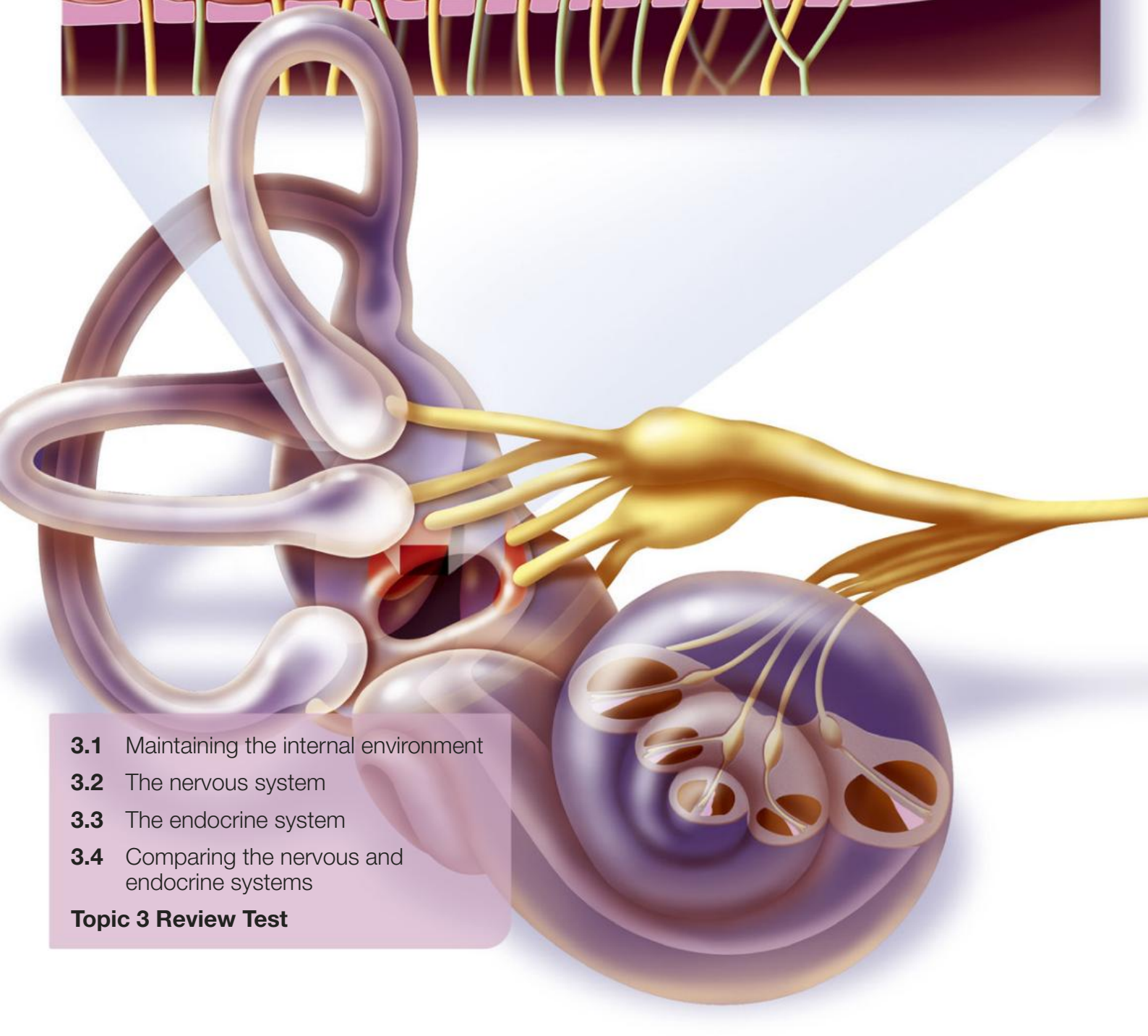
b) Discuss how the future successful bioprinting of kidneys could have an unexpected consequence on reducing illegal activity.

(2 marks)

Total: /85

Topic 3 Homeostasis





Chapter 3.1 Maintaining the internal environment

Science Understanding

Organisms survive most effectively within their tolerance limits. Factors for which organisms have tolerance limits include:

- body temperature
- water availability
- blood glucose level
- carbon dioxide concentration in the blood and tissues.

There are impacts on an organism when conditions fall outside its tolerance limits.

Organisms detect and respond to changes in the internal and external environment.

Homeostasis is the maintenance of a relatively constant internal environment. This ensures the optimum conditions for the body to function.

Homeostasis involves a stimulus–response and negative feedback model.

- Describe the role of sensory receptors.
- Describe the role of effectors.
- Explain the stimulus–response model.
- Recognise that in negative feedback the response inhibits the initial stimulus.

For an organism to function and carry out life's processes, it is essential that the composition and temperature of the internal environment is kept at a relatively steady state. One of the characteristics of life is the ability to **maintain a relatively stable internal environment,** independent of any changes happening in the external environment.

Homeostasis is the maintenance of the 'steady state' in response to changes, in both the external and the internal environments. This steady state is achieved through a range of mechanisms, including:

- Structural: particular physical features which assist in tolerating changes
- Physiological: the myriad of internal processes and mechanisms that detect and respond to changing conditions
- Behavioural: the particular behaviours or actions that help organisms survive in their environment.

Refer to *Figure 311* illustrating the basic concepts of homeostasis in organisms. There are a range of **variable factors** (e.g. pH, temperature, CO_2 levels, ion concentrations) in the internal environment that need to be kept at optimum or desired levels for cell functioning. Changes in either the internal or external environments may cause these variables to become either elevated or lowered. It is the body's homeostatic processes that act to either raise or lower the variables so that the optimum level is maintained.

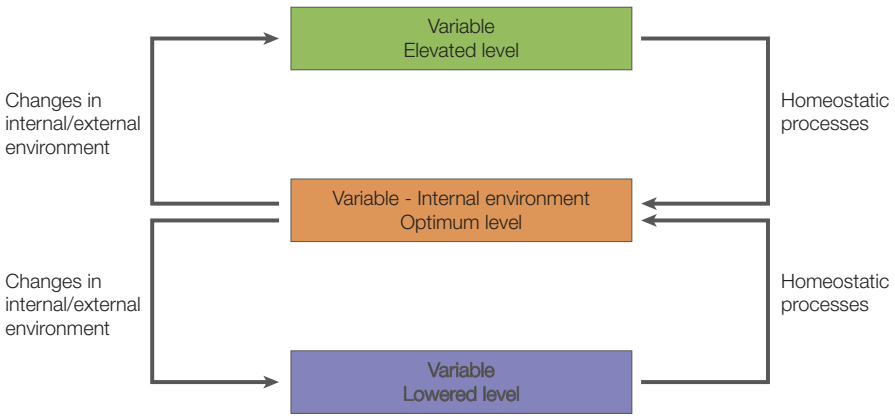


Figure 311 The basic concepts of homeostasis

Tolerance limits

There are several variable factors in the internal environment which need to be kept within particular **tolerance limits** so that organisms can operate most efficiently.

'Liebig's Law of the Minimum' describes the impact of limiting factors in biological systems. The effect was studied in Chapter 2.3 where it was noted that a limiting factor was the one variable that, when in short supply, will slow the rate of photosynthesis, irrespective of how abundant or plentiful the other resources might be. Similarly, if any of the variables that have been discussed, i.e. blood glucose, water, carbon dioxide and temperature, are outside of the tolerance levels then poor functioning of the organism will result, irrespective of the other variables.

Body temperature

For mammals, including humans, body temperate is usually maintained between 36°C and 38°C. Enzymes work best at around 37°C and are responsible for all of the cell's metabolic activity. If the internal temperature rises much above 40°C, this is a life-threatening situation called **hyperthermia** and conversely, a drop of a few degrees below 37°C can also be life-threatening and is called **hypothermia**. Refer to *Figure 312*.

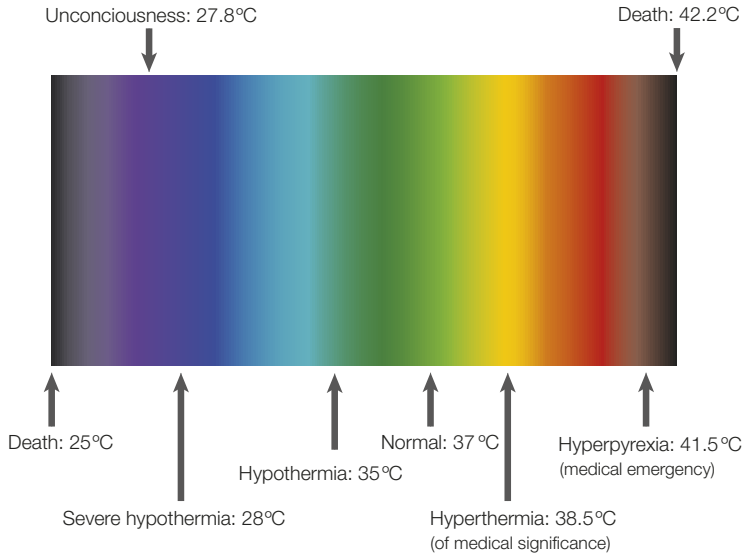


Figure 312 Temperature tolerance for humans

Water

The water/solute concentration balance in both the extracellular and/or intracellular environment is another critical factor that needs to be kept within specific tolerance levels. Shifts away from the normal levels can lead to swelling or shrivelling of cells as a result of osmosis. A solute concentration of about 0.9% NaCl is isotonic with blood plasma.

Blood carbon dioxide concentration

The carbon dioxide concentration in human blood is normally between 5-6% and again it is important that this is kept within these tolerance limits. Carbon dioxide is a non-toxic gas at normal levels and is required to stimulate and control the rate and depth of breathing. At high levels, CO_2 dissolving in the blood can lead to lowering the pH (**acidosis**). At levels greater than 10%, carbon dioxide is highly toxic leading to unconsciousness and ultimately death. Refer to *Figure 313* showing tolerance levels for humans.

Blood glucose level

Blood glucose levels are normally around 75-95 mg/dL (1dL = 1decilitre = 100mL) and sustained deviations from these levels cause serious health issues. The conditions or diseases where sufferers are outside the tolerance level are **hyperglycaemia** (too high blood glucose) and **hypoglycaemia** (too low blood glucose). Left untreated, both conditions quickly lead to symptoms including the loss of consciousness.

Diabetes is a disease associated with a high level of blood glucose, usually as a result of the lack of the hormone insulin or the tissue's responses to insulin. *Figure 314* summarises a range of symptoms associated with the disease; more information about this disease is in Chapter 3.3.

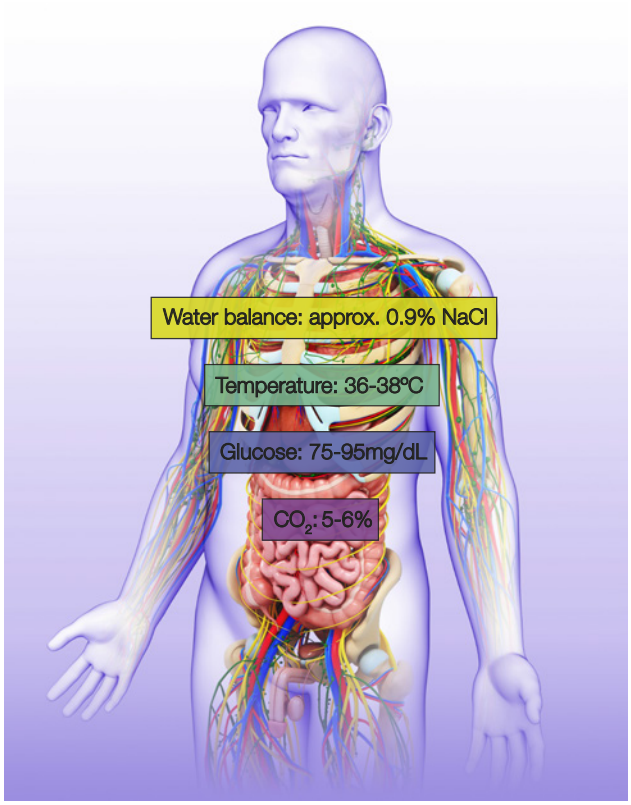


Figure 313 Tolerance levels for humans

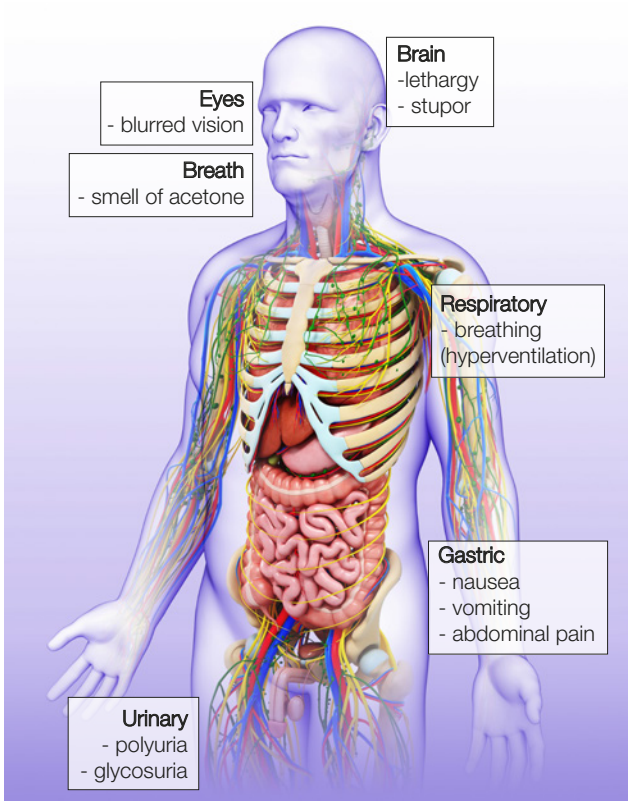


Figure 314 Symptoms of diabetes

The stimulus-response model

The graph shown in *Figure 315* illustrates how a particular variable in the internal environment oscillates about a 'set-point' or desired 'steady state' in practice.

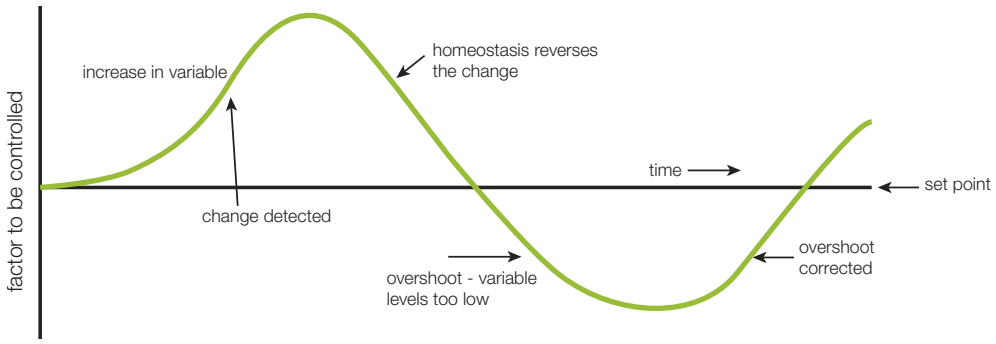


Figure 315 How factors oscillate about a 'set-point'

Factors in the environment cause either an increase or a decrease in the variable(s) and homeostatic responses work in the opposite way to reverse the changes. To help understand the components and mechanisms involved in homeostasis, scientists have put forward the **stimulus-response model**. The elements of the model are given below:

The stimulus-response model	
Stimulus	A stimulus is a variable factor in the internal or external environment that can be detected by the organism.
Receptor	Receptors are the cells or tissues that can detect a change in the external or internal environment (a stimulus).
Transmission	Transmission refers to the relay of the information via nerves and/or hormones to an effector.
Effector	An effector is usually a gland or muscle that brings about a response after receiving the information.
Response	The response is an action which occurs due to the initial stimulus.
Feedback	The impact of the response on the initial stimulus. Feedback may be positive or negative.

Refer to *Figure 316* representing the stimulus-response model. The control centre analyses information from the receptor and determines the appropriate response to the change.

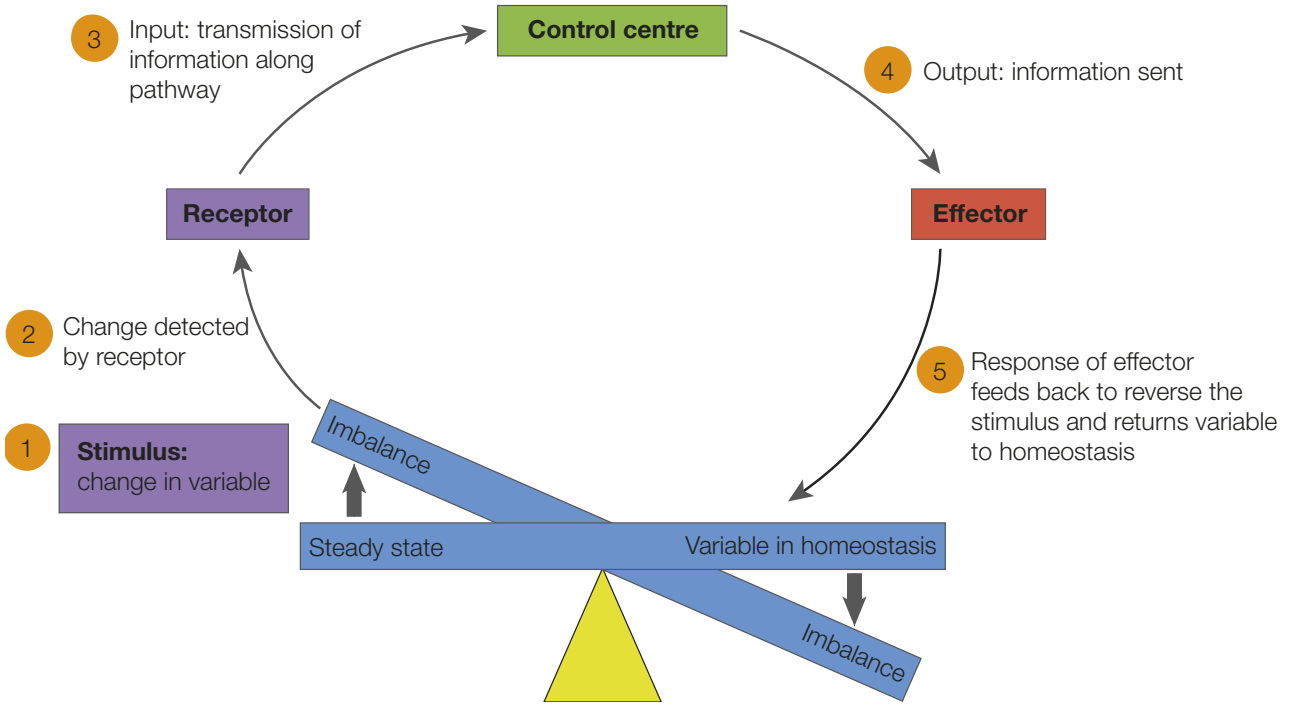


Figure 316 How the stimulus-response model works

Feedback occurs when the response to a particular stimulus has an impact on the original stimulus.

Negative feedback occurs when the response diminishes or reverses the original stimulus, whereas **positive feedback** occurs when the response reinforces or brings about an increase in the initial stimulus.

Homeostasis is characterised by **negative feedback** as it is this mechanism that returns the original variable factor that was changed, back to its steady state (refer again to *Figure 315*). An example here would be when an increase in exercise raises metabolic activity which gives rise to an increase in blood temperature. This increase in temperature is detected by receptors in tissues and the end result is that homeostatic responses by effectors reverse the original stimulus and lower the temperature. This will be discussed further in Chapter 3.4.

FIgure 317 Breastfeeding shows positive feedback

Positive feedback is less common but one example is seen when a newborn baby suckles on mother's breast nipple. The action causes a release of a hormone in the mother which further stimulates the release of milk which was the initial response. Furthermore, breastfeeding also releases oxytocin in the mother's brain, promoting affection and bonding between the two. The oxytocin can pass through the breast milk to the baby further promoting the bond. Increased breastfeeding promotes increased oxytocin release, strengthening the bond between the two (see *Figure 317*).

Helpful online resources

Amoeba Sisters: Homeostasis and Negative/Positive Feedback

<https://www.youtube.com/watch?v=lz0Q9nTZCw4&t=13s>

3.1 Review questions

Multiple choice questions

1. Homeostatic response mechanisms require the transfer and recognition of information from a sensory receptor and an effector. The transmission of this information:

   J is under control of the central nervous system only.
   K is usually a conscious process.
   L may involve both the endocrine and nervous systems.
   M relies only on hormones for short-term responses.

2. In maintaining homeostasis, which of the following is a behavioural adaptation?

   J Skin flushing red as more blood flows to surface.
   K Sweat released on skin to cool down.
   L Increasing or decreasing cell metabolism.
   M Curling up in a ball to keep warm.

3. Living organisms control pH within their tissues. Which of the following is the most valid reason for regulating pH?

   J Control of active transport is achieved by pH.
   K Many reactions can only happen at specific pH levels.
   L pH affects osmosis.
   M All parts of a body must be kept at the same pH to survive.

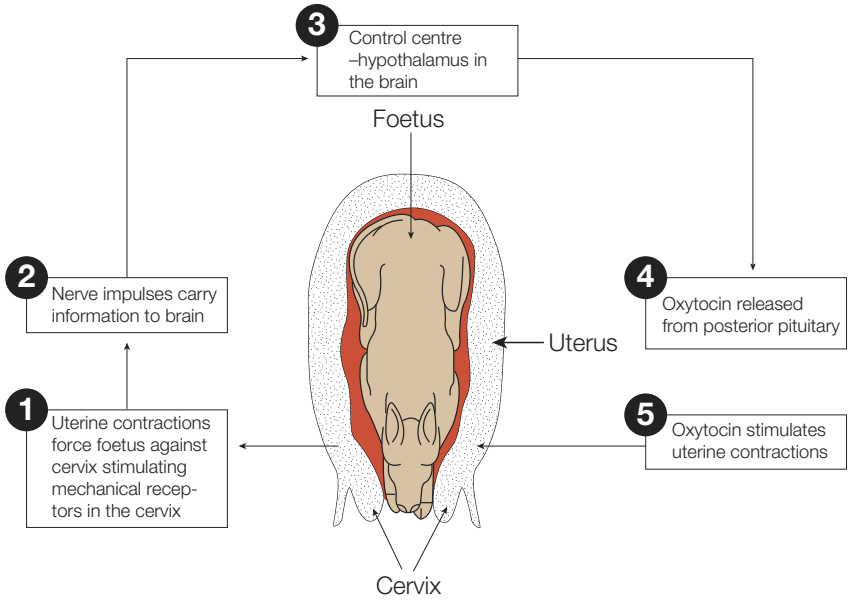
4. A researcher recorded the core body temperature (ºC) of seven participants during an investigation into the effects of exercise. The results are shown below:

   37.4, 37.9, 36.8, 37.2, 38.0, 37.2, 37.5

   Which one of the following correctly calculates the mean (average) and range for the results?

	Mean (average) temperature (ºC)	Range in temperatures (ºC)
J	37.5	1.1
K	37.4	1.2
L	37.2	1.0
M	37.3	1.2

5. The diagram below shows the effect of the hormone oxytocin on the uterus during the birth of a mammal.



   Which of the following options best identifies and explains the feedback loop shown in the diagram above?

	Feedback Loop	Explanation
J	Positive	The production of oxytocin results in the production of more oxytocin.
K	Negative	The production of oxytocin results in the production of more oxytocin.
L	Positive	The production of oxytocin results in the detection of the contraction by receptors in the cervix.
M	Negative	The production of oxytocin results in the detection of the contraction by receptors in the cervix.

Free response questions

1. Outline reasons why homeostasis is such an important process in sustaining life.

2. Name four different factors that humans can respond to.

3. Organisms respond to external and internal stimuli in different ways e.g. structural, behavioural and physiological. Give one example of how an organism might respond in each of these three ways.

4. 'The concept of tolerance levels can be applied to homeostasis.' Explain the meaning of this statement and give an example to illustrate your understanding.

5. State two reasons why it is important for humans to maintain the correct concentration of CO_2 in their blood.

6. Name the two mechanisms used to transmit information in the stimulus-response model.

7. Suggest factors that might give rise to the following changes:
   a) a fall in blood glucose levels

   b) a rise in carbon dioxide concentration in the blood

   c) a high blood solute concentration

8. The temperature of the blood needs to be maintained within a fairly narrow range. Explain possible consequences when the temperature is outside this narrow range.

9. Compare and contrast the roles of receptors and effectors in the stimulus-response model.

10. 'The maintenance of blood glucose concentration between 75-95 mg/dL is a result of negative feedback.' Justify the above statement.

11. Positive feedback occurs when the response causes an increase in the initial stimulus.
    a) Name an example of positive feedback in humans.
    b) Suggest why positive feedback is not common in biological systems.

12. One homeostatic mechanism used to reduce blood temperature is perspiration or sweating. Using this mechanism to lower blood temperature impacts on another important variable.
    a) Name this variable.
    b) Suggest the issue that this causes for the organism and how it has evolved to solve this problem.

Science as a Human Endeavour 3.1 - Are you about to catch a cold?

Anyone whose body systems are 'functioning at ease' is said to be in good health or healthy. 'Dis-ease' results if good health breaks down. In many cases this is described as being sick.

Regulation by the human body of temperature, water availability, blood glucose level and carbon dioxide/oxygen concentration are all essential for good health, as are normal blood pressure and resting heart rate. Relatively sudden and prolonged changes in any one of these may serve as indicators of infection by a pathogen, and thus the onset of a disease.

Recent research has suggested that if a person's skin temperature and heart rate are higher than usual for about two hours there's a strong chance they are getting sick e.g. as a result of being infected by a virus that causes a cold. The elevated skin temperature is a product of a general body temperature increase, a body response that facilitates immune system function. Increased heart rates permit the circulatory system to transport more white blood cells and products of them to the site of infection e.g. capillaries in the lining of the back of the throat.

You may need to refer to the online resources below to answer the questions that follow.

1. One way to 'pre-empt' catching a cold is to be more aware about what causes it and to take steps to minimise the risk of infection. What are the benefits of doing this?

Some of the work of Michael Synder at Standford University in the United States is focussing on the possible use of smartwatches to alert wearers to changes in skin temperature, heart rate and other factors that correlate with the imminent development of a cold.

2. Use your understanding of science as a human endeavour to answer the following questions:
   a) Discuss other potential applications of health monitoring technology in consumer smart watches.

   b) Discuss possible unexpected consequences for individuals using smartwatches that can monitor for health issues.

Helpful online resources

What's Up Dude: Common Cold - What Is A Cold - What Is A Virus - Viral Infection
<https://www.youtube.com/watch?v=bJodnybRE0Q>

Stanford: Michael Snyder:
<https://www.youtube.com/watch?v=PsWNn0FCgJE>

Chapter 3.2 The nervous system

Science Understanding

The nervous system is composed of the central nervous system and the peripheral nervous system.

- Compare the structure and function of sensory neurons, interneurons, and motor neurons.
- Describe the structure of a nerve pathway from receptor to effector.
- Describe the role of synapses and neurotransmitters.
- Describe the role and pathway of reflex responses.

Explain how the nervous ... system works ... to monitor pH in the brain to maintain a constant carbon dioxide level in the blood.

The central nervous system and the peripheral nervous system

The nervous system is one of the two systems responsible for detecting and responding to stimuli from the internal and external environments. Typically, the nervous responses are involved where more rapid and direct communication is required. The nervous system is made up of the **central nervous system** (CNS) and the **peripheral nervous system** (PNS).

In humans, the CNS consists of the brain and **spinal cord** and its primary role is in the storing, arranging and managing the information, whereas the PNS is mainly involved in the transmission of information to and from the CNS. Essentially the nerves in the PNS relay information from the **sensory receptors** to the CNS and from the CNS to the effectors.

Refer to *Figure 321* to see the CNS and a range of nerves of the PNS in a human.

As can be seen, the nerves in the PNS can be further subdivided into the **somatic** (voluntary) and **autonomic** (involuntary) types. The voluntary nerves are under our conscious control; for example, influencing the skeletal muscles, whereas the autonomic system is involuntary and consists of nerves involved in a range of unconscious responses from changes in the heart rate, gland activity and the activity of a range of body systems. The autonomic system is divided into the sympathetic and parasympathetic systems.

Figure 322(a) shows a simple flowchart of different nerves in the CNS and PNS.

Figure 322(b) shows the main parts of the human nervous system.

Please note that the differences between the somatic and autonomic systems and parts of the nervous system are not part of the SACE Stage 2 Biology course and detailed knowledge is not required.

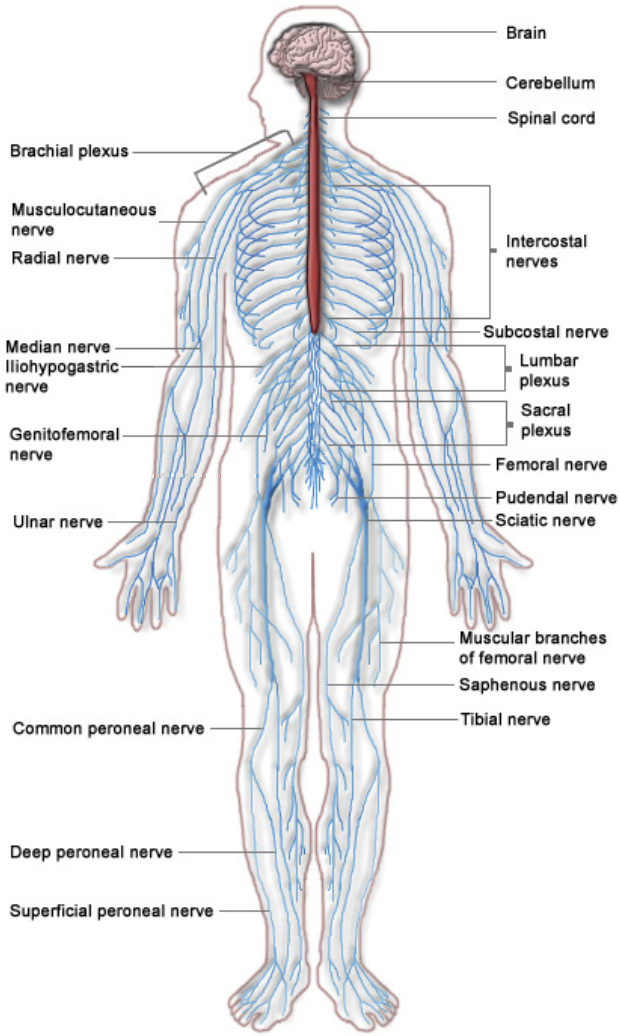


Figure 321 The major nerves of the human body

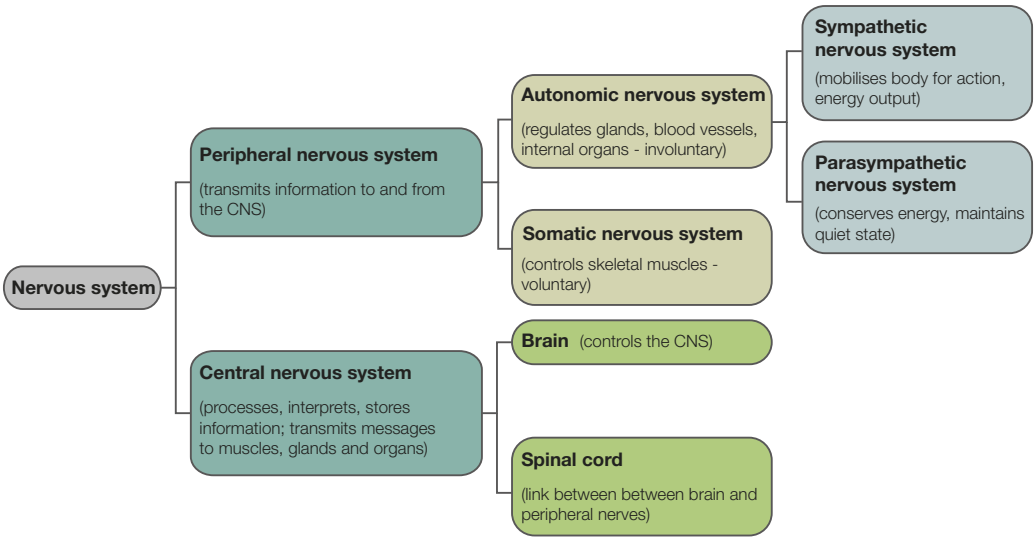


Figure 322(a) The different types of nerves in the human nervous system

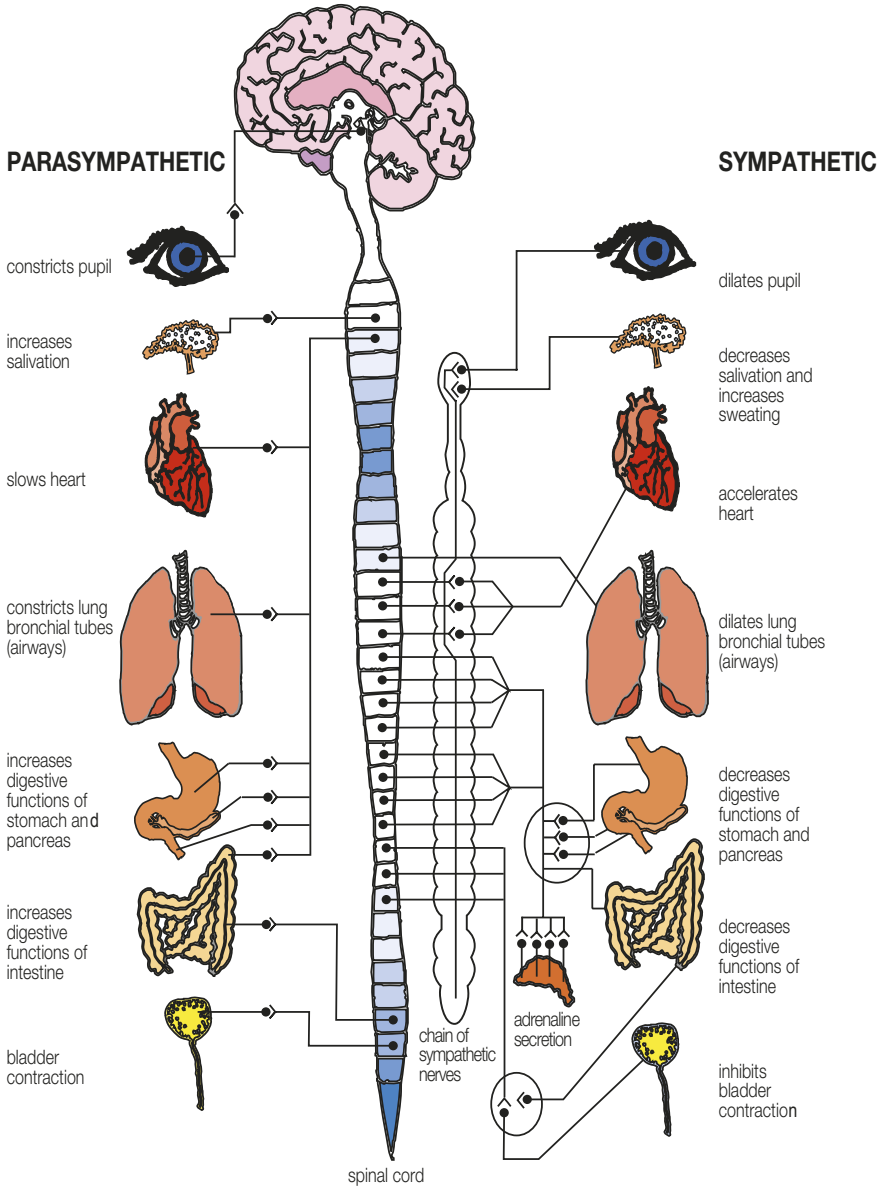


Figure 322 (b) The human nervous system

Neurons

In Chapter 3.1 the concept of a stimulus-response model was introduced. Receptors are modified cells or tissues that can detect stimuli and send messages along nerve cells (neurons) to the CNS and muscles and glands to bring about a particular response. There are three types of neurons in the nervous system (see *Figure 323*).

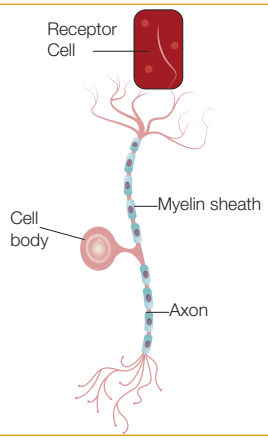
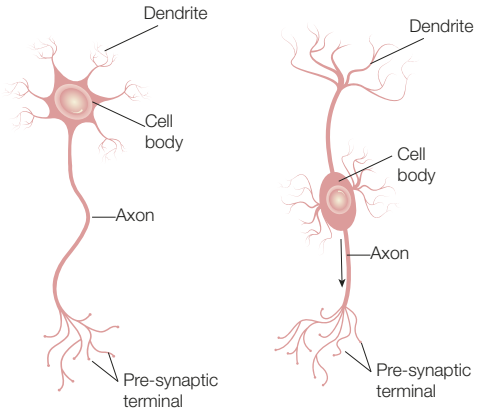
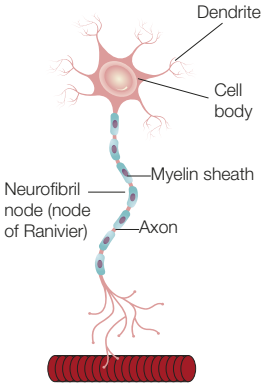
Sensory	Interneuron (relay)	Motor
Sensory neurons are nerve cells that transmit information from a receptor (e.g. cells that detect light, sound, temperature etc.) to the CNS.	Interneurons are located in the CNS and transmit information from sensory neurons to motor neurons.	Motor neurons transmit messages from the CNS to the effectors that are typically muscles or glands.
		

Figure 323 The three main types of neurons and their different structures

Components of a neuron

Dendrites

Dendrites receive impulses from sensory receptors or other neurons and transmit the information toward the cell body.

A cell body

The cell body contains many cell organelles, including a nucleus, endoplasmic reticulum and mitochondria.

Axons

Axons are long extensions of the nerve cell (neuron), necessary to transmit information to another cell or an effector. Whilst axons are microscopic, they may be very long; in some animals they may be several metres long.

At the end of the axons are axon branches that have tiny swellings at their ends that release **neurotransmitter** chemicals which transmit information between neurons or between a neuron and, for example, a muscle cell. Refer to *Figure 324* which illustrates a motor neuron.

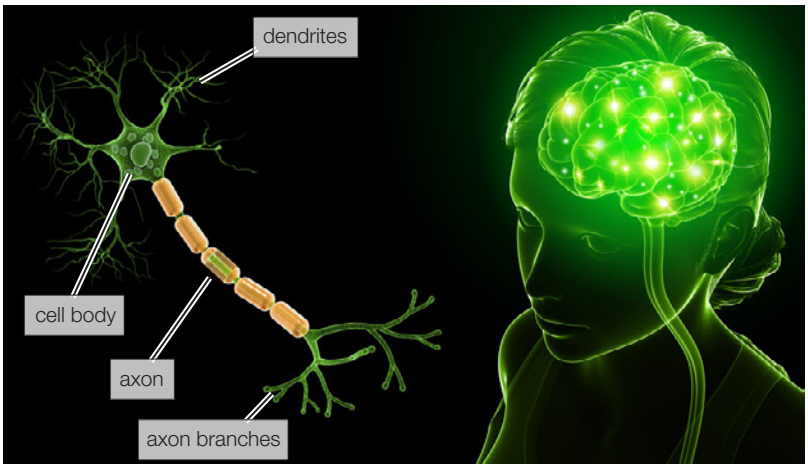


Figure 324 The structure of a motor neuron

The three different types of neurons have different functions and also slightly different structures.

Refer to *Figure 325* illustrating the three different neurons.

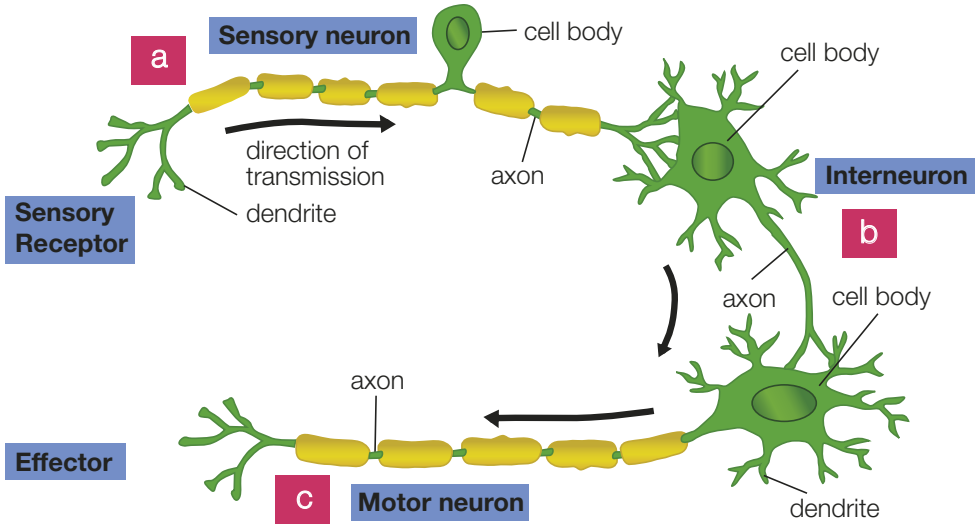


Figure 325 The transmission of a nerve impulse through the three main types of neurons.

A sensory neuron (labelled 'a' above) has a cell body joined by two long processes; the **dendron** and the axon. The extension of the dendrons, called dendrites, act as receptors and transmit information towards the cell body.

Interneurons (labelled 'b' above) have only short axons as they enable connections between a sensory neuron and a motor neuron.

Motor neurons (labelled 'c' above) usually have short dendrites and one long axon.

Neurons transmit messages to specific destinations in the form of **electrochemical impulses.** This process involves changing concentration gradients of sodium (Na^+) and potassium (K^+) ions. This requires the movement across cell membranes through a mixture of facilitated diffusion and active transport. This will not be discussed any further though, as it is not part of the current course outline.

Refer to *Figure 326* for a summary of differences between the three major types of neurons in the nervous system.

	Motor	Interneuron (relay)	Sensory
Structure	Cell body, short dendrites, long axon	Cell body, short dendrites, short axon	Cell body, long dendrites, short axon
Location of cell body	Cell body and dendrites in CNS Axon outside CNS	Cell body etc inside CNC	Cell body and dendrites outside CNS Axon inside CNS
Dendrites	Dendrites synapse with effectors	Dendrites synapse with other neurones	Dendrites synapse with receptors
Axons	End in effector	Axons synapse with other neurones	Axons synapse with relay and other neurones in CNS
Function	Transmit impulses from CNS to effector	Connect sensory and motor neurones to form nerve circuits	Transmit impulses from receptors to CNS

Figure 326 A comparison of the structures and locations of the three major types of neurons.

Helpful online resources

Elearnin: Neurons or nerve cells - Structure function and types of neurons | Human Anatomy | 3D Biology:

<https://www.youtube.com/watch?v=cUGuWh2UeMk>

Some axons have a fatty covering called a **myelin sheath** which is formed by Schwann cells that wrap around the axons. Nerve impulses can **travel faster** along neurons that have the sheath as the impulses jump from node to node. Refer to *Figure 327*.

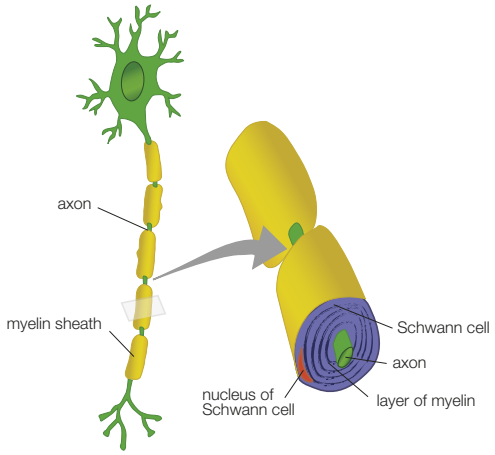


Figure 327 The structure of a typical myelinated neuron

Synapses and neurotransmitters

The junction between neurons or between a neuron and a receptor/effector, is termed a **synapse**. In a synapse, the end of an axon will be found very close to the membrane of a dendrite or cell body of the next neuron. The electrical message cannot cross the **synaptic cleft** (gap between the two neurons). The arrival of a nerve impulse causes the release of a chemical transmitter substance into the synaptic cleft, called a **neurotransmitter,** that diffuses across the space and binds to receptors on the receiving membrane. This activates ion channels in the membrane leading to the nervous impulse being transmitted further. This is why nervous messages are termed **electrochemical** messages because they involve the electrical impulses along axons and the release of neurotransmitters across the synaptic cleft to transmit messages. The neurotransmitter can then be broken down and de-activated by enzymes. Refer to *Figure 328*.

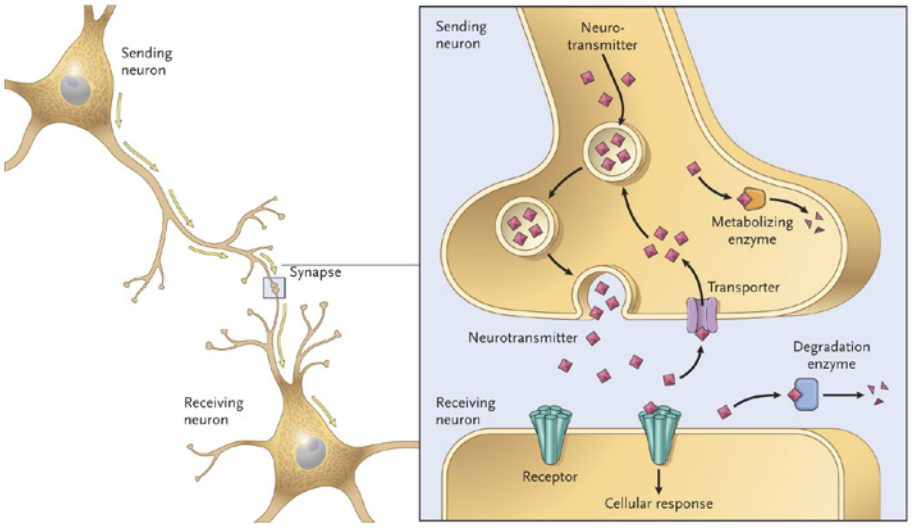


Figure 328 The action of neurotransmitters between neurons

Helpful online resources

Neuroscientifically Challenged: 2-Minute Neuroscience: Synaptic Transmission:
<https://www.youtube.com/watch?v=WhowH0kb7n0>

HarvardX: How a synapse works
<https://www.youtube.com/watch?v=OvVl8rOEncE>

Examples of neurotransmitters

Acetylcholine

Acetylcholine was the first neurotransmitter to be discovered. It was discovered in 1921 by a German *Otto Loewi*. It stimulates muscles and is also found in sensory neurons and the autonomic nervous system. The well known poison botulin works by preventing vesicles in the axon from releasing acetylcholine, leading to paralysis. It also appears there is a strong link between acetylcholine and Alzheimer's disease with about 90% loss of acetylcholine in the brains of those affected by this disease.

Norepinephrine

Norepinephrine was discovered in 1946 by a Swedish biologist *Ulf von Euler* and was found to be linked with switching the nervous system into an 'alert' state. It increases heart rate and blood pressure. Amphetamine drugs (e.g. 'Speed') work by influencing the release of norepinephrine (also called noradrenaline).

Dopamine

Dopamine was discovered in the 1950s by another Swedish scientist *Arvid Carlsson*. It acts as an inhibitory neurotransmitter. Several drugs, including cocaine, opium and alcohol increase levels of dopamine. The disease schizophrenia appears to be linked to increased levels of dopamine. Parkinson's disease is thought to be driven by a lack of dopamine in the brain.Interestingly, approximately 50% of dopamine is made by the gastrointestinal system and studies are showing links between our diet, gut microbiome and mental health.

Serotonin

Serotonin is an inhibitory neurotransmitter linked to emotion and mood. Decreased levels have been associated with depression, anger management and obsessive-compulsive disorder (OCD). Some drugs that are prescribed to assist with depression act on neurons by preventing them from removing excess serotonin thus leaving more in the synapses. The gastrointestinal tract produces 95% of an individual's serotonin, which acts on the brain. This further highlights the importance of a healthy diet and and the link between poor diet and mental health conditions.

Figure 329 is an image of a brain of a person with schizophrenia. Protein shows up as red in the image and what should be noticed is the lack of red colour and hence protein synthesis in the frontal lobes at the top of the image. The synthesis of serotonin in the brain occurs in the frontal lobe of the brain and this area seems to be linked to the disease.

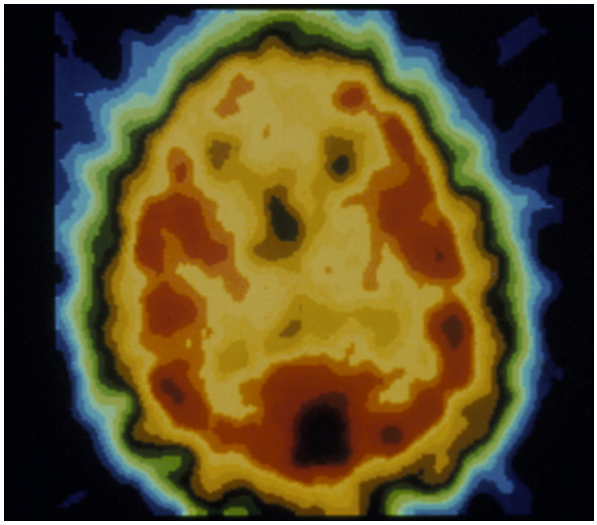


Figure 329 A brain scan of an individual with schizophrenia highlighting a decrease in protein synthesis activity in the frontal lobe

Sensory receptors

The ability to detect changes in the external and internal environment is critical to the survival of organisms. As noted in Chapter 3.1, the first two elements of the stimulus response model were (a) the stimulus and (b) the receptor.

Sensory receptors generally respond to the intensity, location and duration of the stimulus. Stimuli are detected by various receptors which are mostly the dendrites of sensory neurons, specialised to receive the specific stimulus.

There are different types of receptors throughout the human body. Some receptors respond to external stimuli, whereas other receptors respond to internal stimuli. Receptors can generally be classified by the stimulus that they detect. Refer to the table below and *Figure 3210* for a few examples.

Type of receptor	Examples of stimuli detected	Example locations in humans
Mechanoreceptor	sound, touch, pressure, motion, stretch	ear, skin, muscle, tendons, ligaments
Photoreceptor	light	eye
Thermoreceptor	temperature changes	skin, brain (hypothalamus)
Chemoreceptor	detect changes in chemicals, such as solutes, glucose, O_2, H^+ ions	nose, tongue, carotid arteries, brain
Nociceptor	detect tissue damage, pain	skin, muscles, joints (brain interprets the pain message)

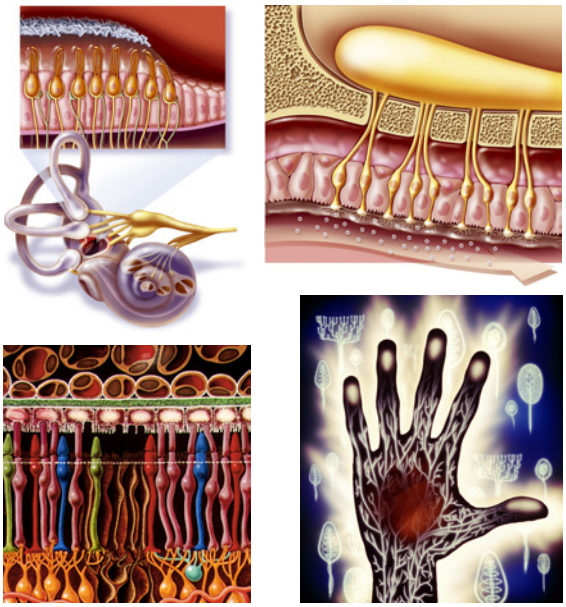


Figure 3210 Human organs for the senses of (top left & clockwise) (a) hearing, (b) smell, (c) touch and (d) sight

Helpful online resources

Let's learn Medicine: SENSORY RECEPTORS 2
<https://www.youtube.com/watch?v=oDitlJgcqRU>

Teacher's Pet: Sensory Receptors
<https://www.youtube.com/watch?v=kBr0Yj_vMQg>

The reflex arc

There are two types of interactions in the human nervous system: involuntary and voluntary.

Involuntary or **autonomic responses** are not under the conscious control of the brain and are classified as automatic, rapid and instinctive responses that do not need to be learned. They are known as reflexes or **reflex actions** and are among the simplest kind of behaviours in humans.

A **reflex arc** is the pathway along which nerve impulses travel when a reflex action occurs. In this action, a receptor is stimulated and an impulse travels along a sensory neuron to an interneuron found in the spinal cord via a synapse. The interneuron stimulates a motor neuron via another synapse and the impulse travels to an effector organ which brings about a response. In a reflex response, the **brain is not directly involved**, to ensure a fast and automatic response to increase the likeliness of an individual being protected and/or surviving.

Reflex actions often have a **protective function,** for example, when you touch a hot object your hand jerks away rapidly. Other reflexes include sneezing, secretion of saliva, coughing, blinking and the constriction or dilation of the pupil of the eye. Refer to *Figure 3211* as an example of a reflex arc.

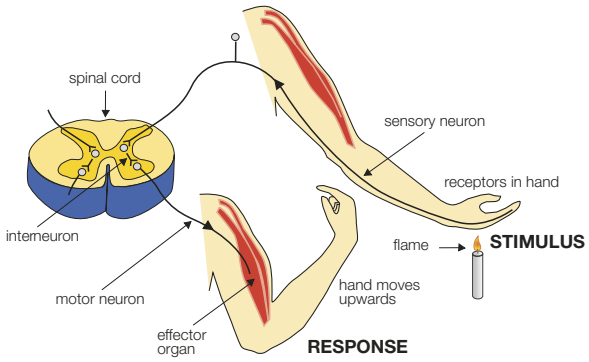


Figure 3211 An example of a reflex arc

Helpful online resources

GCSE Biology: Nervous System and Reflex Arc
<https://www.youtube.com/watch?v=HiuXfbwND9s>

Blood pH tolerance limits

The normal blood pH is approximately 7.4. this will fluctuate very slightly for an individual throughout the day between the normal range of 7.35 to 7.45. It is very important for blood pH to be maintained because if it drops to 6.9 an individual is likely to be in a coma, and at 6.8, death is the likely result. Additionally, a rise in blood pH to 7.8 will also likely result in death.

Relationship between blood pH and carbon dioxide

Blood pH is regulated by breathing out carbon dioxide (CO_2). Cells produce CO_2 as a waste product when they respire aerobically (especially during intense exercise). The CO_2 produced is excreted by cells into the blood by **diffusion**. It dissolves in the blood forming **carbonic acid** (H_2CO_3), which is a weak acid. Increased carbonic acid in the blood **lowers blood pH,** making it **more acidic**. Conversely, when too much CO_2 is breathed out, there is a decrease in carbonic acid dissolved in the blood and the blood pH would increase, as it is less acidic. This could occur when an individual hyperventilates.

Monitoring blood pH and controlling carbon dioxide levels in the blood

The blood pH is detected by chemoreceptors in the **medulla oblongata** (in the brain). A change in the blood pH would cause nervous messages to be sent to the organs of the respiratory system (**the diaphragm and intercostal muscles**) to alter the rate of breathing, and therefore, the concentration of CO_2 in the blood. If the blood pH decreases, the rate of breathing would be increased to breathe out more CO_2 and increase pH back to 7.4 (see *Figure 3212*). Conversely, if the blood pH increases, the rate of breathing would be decreased to breathe out less CO_2 and decrease pH back to 7.4. Therefore, our breathing rate is controlled by our blood pH (levels of CO_2) and not the amount of oxygen available to cells.

Refer to *Figure 3212* and the dot points below for a summary of the main mechanisms involved in the homeostatic control of blood CO_2 levels.

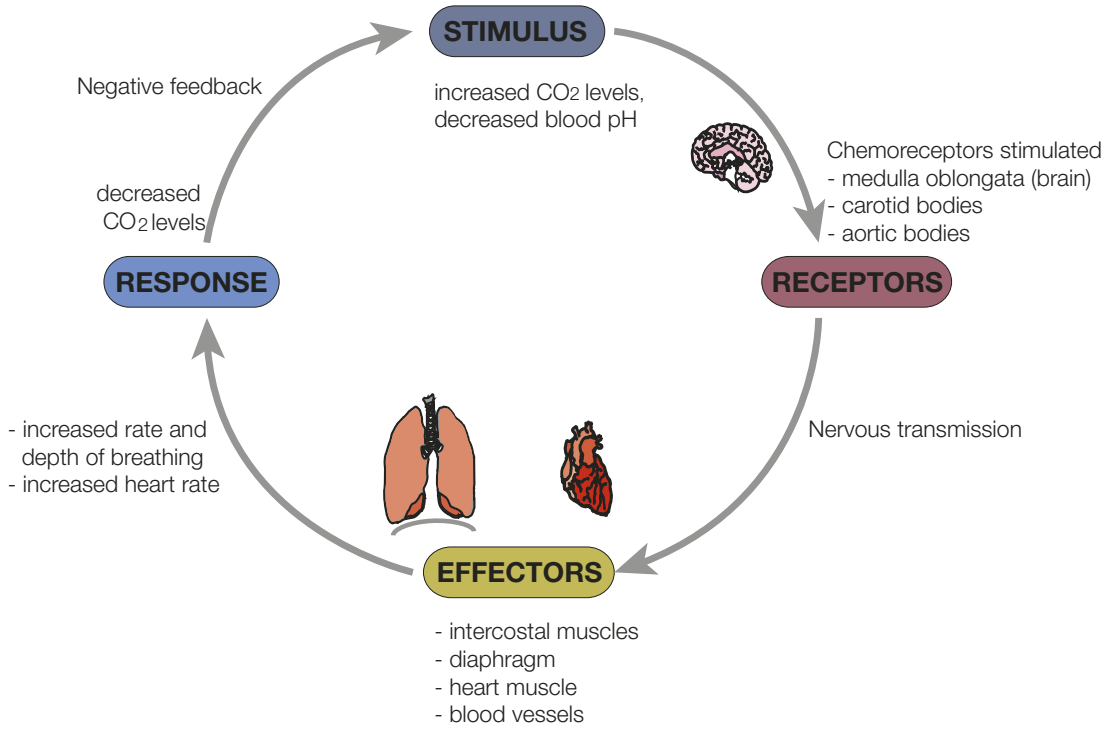


Figure 3212 Mechanisms that control carbon dioxide levels in the blood

- Homeostasis is disturbed by increasing CO_2 levels (e.g. as a result of physical exercise).
- Carbon dioxide diffuses out of the blood where it reacts with water to form carbonic acid (H_2CO_3), which dissociates into bicarbonate ions (HCO_3^-) and hydrogen ions (H^+). The increase in H^+ ions in the blood results in an increased blood pH.

  $CO_2 + H_2O \rightleftharpoons H_2CO_3$

  $H_2CO_3 \rightleftharpoons HCO_3^- + H^+$
- Raised CO_2 and lowered pH are detected by chemoreceptors in the brainstem (medulla oblongata) and tissues in the walls of the aorta and carotid arteries.
- Nerve impulses are transmitted to the effectors.
- The effectors i.e. the **intercostal muscles**, **diaphragm** and heart, respond to the impulse.
- The body responds by increasing the rate and depth of breathing and increasing the heart rate.
- Negative feedback occurs when the response (i.e. lowering CO_2 levels) reverses the stimulus.
- Negative feedback restores the normal level of blood CO_2.

3.2 Review questions

Multiple choice questions

1. *Refer to the diagram on the right of a neuron.*

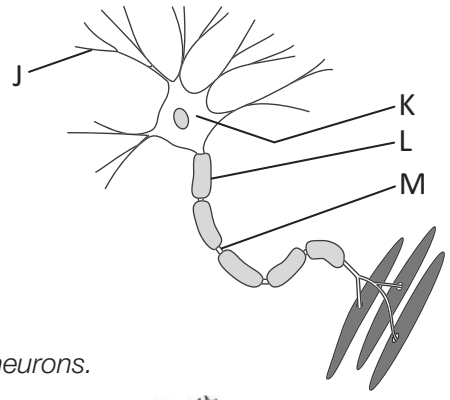
   Which structure is correctly labelled in the diagram?

   J Node of Ranvier

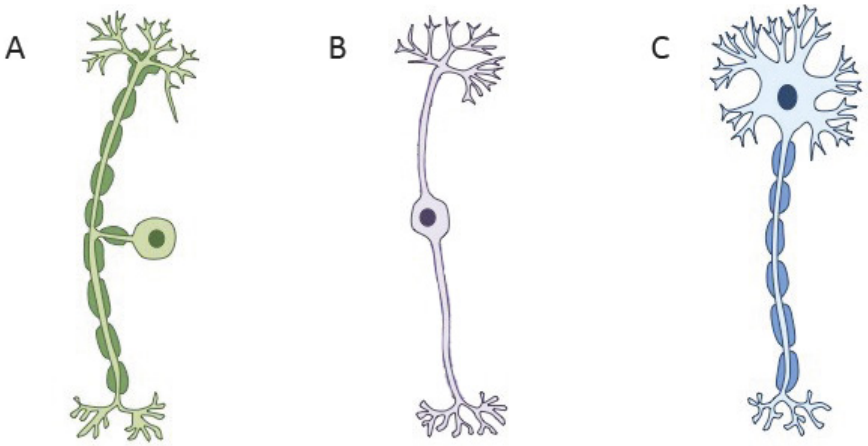
   K Cell body

   L Dendrite

   M Synapse



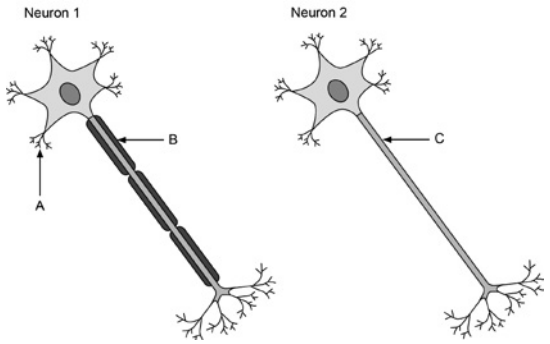
2. *Refer to the diagram below showing the three main types of neurons.*



Which of the following correctly identifies the type of nerve cell and function?

	Cell	Type of Cell	Function
J	A	Interneuron	To detect stimuli and transmit message to CNS
K	A	Motor neuron	To carry message from CNS to effector
L	B	Interneuron	To relay message from sensory neuron to motor neuron
M	C	Sensory Neuron	To detect stimuli and transmit message to CNS

3. *Refer to the diagram below showing two neurons.*



Which of the following correctly identifies the three parts of the neuron and identifies which neuron nervous transmission would occur faster across?

	A	B	C	Neuron that nervous transmission occurs fastest across
J	Axon terminal	myelin sheath	axon	1
K	dendrite	myelin sheath	axon	1
L	Axon terminal	myelin sheath	axon	2
M	dendrite	myelin sheath	axon	2

4. When a nerve impulse reaches the end of a neuron a synapse occurs.

The diagram to the right is a representation of a synapse.

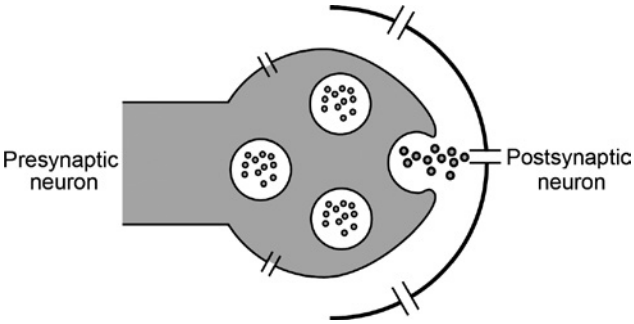
Which of the following is involved in enabling the nerve impulse to reach the adjacent neuron?

J Mitochondria in the postsynaptic membrane release neurotransmitters into the synapse.

K Neurotransmitters diffuse across the synapse and bind to receptors on the presynaptic knob.

L Vesicles in the presynaptic knob are stimulated by the entry of calcium ions to release neurotransmitters.

M Calcium ions are released by vesicles in the postsynaptic membrane and cross the synapse to release neurotransmitters.



5. *Refer to the diagram on the right to answer questions 5 and 6:*

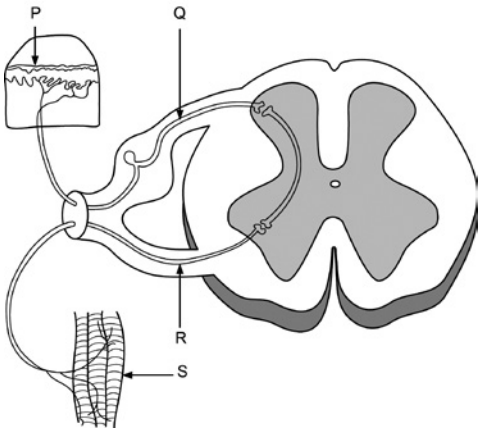
The structure labelled 'R' can be described as a:

J motor neuron carrying information away from the spinal cord.

K motor neuron carrying information toward the spinal cord.

L sensory neuron carrying information away from the spinal cord.

M sensory neuron carrying information toward the spinal cord.



6. Which of the following statements about the detection of a stimulus in the reflex Arc shown to the right is correct? It is detected by:

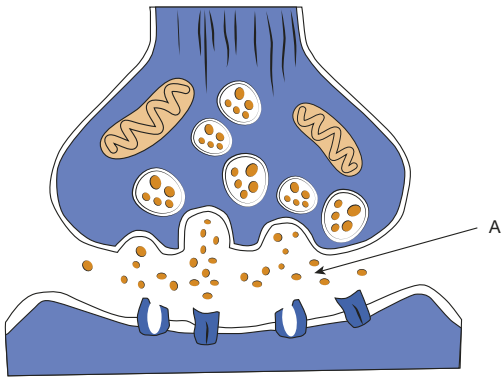
J sensory neurons labelled 'P' and transmitted through motor neurons labelled Q.

K receptors labelled S and transmitted by interneurons labelled R.

L receptors labelled S and transmitted through sensory neurons labelled R.

M receptors labelled P and transmitted through sensory neurons labelled Q.

7. *Refer to the diagram on the right showing a synapse.*



What is happening at the point labelled A?

J Neurotransmitters are being engulfed by endocytosis

K Ca^{2+} is moving across the synaptic cleft

L Neurotransmitters are moving across the synaptic cleft

M Ca^{2+} is being engulfed by endocytosis

8. When a person picks up a heavy item and their knees buckle, the tension across their knees triggers a reflex that contracts the thigh muscles, which provides support. This prevents an individual from collapsing.

Based on the information above, it is correct to say that:

J Muscles in the thigh act as sensors to detect the heavy load.

K Information moves from the spinal cord to the thigh muscles via a motor nerve cell.

L Information moves rapidly to the brain by nerves to enable co-ordination of the response.

M The quick response is possible due to the coordinated actions of nerves and hormones.

9. A person stepping on a sharp object would initiate a reflex response to remove themselves from immediate danger.

Which one of the following would be a part of this reflex response?

J Negative feedback would occur to stop the action after the response had occurred.

K A hormone would be secreted that would initiate an increased release of energy in muscle cells in the leg.

L A nerve impulse would move from a sensory neuron to a receptor cell.

M A interneuron neuron in the CNS would allow the message to travel from a sensory neuron to a motor neuron.

10. Hyperventilating can result in an individual fainting, which in turn allows the breathing rate to be reset back to normal.

Correctly identify the blood carbon dioxide concentration and resulting blood pH that can arise from hyperventilating.

	Blood CO_2 Concentration	Blood pH
J	Increase	Increase
K	Increase	Decrease
L	Decrease	Increase
M	Decrease	Decrease

Free response questions

1. The nervous system can be divided into two types; the CNS and PNS.

a) State the difference between the CNS and PNS.

b) Describe the function of the CNS and the PNS.

2. One classification of nerves divides them into two groups: the somatic nerves and the autonomic nerves.
   a) State the role of somatic and autonomic nerves in the body.

   b) Provide examples to illustrate the different actions of the two types of nerves.

3. Sensory neurons and interneurons have different structures and different functions in the nervous system. Outline how the structural features of each suit their functions.

4. Neurons are nerve cells found in both the CNS and PNS.
   a) Name the three main components of a neuron.

   b) For each component, state how its structure suits its function.

5. A reflex arc is the pathway taken by the nerve impulses involved in a reflex response. One example is when bright light is directed at a human eye and the pupil constricts.
   a) State why this is a reflex response.

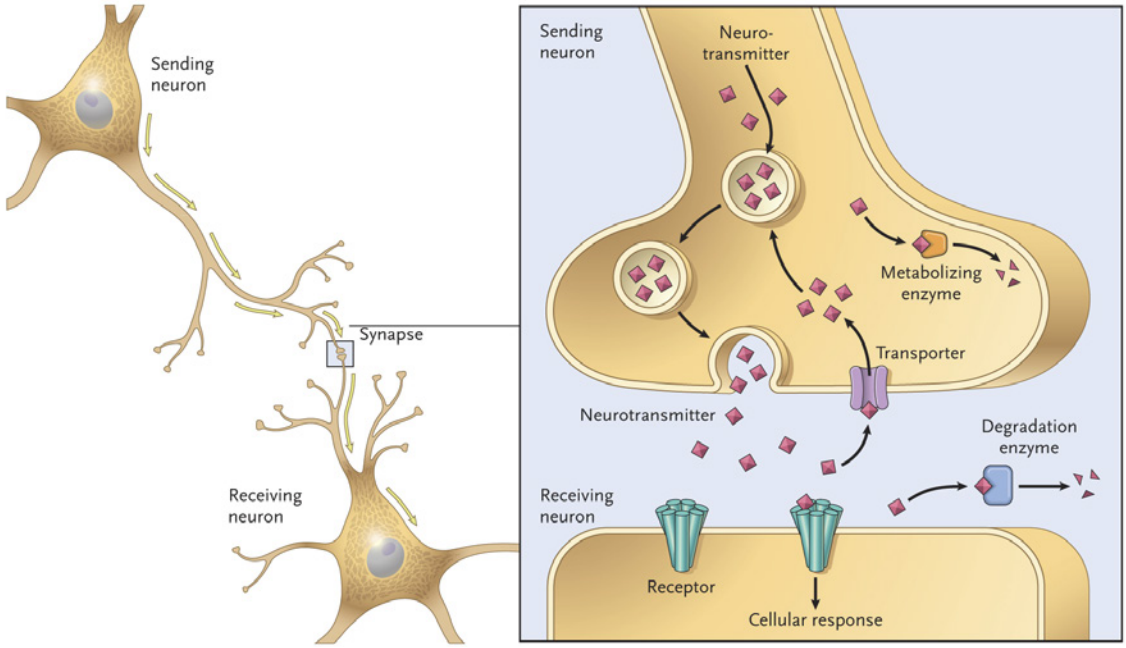
   b) Name the stimulus, the receptor and the effector in this example.

   c) Explain how this response might provide a protective function in humans.

6. Sensory receptors respond to stimuli in the environment. These receptors are often classified by the stimulus they detect.
   a) State the type(s) of stimuli that mechanoreceptors and chemoreceptors detect.

   b) 'Sensory receptors are really modified dendrites of sensory neurons.' Provide an argument in support of this statement.

7. *Refer to the following diagram:*



a) Outline the role of neurotransmitters in the transmission of nerve impulses.

b) Using evidence from the diagram, name the process by which neurotransmitters move into the synaptic cleft. Explain why this process is necessary.

c) Suggest why large numbers of mitochondria might be found in the axon terminals.

8. Explain why the process of active transport is heavily involved in the transmission of nervous impulses.

9. Recreational drugs alter the way that people think, feel and behave by altering the activity of neurotransmitters. One such drug, cocaine, attaches to the dopamine transporter in the membrane of the nerve cell and this gives rise to increased levels of dopamine in the synapses.

a) Describe how drugs such as cocaine can alter mood, feelings and behaviour.

b) Provide a possible mechanism that might lead to addiction or long-term damage caused by habitual use of drugs such as cocaine.

10. A cough is a normal response by the body to rid itself of foreign, unwanted particles. Cough hypersensitivity syndrome is a disease where individuals become hypersensitive to a range of triggers causing them to have frequent uncontrolled coughing episodes, seriously impacting on their quality of life. A cough centre in the medulla region of the brain detects irritants.

    a) Explain why coughing is a reflex response.

    b) For a typical cough reflex, give an example for each of the following:

- stimulus
- receptor
- effector
- response

    c) Predict some possible modes of action for medications that may act as cough suppressants.

11. Strenuous exercise leads to an increase in CO_2 levels in the blood.

    a) Explain why it is necessary to increase the rate and depth of breathing to maintain normal body function during and immediately after exercise.

    b) Describe how an increased carbon dioxide concentration in the blood is detected.

    c) Explain how the control of CO_2 levels in the blood involves negative feedback and is therefore considered to be an example of homeostatic control.

Science as a Human Endeavour 3.2 – A bionic spinal cord

Paralysis is the loss of the ability to move caused by disease or nerve damage. Paralysis of both legs is called paraplegia – a person paralysed like this is described as being paraplegic.

The leading cause of paraplegia is spinal cord injury. There are more than 10, 000 people in Australia today who have been disabled by a spinal cord injury. The overwhelming majority of spinal cord injuries are caused by serious transport-related accidents, for example, car crashes.

A landmark study published in February 2016 in the journal *Nature Biotechnology* detailed research by Australian scientists that promises to get paralysed patients literally back on their feet and walking again.

This involves a paperclip-sized device that is implanted into a blood vessel in the brain without the need for brain surgery. Once in place it can detect and translate neural activity; for example, the intention to walk, which is then se nt wirelessly to 'robotic legs' attached to the patient, permitting them to walk by thought alone. The original trials performed using sheep showed the bionic spinal cord is safe for long-term use. Following human trials, the device could be available for paraplegic individuals to help them walk again.

You may need to refer to the online resources below to answer the questions that follow.

1. With reference to the development of the bionic spinal cord, describe how advances in science understanding in one field (such as surgical reversal of paralysis) influence other areas of science, technology or engineering.

2. Explain how the development of the bionic spinal cord can positively influence the Australian economy.

Helpful online resources

TomoNews US: Mind control: Australian-made bionic spine moves robotic limbs using your thoughts

<https://www.youtube.com/watch?v=QGW2WbSSG9s>

Chapter 3.3 The endocrine system

Science Understanding

The endocrine system releases hormones that are amino acid derivatives, peptides, proteins, or steroids.

Hormones travel to target sites via the blood.

Hormones can alter the metabolism of target cells, tissues, or organs.

- Compare the action of insulin and glucagon in blood sugar regulation.
- Describe how diabetes mellitus can result from a hormonal imbalance.
- Describe the action of thyroid stimulating hormone and thyroxine in metabolism.
- Describe the effect of antidiuretic hormone (ADH) on the nephron in osmoregulation..
- Discuss links between osmoregulation, blood volume, and blood pressure.
- Describe the role of thyroid-stimulating hormone in the production of thyroxine.

Explain how the ... endocrine system works ... to:

- enable osmoregulation
- maintain blood sugar level

Hormones

Hormones are chemicals that are produced by cells and carried in the blood to bring about an effect elsewhere in the body. They are usually produced by **endocrine glands** and control activities in a wide range of areas from growth, reproduction, solute concentration of the blood, glucose concentrations and blood temperature, to name just a few. Nerves communicate along cells via nerve impulses, whereas hormones are the **chemical** form of communication between tissues and cells and **travel in the bloodstream.**

There are three types or classes of hormones:

1. **Peptide and protein hormones:** peptides consist of a short chain of amino acids (polypeptide) and proteins consist of longer polypeptide chain(s).
2. **Amino acid derived hormones:** these are small molecules that are derived from the amino acids tyrosine and tryptophan.
3. **Lipid/steroid hormones:** lipid-based hormones, derived from cholesterol that are usually insoluble in water and travel through the blood bound to proteins.

The following table summarises the properties of these three classes of hormones::

Property	Peptide/protein hormones	Amino acid derived hormones	Steroid hormones
Synthesis	generally synthesised in the RER and often requires cleavage to activate	synthesised from one amino acid (tyrosine or tryptophan)	synthesised from cholesterol
Storage	stored in vesicles	stored before release	released into bloodstream immediately
Solubility	most are polar (water soluble) and travel in the blood	some are lipid soluble (thyroxine) and others are water soluble (adrenaline)	non-polar (lipid soluble)
Receptors	bind to receptors in the cell membrane which activates secondary messengers inside the cell	some act on cell membrane receptors, others bind to receptors inside the cell	are primary messengers that bind to intracellular receptors
Examples	insulin, glucagon, anti-diuretic hormone (ADH)	T3, T4 (thyroxine) (which act similar to steroids) adrenaline, melatonin (which act similar to proteins)	progesterone, oestrogen, testosterone

Refer to *Figure 331* (a) and (b) illustrating the action of (a) steroid hormones and (b) peptide and protein hormones.

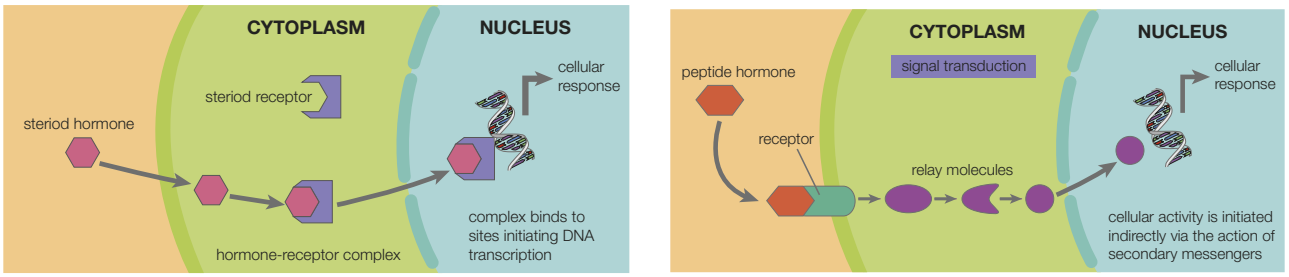


Figure 331 The action of (a) steroid hormones and (b) peptide and protein hormones

The **protein and peptide** hormones are often polar (water soluble) and **do not travel into the cell**; their action occurs as a result of binding to target cell membranes that possess complementary receptors to the hormone. **Steroid** hormones are non-polar (lipid soluble) and bring about their effect by travelling **into the cell** and binding to internal receptors.

Refer to *Figure 332* that illustrates the major endocrine glands of the human body and their location.

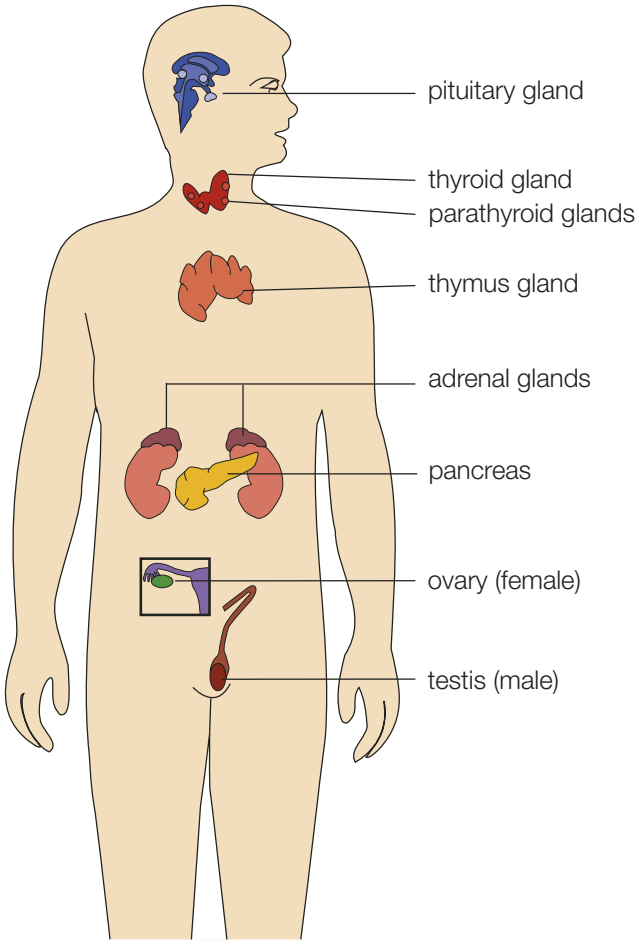


Figure 332 The major endocrine glands of the human body

Helpful online resources

Khan Academy: Types of hormones
https://tinyurl.com/3b7u8tpe

Academic Algonquin: Mechanisms of Hormone Action
<https://www.youtube.com/watch?v=TgNwxF3aQpE>

Helpful online resources

TED-Ed: How do your hormones work? - Emma Bryce
https://www.youtube.com/watch?v=-SPRPkLoKp8&t=200s

TED-Ed: How do steroids affect your muscles— and the rest of your body? - Anees Bahji
https://www.youtube.com/watch?v=itEXhxjOPjk

The table below summarises some important endocrine glands and the hormones they produce.

Gland	Hormone(s)	Action(s)
Pituitary	Oxytocin	uterine contractions during childbirth
	Antidiuretic (ADH)	reabsorption of water in the kidneys
	Human Growth (hGH)	growth of body cells and tissues
	Follicle stimulating (FSH)	stimulates ovaries (eggs) and testes (sperm)
	Luteinising (LH)	stimulates ovulation (release of eggs) in females and the release of testosterone in males
	Thyroid-stimulating (TSH)	stimulates the activity of the thyroid gland
Thyroid	Thyroxine	stimulates metabolism and heat production
Parathyroid	Parathyroid (PTH)	stimulates release of calcium from bone into the blood
Pancreas	Insulin, Glucagon	lowers blood glucose (sugar), raises blood glucose
Adrenal	Adrenaline	increases blood sugar, constricts blood vessels and increases heart rate and breathing rate
Testes	Testosterone	development of male secondary sexual characteristics, muscle development and controls sperm production
Ovaries	Oestrogen, Progesterone	development of female secondary sexual characteristics, maintains uterine lining

The **pituitary gland**, which is located at the base of the brain, is often referred to as the master endocrine gland because of its role in controlling the action of other endocrine glands.

Blood glucose regulation

Glucose is an essential substrate for energy supply. It is broken down in both aerobic and anaerobic respiration to release energy for ATP production. However, it is important for the body to maintain blood glucose levels within the **tolerance range** of 75 to 95 mg/dL. This is because high blood glucose levels can cause complications, such as increased blood pressure, cardiovascular disease, nerve damage, blindness and increased infections.

The body therefore has homeostatic processes, including negative feedback, that operate to keep glucose levels within the tolerance range.

Chemoreceptors in the **Islets of Langerhans** (see *Figure 333*) of the pancreas detects changes in blood glucose levels in the blood.

In response to an **elevated blood glucose level** (e.g. after eating carbohydrates), **insulin** (peptide hormone) is released from the **beta (β) cells** of the Islet of Langerhans into the blood (see *Figure 333*). Insulin binds to specific receptors on cells, especially liver, muscle and adipose (fat) cells, stimulating them to take up glucose from the blood (see *Figure 344*). Under normal circumstances (non-diabetic), the blood glucose levels will **decrease** to the normal **tolerated range** as a result. This is detected by the chemoreceptors, resulting in the termination of insulin release. This is an example of **negative feedback**, where the response reverses the stimulus.

The glucose can then be used for **respiration** by these cells or **stored**. The **liver** is the major store of carbohydrates, and converts excess glucose absorbed from the blood into a complex carbohydrate called **glycogen.**

In response to decreased **blood glucose levels** (e.g. when exercising or fasting), **glucagon** (peptide hormone) is released from the **alpha (α) cells** of the Islets of Langerhans into the blood (see *Figure 333*).

Glucagon binds to specific receptors on liver cells, which stimulates them to break down their glycogen stores into glucose and release the glucose into the blood. This **increases** blood glucose levels back into the normal **tolerated range**. This is detected by the chemoreceptors, resulting in the termination of glucagon release. This is also an example of **negative feedback**.

Refer to *Figure 335* for a summary of the homeostatic control of blood glucose levels by insulin and glucagon.

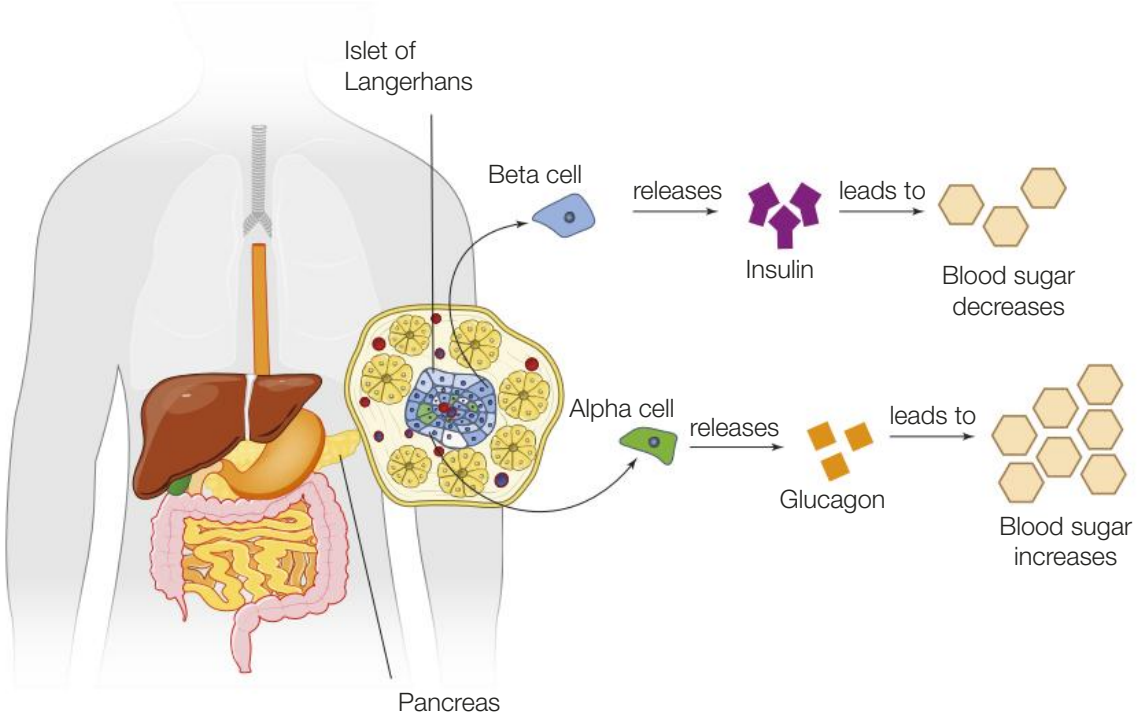


Figure 333 The pancreas produces and secretes the hormones insulin and glucagon, which regulate blood glucose levels

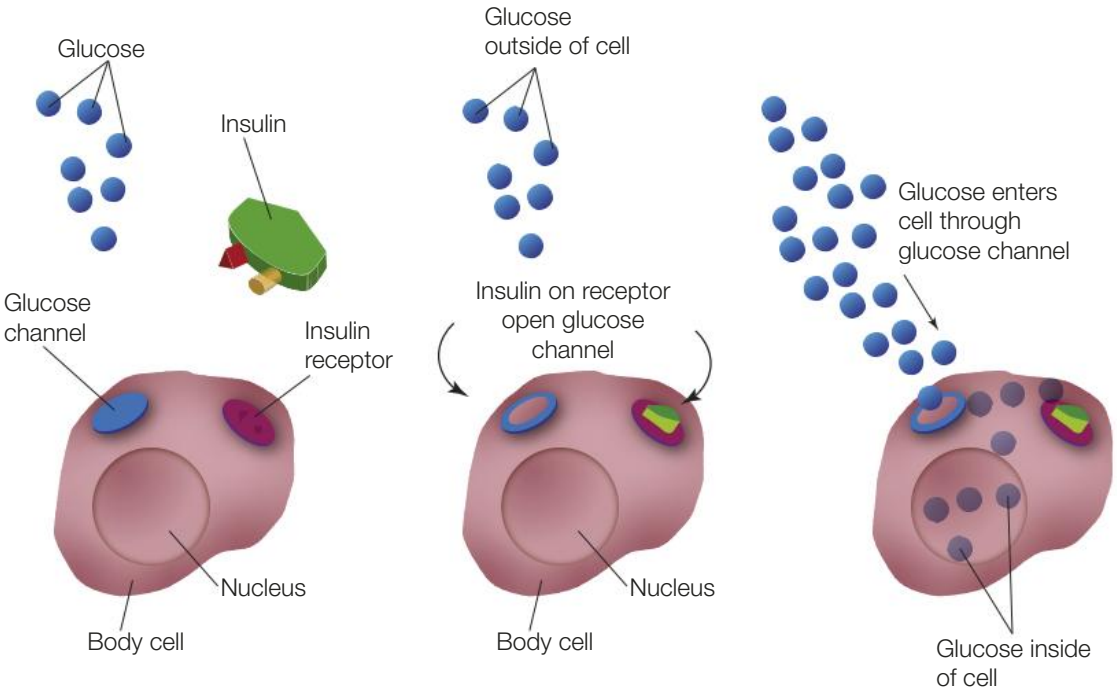


Figure 334 Insulin binds to its complementary receptor stimulating glucose channels to open so that body cells can take up glucose for cellular use or storage

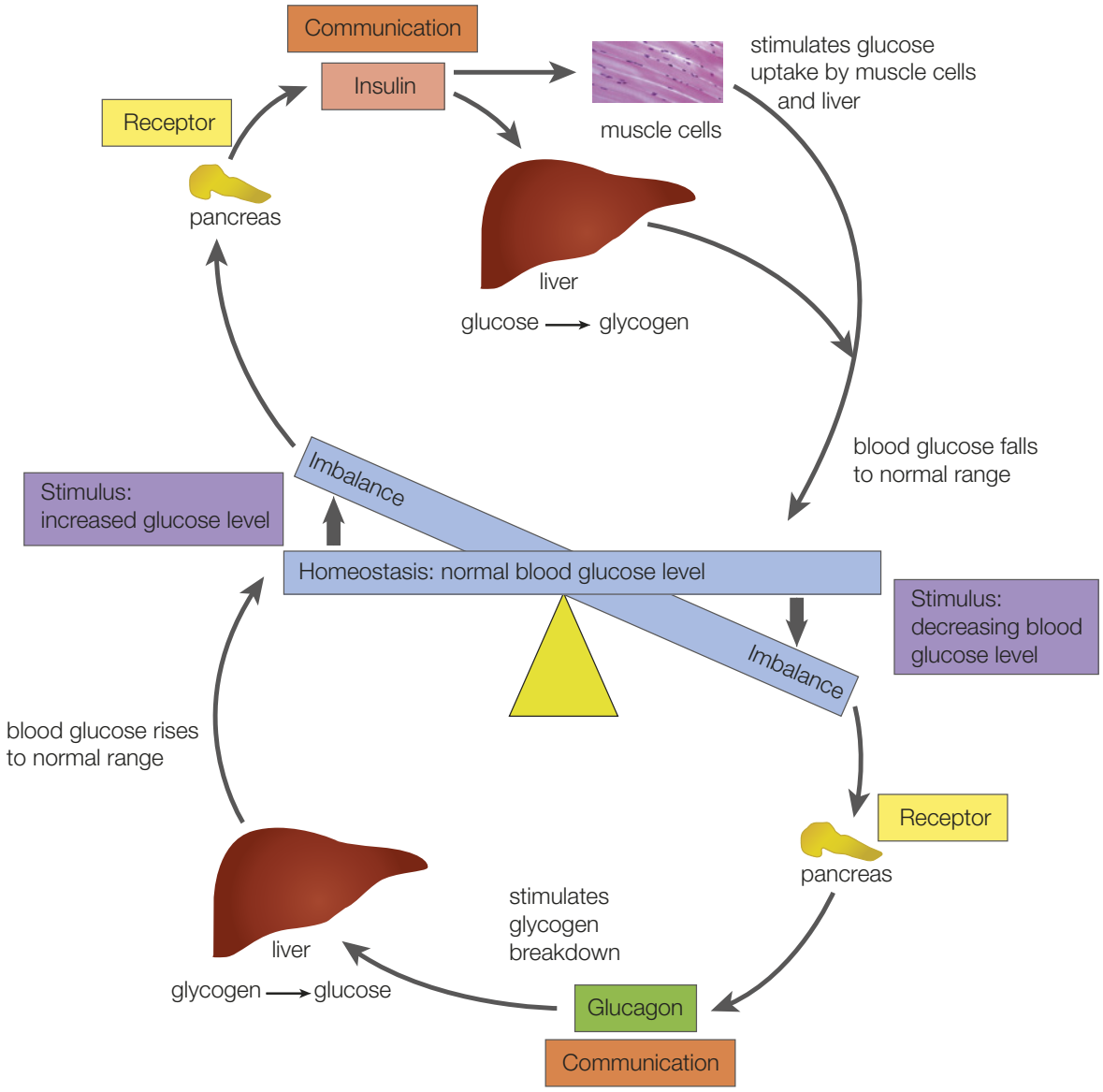


Figure 335 The homeostatic control of blood glucose

Helpful online resources

Cognito: GCSE Biology - Control of Blood Glucose Concentration #56

https://www.youtube.com/watch?v=OHrX3X3LGzI

Diabetes mellitus

Diabetes mellitus (diabetes) is a metabolic disorder where a person does not produce enough insulin, and/or the body does not respond properly to insulin (**insulin resistance**). This means that individuals with diabetes cannot easily regulate their blood glucose levels.

Decreased blood glucose levels, known as **hypoglycaemia**, causes symptoms related to lack of energy due to decreased glucose availability to cells. These include feeling weak, headaches, sleepy, dizzy, etc. As the brain requires a constant supply of energy, generally in the form of glucose, an extended lack of supply can result in unconsciousness and even death.

Elevated blood glucose levels, known as **hyperglycaemia**, can cause a range of symptoms in diabetics. As both type 1 and 2 diabetes can result in elevated blood glucose levels, the symptoms outlined in the table below can be applied to both conditions.

Symptom	Explanation
Excessive urination	Diabetics cannot reduce their blood glucose levels efficiently through the action of insulin so excess glucose is filtered by the kidneys and lost in the urine.
Thirst and dry mouth	As excess fluid is lost through increased urination, diabetics can feel very thirsty and have a dry mouth, promoting the consumption of water.
Hunger and tiredness	If a diabetic cannot produce enough insulin or their cells resist insulin, the cells cannot take up sufficient glucose to fuel their activity. This can result in a lack of energy and a feeling of hunger because the body's cells haven't been able to access enough energy.
Blurred vision	Excess blood glucose levels cause the lens in the eyes to swell, which increases refraction of light. As a result, the light does not hit the retina and a blurry image is seen.
Increased infections	Increased glucose levels provide suitable conditions for microorganisms such as bacteria and fungi. This can result in increased infections, especially urinary tract infections.

If diabetes is not suitably managed and the individual continues to experience chronic high blood glucose levels, it can lead to **further complications** such as cardiovascular disease, nerve damage, eye damage, kidney damage, gangrene, coma and even death.

Type 1 diabetes

Type 1 diabetes is an **autoimmune** condition whereby the immune cells are activated to produce **antibodies** against insulin and/or the β cells in the Islets of Langerhans (see *Figure 336*). As the insulin and beta cells become destroyed, the affected individual cannot produce and release sufficient insulin to control their blood glucose levels. Type 1 diabetics therefore have elevated blood glucose levels after consuming carbohydrates because the body's cells cannot be stimulated to take up glucose from the blood.

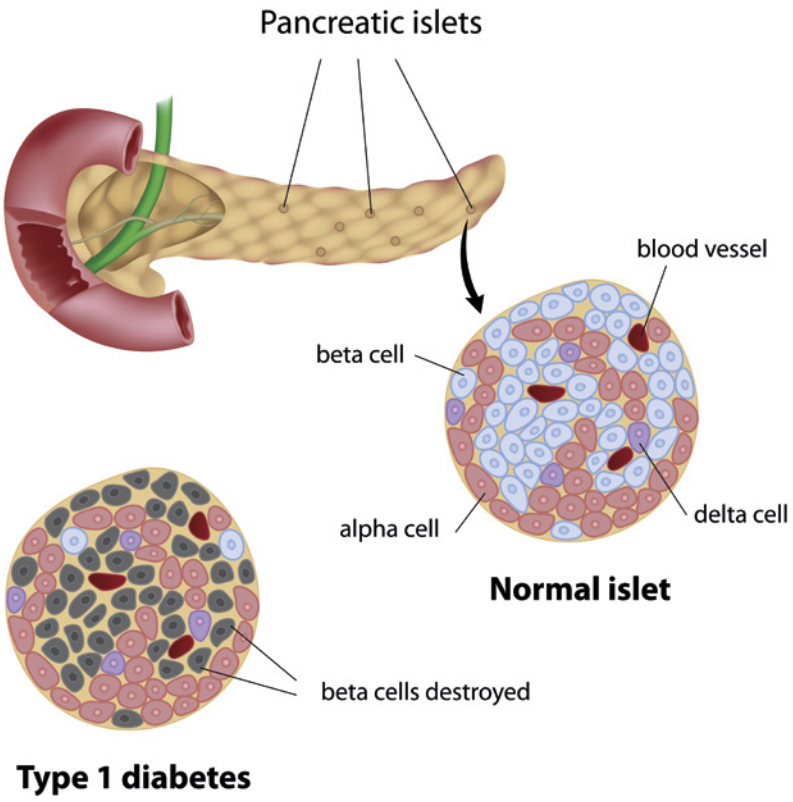


Figure 336 The immune system of type 1 diabetics attacks and destroys the insulin producing beta cells of the pancreas

The cause of type 1 diabetes is unknown, but some cases can be inherited, and others can be caused by a pathogenic infection triggering an autoimmune response. Type 1 diabetes is **not** caused by poor lifestyle choices and cannot be prevented. Because type 1 diabetics can **still respond to insulin**, they can be treated with **insulin injections**. These injections are generally administered prior to meals and contain a mixture of rapid-acting and long-acting insulin. Affected individuals can also use an insulin pump as an alternative to injections to administer insulin. Insulin cannot be taken orally because it is a peptide hormone (protein) that would be digested in the gastrointestinal tract.

Type 2 diabetes

Type 2 diabetes is a condition that develops over time and unlike type 1 diabetes, is predominantly attributed to poor diet and lifestyle choices. However, some individuals can have a genetic predisposition to developing type 2 diabetes. With type 2 diabetes, the body's cells progressively become resistant to insulin and cannot respond, resulting in increased glucose remaining in the blood (see *Figure 337*). To compensate for this **insulin resistance**, the pancreas produces greater amounts of insulin in order to reduce blood glucose levels. This overproduction of insulin places increased pressure on the beta cells of the pancreas, and over time, they can wear out, resulting in a significant reduction of beta cells. As a result, the pancreas produces significantly less insulin. The high blood glucose levels associated with type 2 diabetes are therefore generally caused by a combination of insulin resistance and not enough insulin being produced.

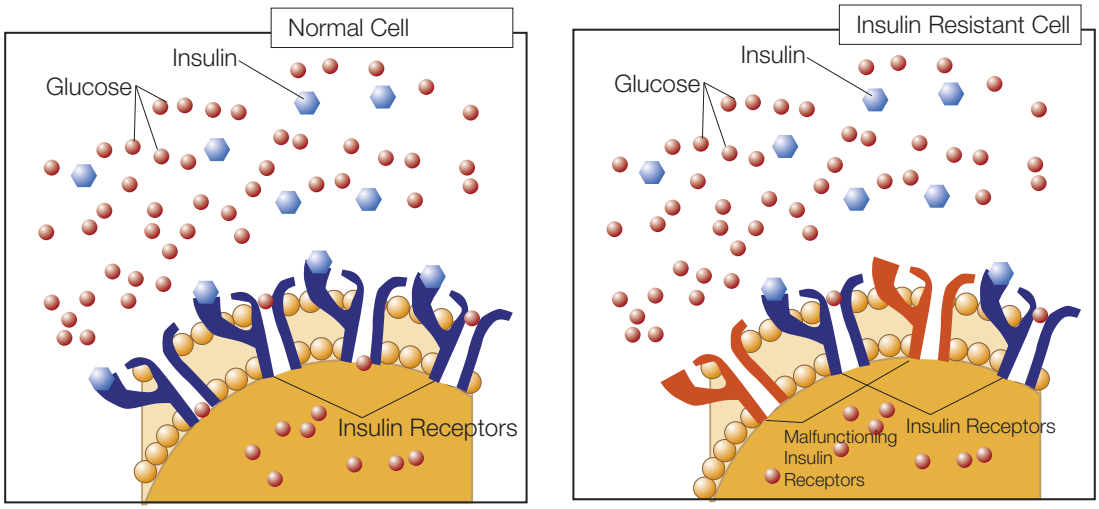


Figure 337 Malfunctioning insulin receptors (red) cannot bind to insulin, which means they are unable to activate glucose channels to open to allow glucose to enter the cell

As type 2 diabetics generally exhibit insulin resistance, there is no current cure. For this reason, modifiable diet and lifestyle choices, such as healthy diet and increased exercise are required to manage type 2 diabetes. If blood glucose levels cannot be controlled by making changes to diet and lifestyle, medication may be prescribed, which aims to reduce insulin resistance. In some cases, when type 2 diabetes has progressed and the pancreas cannot produce enough insulin, insulin injections may be required to manage blood glucose levels.

Helpful online resources

Cognito: GCSE Biology - Type 1 vs Type 2 Diabetes - What is Diabetes and How to Treat It #57

https://www.youtube.com/watch?v=bFnO8Uc9gjQ

Control of metabolism

Metabolism refers to the vast array of biochemical reactions occurring in an organism. Among the most important of these are cell respiration reactions which release energy for ATP production and heat.

Thyroxine (T4) is a hormone produced by the **thyroid gland** and secreted into the circulatory system. It acts on most cells in the body to regulate metabolism by increasing the **basal metabolic rate** (BMR). As a result of this, thyroxine promotes the generation of heat. Iodine is required for the production of thyroxine and a lack of iodine causes the thyroid to enlarge in a condition known as goitre.

Lack of thyroxine will cause slowing of thought and speech, lethargy, sleepiness, decreased appetite and cold intolerance. Too much thyroxine will cause rapid heartbeat, shortness of breath, increased appetite and intolerance to heat. The thyroid gland is found in the neck region, refer back to *Figure 332*.

Refer to *Figure 338* for a simplified negative feedback loop illustrating the control of blood thyroxine levels.

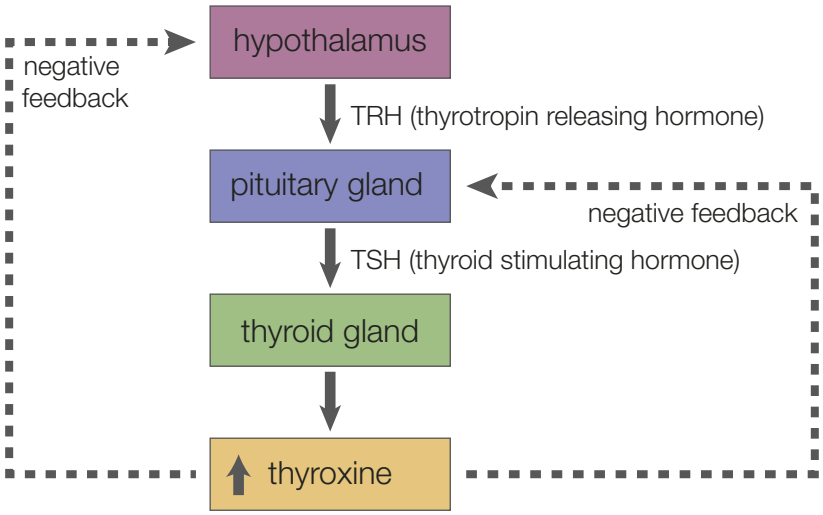


Figure 338 The control of blood thyroxine levels

The following points summarise the feedback loop:

- If thyroxine levels fall, this is detected by receptors in the **hypothalamus** region in the brain.
- The hypothalamus secretes thyrotropin releasing hormone (TRH) which stimulates the anterior pituitary gland to release **thyroid stimulating hormone** (TSH).
- TSH travels through the bloodstream to the thyroid gland which then releases thyroxine.
- Increased levels of thyroxine increase metabolic rate and thus stimulate energy release for ATP production and heat production.
- This is an example of negative feedback where increasing thyroxine levels are detected by the hypothalamus and the stimulus is reversed.

In this example of hormonal regulation, the release of one hormone, TSH, is regulated by the action of another hormone TRH. In other cases, hormonal responses can be stimulated by the nervous system.

Helpful online resources

TED-Ed: How does the thyroid manage your metabolism? - Emma Bryce
<https://www.youtube.com/watch?v=iNrUpBwU3q0>

Osmoregulation by the human body

In Chapter 2.4, osmosis was studied as the movement of water across a semi-permeable membrane. The average solute concentration inside cells is approximately equivalent to 0.9% sodium chloride and examples were presented whereby changing the external concentration to either a higher or lower solute concentration caused a nett movement of water either into or out of the cell. Most cells cannot sustain significant water gain or loss and as a consequence, the solute/water balance in the intracellular environment, blood and tissue fluids needs to be carefully maintained within set tolerance limits. The homeostatic control of this is called **osmoregulation**.

There are at least six separate hormones that impact on osmoregulation in humans and in this chapter the focus is on **antidiuretic hormone** (ADH), also known as vasopressin, which is a **peptide hormone** produced in the hypothalamus and stored before release from the posterior pituitary gland. A diuretic is an agent that increases the rate of urine formation, therefore an antidiuretic such as ADH decreases urine formation. The **collecting ducts in the nephrons** of the kidneys are effectively impermeable to water in the absence of ADH.

Refer to *Figure 339* which provides a simplified version of the stimulus-response model of osmoregulation and involving an **increase in solute concentration**.

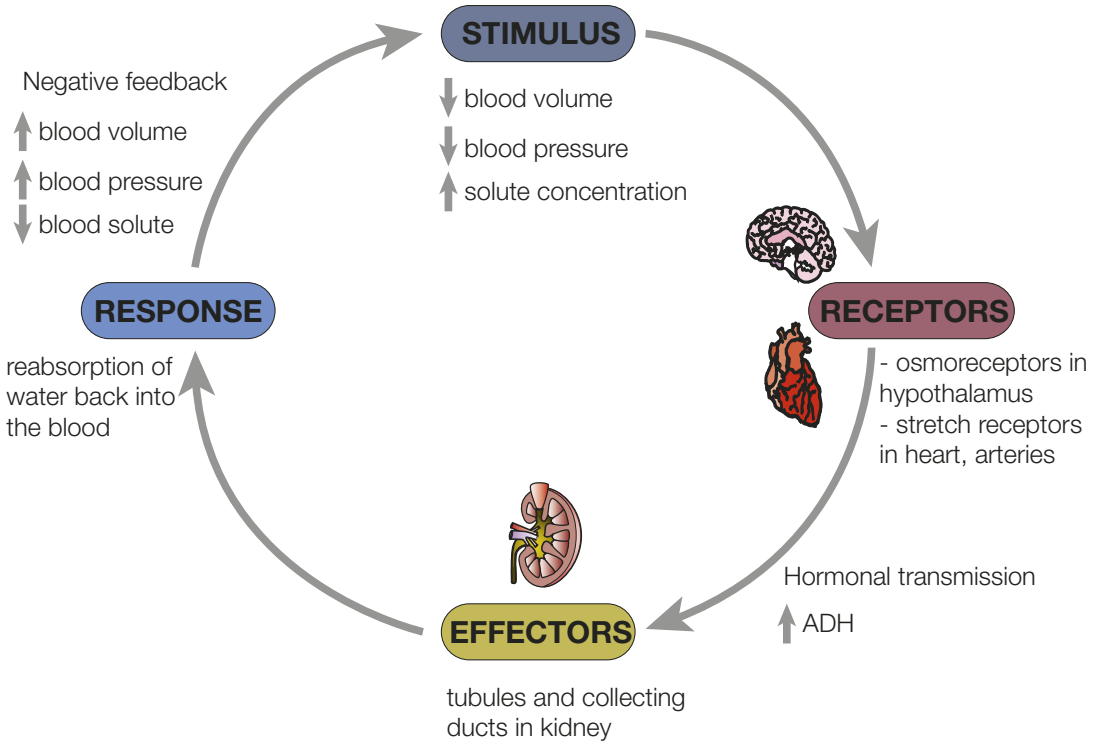


Figure 339 Homeostatic control of the body's water/solute balance

Increase in antidiuretic hormone secretion

Osmolarity is detected in the **hypothalamus (brain)** by neurons known as an **osmoreceptors**, which stimulate secretion of ADH from the posterior pituitary gland when an **increased solute concentration** is detected. **Stretch receptors** in the heart and arteries can also be involved in stimulating the release of ADH from the pituitary gland. This occurs when a **decreased blood volume** and therefore **decreased blood pressure** is detected by the stretch receptors.

ADH travels through the blood to the kidneys. Increased ADH in the blood results in an increased number of **aquaporins** inserted into the cell membranes of the **collecting ducts in the nephrons** of the kidneys. This allows the nephrons to **reabsorb more water** back into the capillaries from the filtrate. As a result, a **lower volume of urine** is produced that will be **more concentrated**.

Some causes of **increased ADH** release are:

- Increased solute concentration in the blood and therefore decreased blood volume and pressure, from not drinking enough water, diarrhoea, excessive sweating (intense exercise), overexposure to heat (dehydration).
- Increased solute concentration in the blood from consuming products high in salt or sugar, such as chips and gravy, cured meats, sugary drinks, etc. Salts and sugars are absorbed into blood from digestive system, increasing solute concentration.
- Some medications can block receptors involved in sodium and water reabsorption, increasing sodium and water loss, decreasing blood volume and pressure.

Decrease in antidiuretic hormone secretion

Osmoreceptors in the hypothalamus detect **decreased solute concentations** in the blood and stretch receptors detect **increased in blood volume and blood pressure**. Detection of these stimuli inhibits ADH release from the posterior pituitary gland resulting in less ADH in the blood. As a result, the number of **aquaporins** inserted into the cell membranes of the collecting ducts of the nephrons also **decreased**. This results in **less reabsorption of water** to the capillaries from the filtrate and an **increased volume of urine** (which is **more dilute**).

Some causes of **decreased ADH** release are:

- An increased volume of blood and hence increased blood pressure from factors such as excessive consumption of water.

- The consumption of alcohol. Alcohol inhibits the release of ADH from the posterior pituitary gland. This results in excessive urination (including the 'breaking the seal' effect) and therefore dehydration, resulting in a hangover.
- Kidney disease can result in receptors on collecting ducts not responding to ADH even though enough is being produced. An example of this is diabetes insipidus (not to be confused with diabetes mellitus).

Figure 3310 illustrates the functional component in the kidney (i.e. **nephron**) responsible for re-absorbing water back into the bloodstream. This occurs because there are a greater number of aquaporins in the cells in the walls of the blood vessels. The presence of ADH increases the permeability of the membranes of the distal tubule and the collecting duct so that more water is kept in the bloodstream and less is lost as urine. Please see *Figure 3311* for a summary of the major organs involved in osmoregulation.

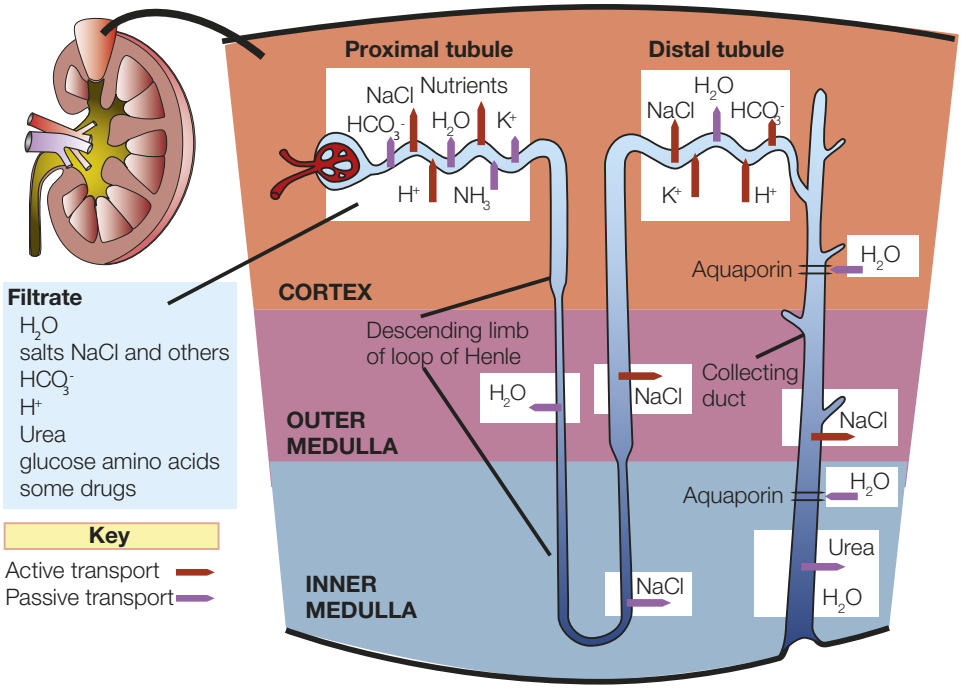


Figure 3310 Processes involved in osmoregulation by nephrons (not all details are required but it is essential that details surrounding the collecting duct and aquaporins are understood)

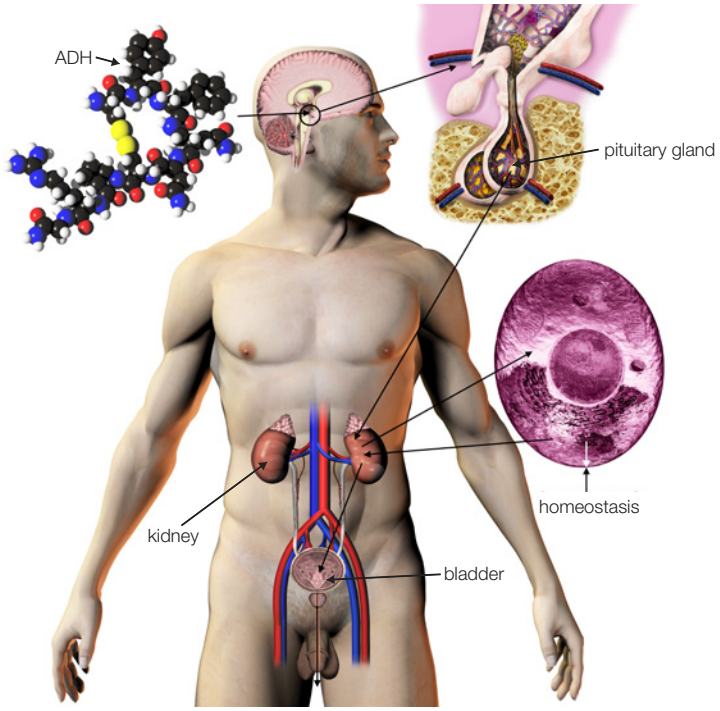


Figure 3311 The major organs involved in osmoregulation

Helpful online resources

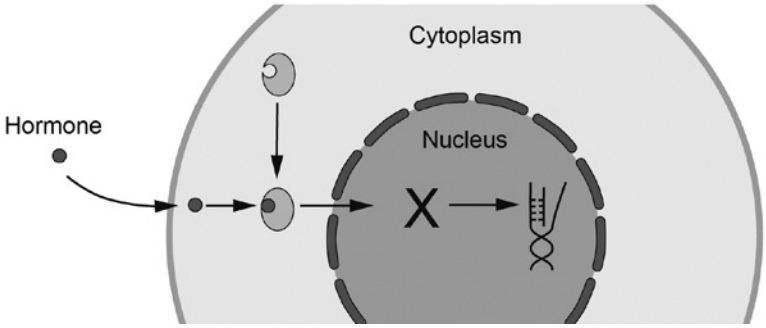
GTAC: Chemical Signalling: Antidiuretic hormone (ADH)
<https://www.youtube.com/watch?v=r15H_xQqOd8>

TED-Ed: How do your kidneys work? - Emma Bryce
<https://www.youtube.com/watch?v=FN3MFhYPWWo&t=73s>

3.3 Review questions

Multiple choice questions

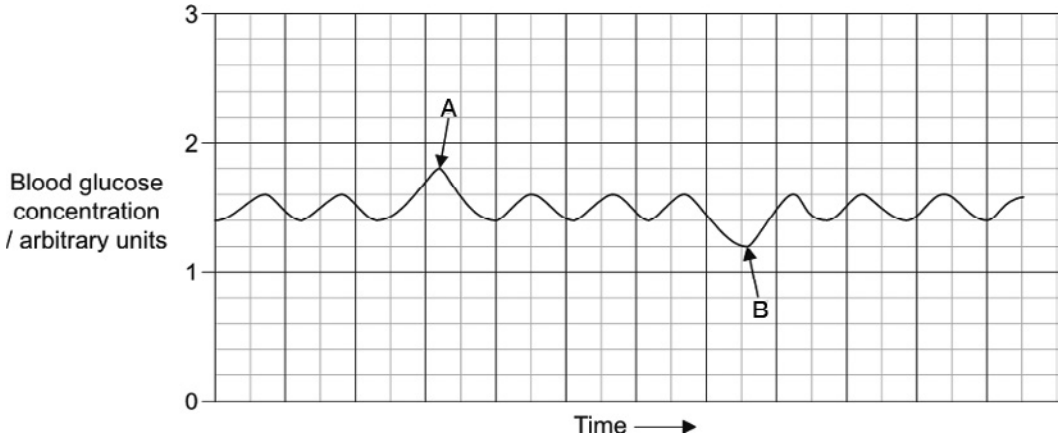
Questions 1 and 2 refer to the diagram shown below.



1. The hormone represented in the diagram above is:
   - J lipid soluble and binds with a receptor in the cytoplasm.
   - K lipid soluble and binds with a receptor on the cell membrane.
   - L water soluble and binds with a receptor in the cytoplasm.
   - M water soluble and binds with a receptor in the nucleus.
2. Which of the following processes is occurring in the nucleus and is identified by the letter X in the diagram?
   - J A hormone-receptor complex binds to RNA.
   - K A secondary messenger binds to DNA.
   - L A hormone-receptor complex binds to DNA.
   - M A secondary messenger binds to RNA.
3. The effect of consuming a glucose drink on blood glucose levels of two individuals was determined. One of these people suffered from type 1 diabetes. Just before consuming the glucose drink both individuals had a blood glucose concentration of 5 mmol/litre. One hour after consuming a glucose drink Person A had a blood glucose concentration of 11 mmol/litre and Person B had a blood glucose concentration of 6 mmol/litre.

   The reason for the blood glucose difference between the two individuals was that Person:
   - J A was diabetic and therefore required less glucose in cells for respiration.
   - K B was diabetic and therefore lost excess glucose through the kidneys.
   - L A was diabetic and therefore was unable to store glucose as glycogen in the liver.
   - M B was diabetic and therefore was unable to release sufficient glucose from muscle cells.
4. Which of the following responses occurs when blood glucose levels are low?
   - J Insulin is released from the β cells of the pancreatic islets.
   - K Insulin is released from the α cells of the pancreatic islets.
   - L Glucagon is released from the β cells of the pancreatic islets.
   - M Glucagon is released from the α cells of the pancreatic islets.

5. The following graph displays changes in blood glucose concentrations over time.

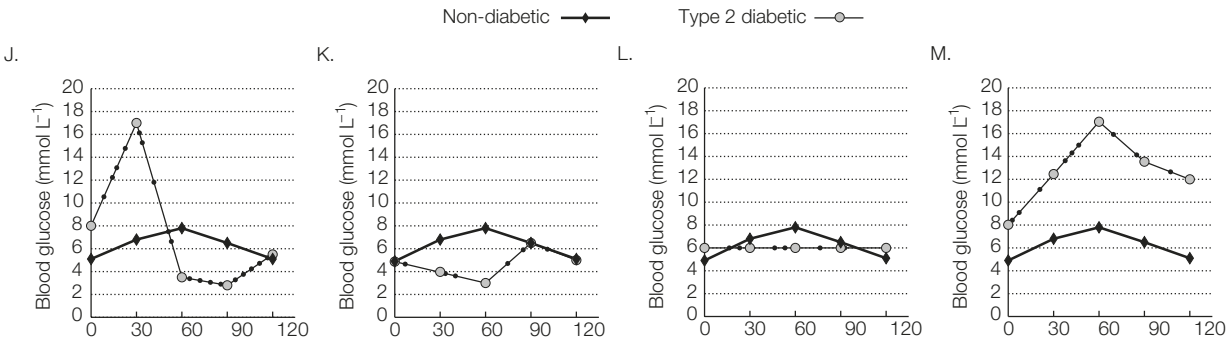


Select the correct hormones that would be released at points 'A' and 'B' respectively.

	A	B
J	Insulin	Glucagon
K	Thyroxine	Glucagon
L	Glycogen	Insulin
M	Glucagon	Insulin

6. The glucose tolerance test is used to investigate the control of blood glucose levels in the human body. Patients consume 75 g of glucose and their blood glucose is monitored for 2 hours.

Identify the graph that could represent the results of glucose tolerance tests in a non-diabetic person and a person with untreated type 2 diabetes?



7. The stimulus for the regulation of water balance is received by the osmoreceptors in the:

J hypothalamus.

K medulla oblongata.

L cerebrum.

M kidney tubule.

8. A mammal consumed one litre of water in 10 minutes.

Which of the following secretions into the bloodstream is likely to occur?

J Decreased adrenaline

K Decreased ADH

L Increased adrenaline

M Increased ADH

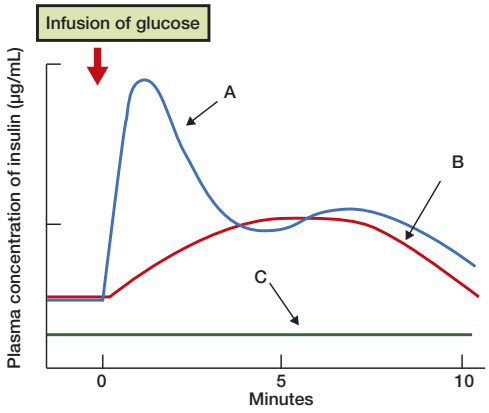
Questions 9 and 10 refer to the information and table below:

Jake performed an experiment to investigate the effects of drinks containing caffeine on urine output.

Jake drank nothing for two hours and then drank one litre of water as quickly as he could. His urine was collected every 20 minutes for the following two hours. He again drank nothing for two hours before repeating the test with diet cola and then with a sugarfree red energy drink. The results are displayed in the table below:

Time (mins)	Urine output (mL)		
	Water	Diet cola	Sugarfree red energy drink
20	60	63	61
40	81	90	97
60	75	85	95
80	52	65	71
100	41	43	50
120	43	45	42

9. With reference to the data in the table, which of the following statements is the most correct?
   - J Drinking diet cola has no effect on urine output.
   - K Drinking water causes urine output to decrease.
   - L Drinking sugarfree red energy drink causes urine output to increase.
   - M Drinking water causes a greater increase in urine output than diet cola.
10. With reference to the data in the table, which of the following statements is the most correct?
   - J The experiment is valid due to variables being kept the same but not reliable due to there being no repeated trials.
   - K The experiment is valid due to variables being kept the same and reliable because of repeated trials.
   - L The experiment is not valid because it does not have a control but is reliable due to the repeated trials.
   - M The experiment is not valid because it does have a control and is not reliable due to having repeated trials.
11. *Refer to the graph below that shows the insulin release in response to a high carbohydrate meal for three individuals.*



Which one of the following options is true with regards to the graph:

- J Individual A has type 1 diabetes.
- K Individual B has type 2 diabetes.
- L Individual C has type 2 diabetes.
- M Individual C does not have diabetes mellitus.

12. An increase in thyroxine (T4) will:
   - J cause a decrease in metabolism.
   - K inhibit the release of thyrotropin releasing hormone due to negative feedback.
   - L inhibit the release of thyroid stimulating hormone due to negative feedback.
   - M result in an individual feeling tired.

Free response questions

1. The pituitary gland is often termed the master endocrine gland.
   a) State the reason for this.

   b) Give an example of when the pituitary releases a hormone that acts directly on a target tissue.

   c) Give an example of when the pituitary achieves its effect by releasing a hormone that stimulates another endocrine gland.

2. Diabetes is a disease associated with poor regulation in maintaining the correct blood glucose levels.
   a) State the cause of type 1 diabetes and explain the resulting effect on controlling blood glucose levels.

   b) Explain how type 2 diabetes is caused.

   c) Explain how type 2 diabetics can manage their blood glucose levels.

3. Complete the table below, summarising the actions of some homeostatic processes involving the action of hormones:

Example of homeostasis	Stimulus	Receptor	Hormone(s)	Effector	Response
Blood glucose concentration			increase in glucagon		
Metabolic rate	increase in metabolic rate				
Osmoregulation					increase in water re-absorption in tubules

4. Osmoregulation involves a regulation of the water/solute balance in cells, blood and tissue fluids.
   a) State two reasons why osmoregulation is important for organisms.

   b) Name two factors that decrease solute concentration in tissues.

   c) Name two factors that increase solute concentration in tissues.

5. Outline the role of the nephron in osmoregulation.

6. Explain why the maintenance of blood levels of thyroxine is an example of negative feedback.

7. Hormones are categorised as either peptide, protein or steroid.
   a) Describe the differences between each type of hormone.

   b) Explain the mode of action of all three categories of hormones, with reference to their corresponding molecular composition.

8. It has been discovered that certain receptors in mitochondria are complementary to thyroxine. Explain the likely significance of this for the role of thyroxine in controlling metabolic rate.

9. Goitre is a disease often associated with a lack of iodine in the diet. Iodine is a mineral that plants obtain from the soil and is required for the production of thyroxine in humans. The disease often presents with a pronounced swelling in the neck caused by an overactive thyroid gland.
   a) Suggest why this disease is often prevalent in people living in tropical mountainous regions, such as Papua New Guinea.

b) Relate the overactive thyroid gland to a malfunction of negative feedback in this situation.

c) Describe why the addition of even a small amount of iodine to the diet will quickly reverse the symptoms.

10. The hormone atrial natriuretic peptide (ANP) is released from heart tissue in response to a higher blood volume. It acts to decrease blood pressure by decreasing sodium reabsorption in the kidneys.

a) Compare the actions of ADH and ANP on water/solute balance.

b) Describe how the kidney tubules respond to ANP and explain how this helps to reverse the initial stimulus.

11. Explain the link between osmoregulation and blood volume.

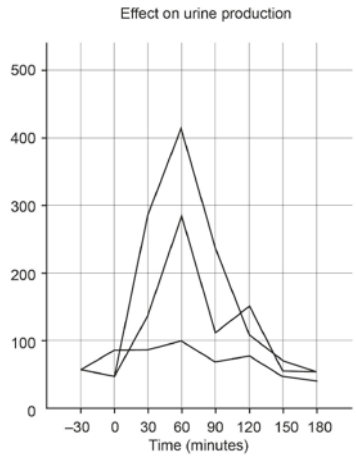
12. An investigation was performed to research how urine production was affected by drinking different salt solutions. Three groups of 10 volunteers were chosen and each group drank 1 litre of different solutions: Group 1 distilled water; Group 2 10% salt solution; and Group 3 30% salt solution.

Urine samples were collected from each individual that participated in the experiment 30 minutes before they drank the solution and then every 30 minutes afterward, and the volume of urine was then recorded.

The table below shows the average volume of urine collected every 30 minutes from the three groups.

	Average urine production (mL)		
Time (minutes)	**Group 1: Distilled water**	**Group 2:10% Salt solution**	**Group 3:30% Salt solution**
–30	56	58	55
0	48	47	51
30	287	138	85
60	415	285	98
90	235	112	67
120	103	82	77
150	68	54	46
180	54	52	40

The graph below is a student's attempt to represent the data shown in the table.



a) Identify three errors in the graph.

b) Discuss an important safety consideration that needs to be planned for in this investigation.

c) Explain why urine was collected from each volunteer 30 minutes prior to drinking 1 litre of their solution?

d) Identify *two* variables *not* indicated in the information for this question that needed to be maintained across all three groups during the investigation to ensure a fair test was conducted.

e) State *one* factor that is changed in the normal internal environment due to the drinking of 1 litre of 30% salt solution.

f) State the time where the blood concentration of ADH would be the lowest for the individuals in Group 1. Justify your answer using data.

Science as a Human Endeavour 3.3 – Hormone replacement therapy

The time in a women's life when her menstrual cycle stops is called menopause. This natural event occurs when ovulation ceases and the ovaries no longer produce the hormone oestrogen. Most women in Australia experience menopause when they are about 50 years old.

For many women the lead up to menopause and the time after are marked by a series of uncomfortable and sometimes debilitating symptoms. These include hot flushes, night sweats and interrupted sleep that in turn lead to tiredness, irritability and sometimes depression. Menopausal symptoms can be relieved by lifestyle changes and hormone replacement therapy.

Hormone replacement therapy is a treatment that involves a woman taking the hormones that her body stops making after menopause. The decision to start hormone replacement therapy is based on a medical assessment, the needs of the individual and includes social and economic considerations.

You may need to refer to the online resources below to answer the questions that follow.

1. Discuss how friendships and social networks could influence post-menopausal women's perception of undergoing hormone replacement therapy.

2. Discuss two limitations of hormone replacement therapy for post menopausal women.

Helpful online resources

Better Health Channel Victoria: Hormone replacement therapy (HRT) and menopause

<https://www.betterhealth.vic.gov.au/health/conditionsandtreatments/hormone-replacement-therapy-hrt-and-menopause>

Newcastle Herald: Women at risk from lack of HRT treatment

<https://www.newcastleherald.com.au/story/945415/women-at-risk-from-lack-of-hrt-treatment/ >

Chapter 3.4 Comparing nervous and endocrine systems

Science Understanding

In human beings, homeostasis depends on the functioning of the nervous and endocrine systems.

Hormonal responses are stimulated by either the nervous system or other hormonal messages.

- Describe the role of adrenaline in the 'fight or flight' response.

The nervous system and endocrine system function independently or together to achieve homeostasis.

- Compare the action of the nervous and endocrine systems.
- Explain how the nervous and endocrine systems work ... together to control body temperature.

Chapter 3.2 was concerned with the role of the nervous system in simple stimulus-response reflexes as well as the role of the system in the homeostatic control of carbon dioxide levels in the blood. Chapter 3.3 focused on the role of the endocrine system and the hormones it produces to control blood glucose levels, metabolic reactions and osmoregulation.

The homeostatic control of other factors involves both the nervous and endocrine systems working together as two systems of communication that can combine to bring about the required responses.

Adrenaline and the 'fight or flight' response

The response of animals (especially mammals) to stress is termed the **'fight or flight' response** and has evolved as a protective mechanism enabling organisms to react quickly and be able to respond to life-threatening situations. This allows organisms to be prepared to:

- fight for **survival** or
- take flight (or quickly move away) from the danger

Figure 341 When 'flight' is better than 'fight'

The response usually begins when sensory receptors (e.g. in eyes or ears) transmit information to the brain, ultimately the **hypothalamus**. It is the hypothalamus, communicating via the nervous system, that sets up the fight or flight response. *Figure 341* illustrates the flight response of this gazelle which is the cheetah's prey. *Figure 342* summarises the fight or flight response (not all details are required for this course).

Helpful online resources

Braive: The Fight Flight Freeze Response

<https://www.youtube.com/watch?v=jEHwB1PG_-Q>

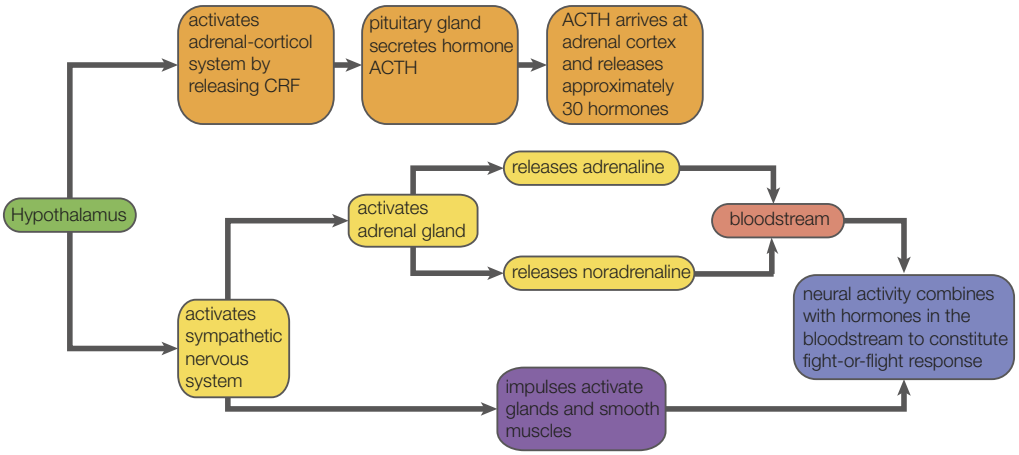


Figure 342 A summary of the 'fight or flight' response (not all details are required)

The hypothalamus initiates its actions via the autonomic nervous system; a system linked to the control of breathing, blood pressure, heart rate and other involuntary actions. It is the sympathetic component (refer to *Figures 322 (a) and 322 (b)* in Chapter 3.2) which is activated and prepares the body to respond to danger.

Hormones are generally slow acting; however, **adrenaline** is a notable exception. Adrenaline is involved in the 'fight or flight' response and is fast acting. Adrenaline can be released into the bloodstream due to a variety of reasons such as danger, stress, shock, excitement, etc. These emotions cause the hypothalamus of the brain to activate nervous pathways (the sympathetic nervous system), which in turn causes the release of adrenaline from the adrenal medulla (on top of the kidneys) into the bloodstream.

Adrenaline overrides the normal homeostatic control. It **inhibits the secretion of insulin** and binds to specific protein receptors on the surface of liver cells. This activates a series of steps that ultimately converts glycogen to glucose, increasing blood glucose levels. This glucose can then be transported to cells to be used for energy required for the **'fight or flight'** response.

Overall, adrenaline increases our alertness and prepares us to 'fight' or 'run' away from danger to increase our chance of **survival**.

Some physiological changes that adrenaline also initiates/contributes to are listed below (see *Figure 343* for more information):

- increase in heart rate
- increase in blood pressure
- dilation of bronchial tubes in lungs
- dilation of pupils
- increased blood flow to muscles
- increased metabolic rate.

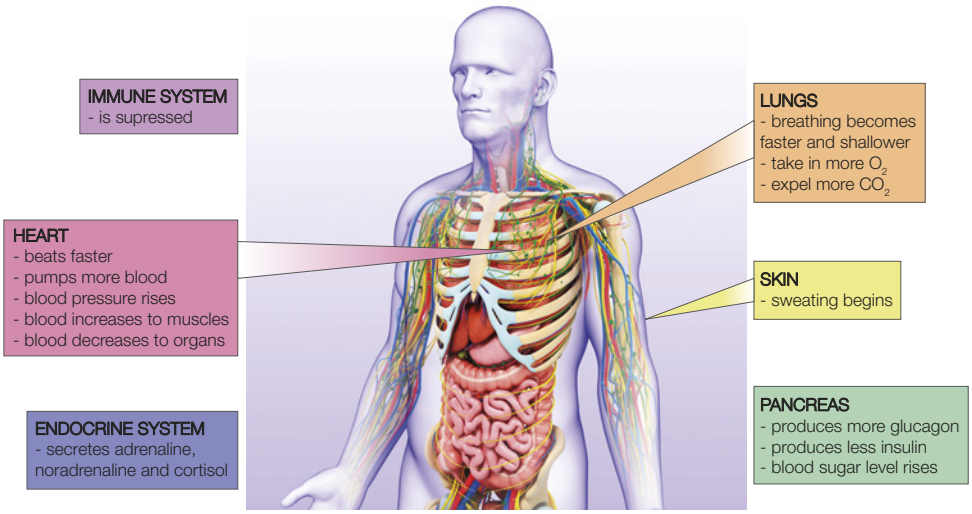


Figure 343 How the body responds to a sudden threat

Helpful online resources

Life Noggin: The Science of Adrenaline

<https://www.youtube.com/watch?v=GilWRuk81tk>

The control of body temperature

Mammals and birds are characterised by the ability to maintain a relatively constant body temperature, irrespective of changes in the external environment. Some aspects of the importance of this to metabolism and survival in general were mentioned in Chapter 3.1.

In humans, the normal temperature of the blood and tissue fluids is approximately **37°C**. The control of blood temperature involves **both nervous and hormonal transmissions**, which is coordinated by the hypothalamus in the brain. In an environment where the temperature is much less than 37°C, an individual will lose more heat if they are not wearing suitable clothes for the cold conditions. Almost all heat loss occurs through the skin, which is a vital organ in regulating the transfer of heat to and from the environment.

Mechanisms that help to produce and conserve heat in animals

Body hair or feathers

The erection of hairs or feathers on the skin helps to trap a layer of air close to the body which provides an insulating barrier to **reduce heat loss**. In cold conditions, nervous signals are sent to the small muscles called erector pili, just below the surface of the skin, causing them to contract. This generally results in the appearance of 'goosebumps' on human skin (see *Figure 344*(a). Humans have little body hair though so this is not a very effective response. However, it is effective in most mammals and birds. The polar bear is a mammal that is well adapted to low temperatures because of its thick insulating coat of hair (see *Figure 344*(b)).

Figure 344 (a) The formation of 'goose bumps'; and (b) Polar bears are well adapted to low temperatures

Blood flow to the skin

Restricting the flow of blood to the surface of the skin reduces heat loss by conduction and radiation to the external environment. **Arterioles** that supply blood to the skin surface have a thin elastic layer (smooth muscle) that has the ability to open up (dilate) and allow more blood to flow (**vasodilation**), or constrict and allow less blood to flow (**vasoconstriction**).

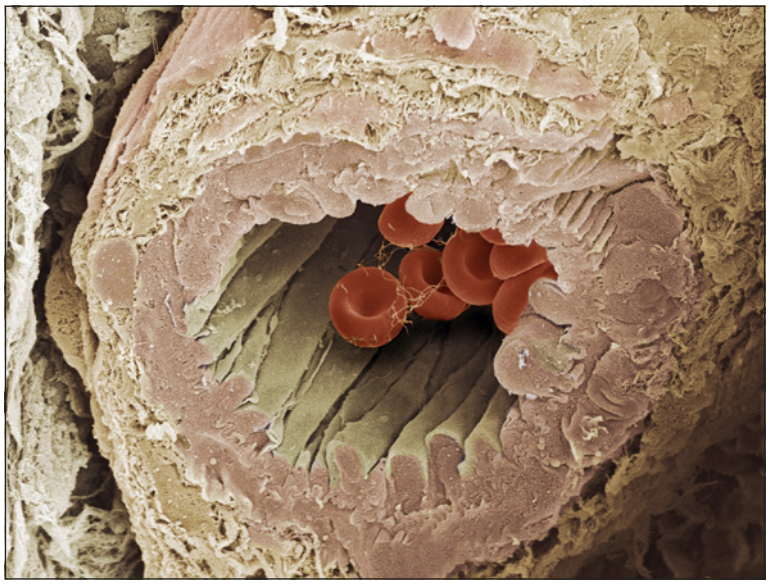


Figure 345 A SEM of an arteriole

Refer to *Figure 345*, taken by a scanning electron microscope (SEM), of an arteriole in which some red blood cells are visible in the lumen or space inside the arteriole. Also visible is the inner wall that is thin and folded, and the thin elastic layer that can dilate or constrict. The pink layer consists of smooth muscle cells that enable **vasodilation and vasoconstriction** to occur. In this instance of reducing heat loss, it is vasoconstriction that is activated. *Figure 346* illustrates an arteriole in three states: normal, constricted and dilated.

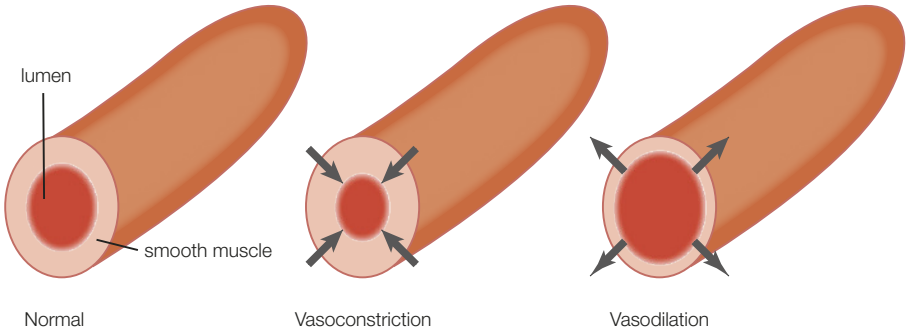


Figure 346 Vasoconstriction and vasodilation

A similar effect is achieved when **pre-capillary sphincters** (small rings of muscle tissue) constrict. When this happens, blood is diverted away from the surface of the skin and through the **shunt vessel** rather than through the capillary network near the skin's surface. Again, this reduces heat loss by conduction and radiation. Refer to *Figure 347*.

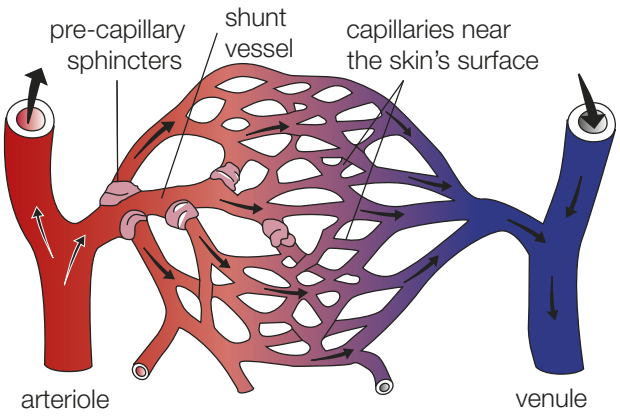


Figure 347 The role of capillaries in heat transfer

Shivering

Shivering involves minor contractions and relaxations of the skeletal muscles and requires energy from aerobic respiration. Heat released as a result of this metabolic activity warms the blood that warms the body as it circulates.

Metabolic rate

Increasing the levels of the hormone thyroxine (refer to Chapter 3.3) and adrenaline (earlier in this Chapter) both increase the rate of metabolism and thus help to generate more heat to raise blood temperature.

Mechanisms that help to reduce heat production and help lose heat

Generally these mechanisms are the reverse of those mentioned above:

- Animals tend to have flattened hair or feathers so as not to trap of a layer of air near the skin.
- The arterioles are vasodilated to increase blood flow to the skin.
- The pre-capillary sphincters are relaxed again, increasing blood flow to the skin to maximise heat loss.
- The metabolic rate is reduced to minimise heat production
- **Sweat glands** release moisture onto the skin surface and **evaporative cooling** causes heat loss (see *Figure 348*).

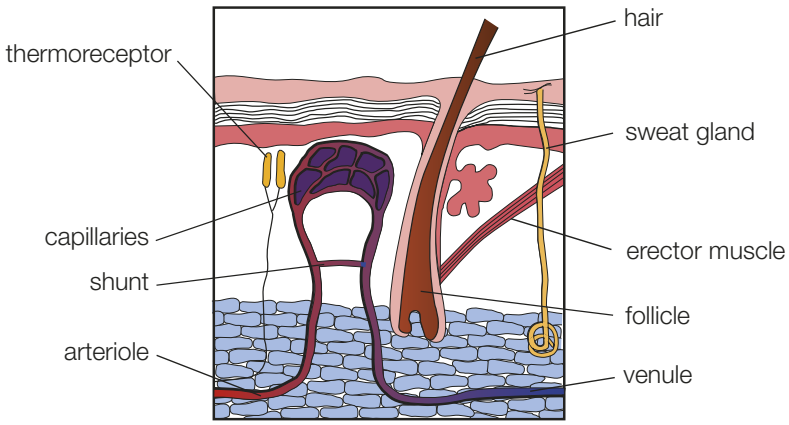


Figure 348 The location of sweat glands in the skin

This model of temperature control is regulated by both nerve impulses and hormones. The table below summarises the main mechanisms or processes involved in the homeostatic control of blood temperature and indicates the main mode of transmission in each case.

Homeostatic process	Mode of transmission
Hair/feather erection on the surface of the skin	Nervous
Sweating	Nervous
Skeletal muscles (shivering)	Nervous
Thyroxine (metabolic rate)	Hormonal
Adrenaline (heart rate etc.)	Hormonal
Vasoconstriction/vasodilation	Nervous/Hormonal
Sphincter muscles	Nervous/Hormonal

Decrease in blood temperature summary

1. The stimulus is a decrease in blood temperature (**36°C**).
2. Blood temperature is monitored by the thermoregulatory centre in the **hypothalamus** of brain. The thermoreceptors in the hypothalamus detect the decrease in blood temperature.
3. A variety of nervous and hormonal transmissions are activated:
    - Nervous messages are sent to the skeletal muscles, which makes them contract (**shivering**), burning energy and creating heat as a by-product.
    - Increased nervous messages are sent to smooth muscle cells in the arterioles and pre-capillary sphincters that supply blood to the skin surface resulting in **vasoconstriction**. This decreases flow of blood to the surface of the body, reducing loss of heat (see *Figure 349*).
    - Increased secretion of thyroxine and adrenaline occurs from the thyroid and adrenal glands respectively. This results in **increased metabolic rate** and increased heat production.
    - Increased nervous messages are also sent to erector-pili muscles in skin causing them to contract, to erect hairs. This may cause appearance of 'goosebumps.'
4. Collectively, these responses increase heat production and retain heat in the body, resulting in an **increase in blood temperature**.
5. The thermoreceptors in the hypothalamus detect when blood temperature is back to the normal temperature (37°C), and the transmissions to increase temperature are terminated. The responses have inhibited the stimulus that caused the responses, therefore **negative feedback** has occurred.

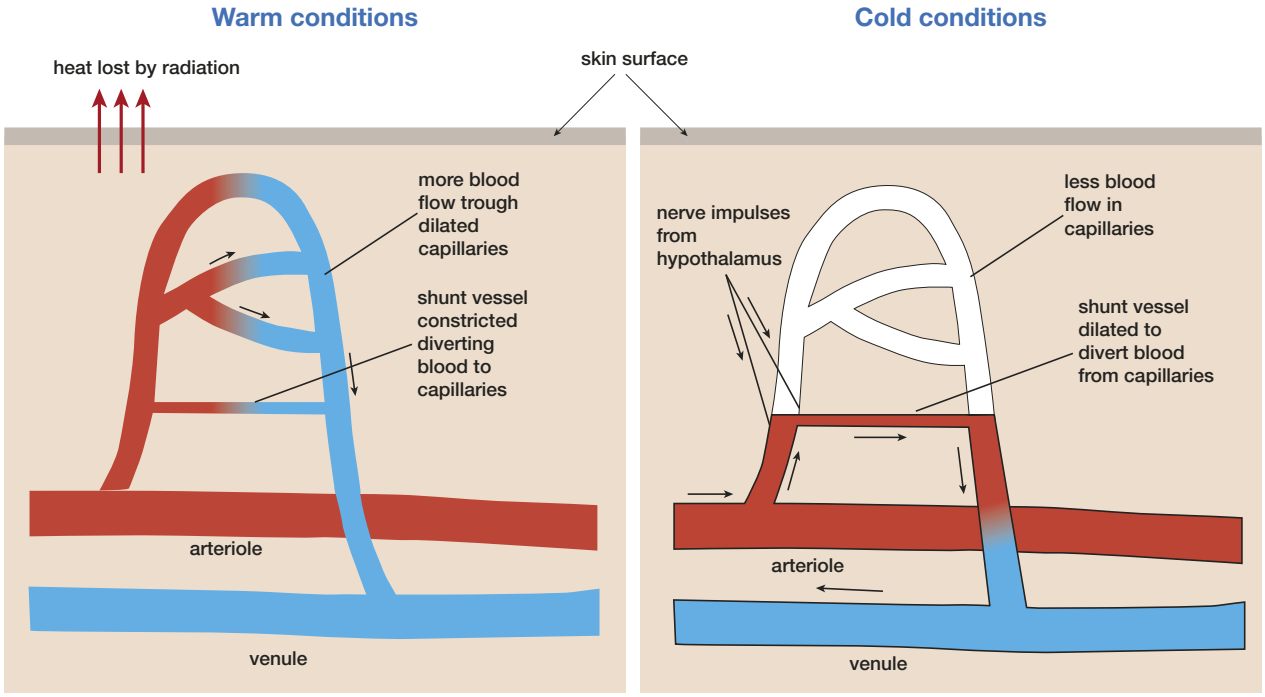


Figure 349 The effects of vasoconstriction and vasodilation on blood flow to capillaries close to the skin surface

Increase in blood temperature summary

1. The stimulus is an increase in blood temperature **(38°C**).
2. Blood temperature is monitored by the thermoregulatory centre in the **hypothalamus** of brain. The thermoreceptors in the hypothalamus detect the increase in blood temperature.
3. A variety of nervous and hormonal transmissions are activated:
    - Nervous messages are sent to the **sweat glands** (see *Figure 348*), causing them to release sweat onto the surface of the skin. The evaporation of the sweat off the skin, takes heat with it, resulting in a cooling sensation (**evaporative cooling**).
    - Decreased nervous messages are sent to smooth muscle cells in the arterioles and pre-capillary sphincters that supply blood to the skin surface resulting in **vasodilation**. This increases flow of blood to the surface of the body, increasing loss of heat (see *Figure 349*).
    - Decreased secretion of thyroxine and adrenaline occurs from the thyroid and adrenal glands respectively. This results in **decreased metabolic rate** and decreased heat production.
    - Decreased nervous messages are sent to erector-pili muscles in skin causing hairs to lie flat, increasing heat loss (as insulating layer of trapped air is not present).
4. Collectively, these responses decrease heat production and increase heat loss from the body, resulting in a **decrease in blood temperature**.
5. The thermoreceptors in the hypothalamus detect when blood temperature is back to the normal temperature (37°C), and the transmissions to decrease temperature are terminated. The responses have inhibited the stimulus that caused the responses, therefore **negative feedback** has occurred.

Refer to *Figure 3410* for a visual summary of the homeostatic control of blood temperature

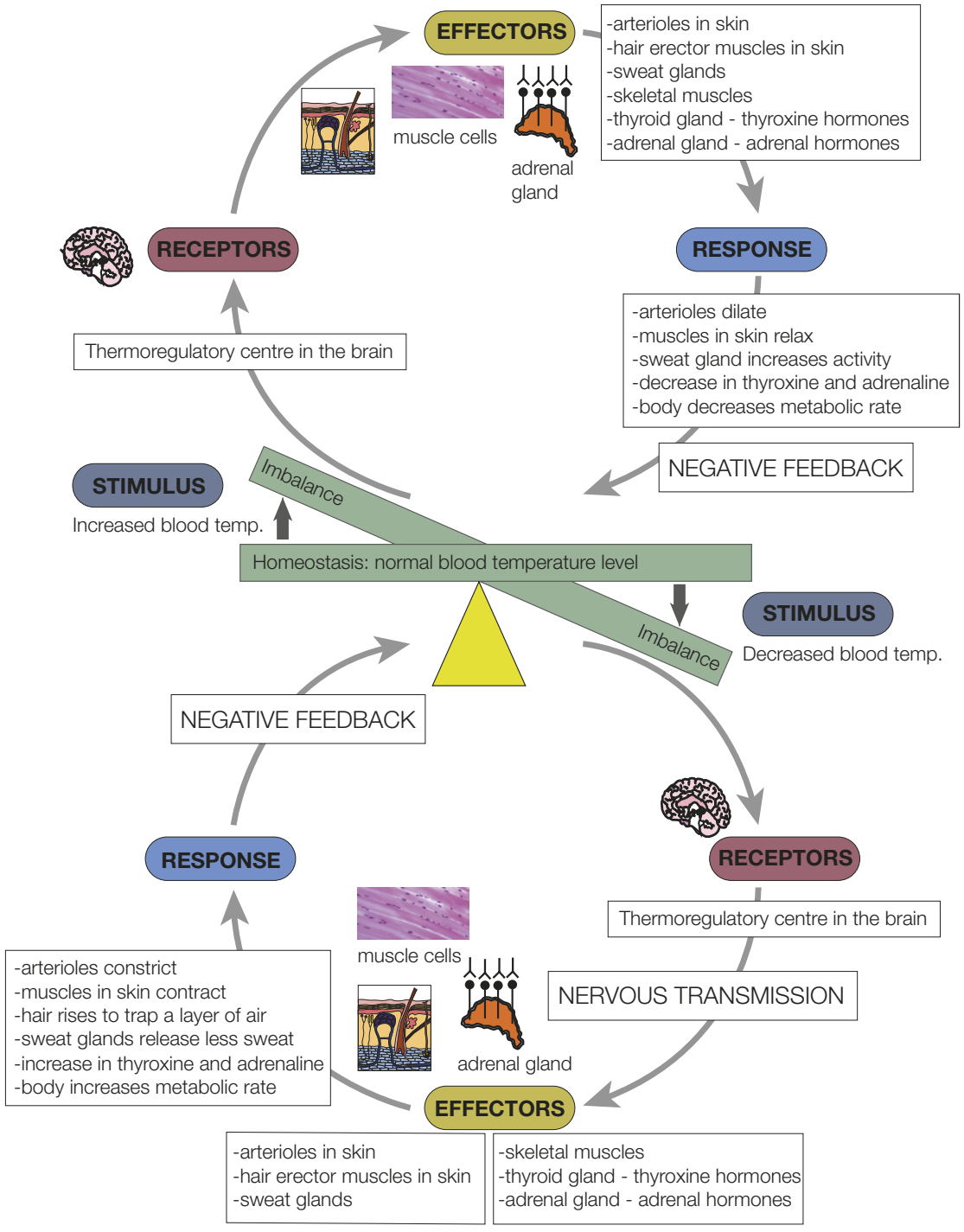


Figure 3410 A summary of the homeostatic control of blood temperature

Helpful online resources

Cognito: GCSE Biology - How We Control Our Body Temperature #55
<https://www.youtube.com/watch?v=IGsQi0JZUTw>

MinuteEarth: Why Do Bats Carry So Many Diseases? (like Coronavirus)
<https://www.youtube.com/watch?v=Ao0dqJvH4a0>

Comparing the action of the nervous system and the endocrine system

The table below is a brief summary to compare the modes of action of nerve impulses and hormones as presented in Chapters 3.1-3.4.

Area of comparison	Nervous system	Endocrine system
Type of transmission	Electrochemical message via nerves and neuro-transmitters in synapses	Chemical message via hormones
Medium of transmission	Neurons or nerve cells	Bloodstream
Speed of transmission	Fast, typically within milliseconds	Slower, typically seconds to hours or days
Duration	Brief, usually seconds	Longer lasting, usually hours or longer
Target cells	Usually muscle cells, glands or other neurons	Tissues or organs with complementary receptors
Specificity	Usually targets specific tissues directly	Less specific-a range of target tissues is common
Response	Often muscle contraction or secretion of a product from a cell	Often a response at the protein or genetic level

3.4 Review questions

Multiple choice questions

1. When compared to hormones, nervous impulses generally have a:
   - J short duration and a short response time and are involved in short-term adjustments.
   - K short duration and a short response time and are involved in long-term adjustments.
   - L long duration and a short response time and are involved in short-term adjustments.
   - M long duration and a long response time and are involved in short-term adjustments.
2. Which of the following options correctly identifies a difference between the endocrine and nervous systems?

	Endocrine system	Nervous system
J.	Electrochemical message	Chemical message
K.	All or none response	Can produce strong or weak responses
L.	Affects one target organ at a time	Affects many target organs at one time
M.	Long-lasting response	Short-lived response

3. Which one of the following is true concerning the action of nerves and/or hormones?
   - J Nerves produce longer lasting effects than hormones.
   - K Hormones are faster than nerves when responding to stimuli.
   - L Hormones may work together with nerves in managing some body processes.
   - M Nervous responses are less specific in their target organs.

4. Which of the following options corresponds with how the hypothalamus responds to a very high body temperature?

   J Stops receiving sensory input.

   K Causes dilation of skin arterioles.

   L Slows the heart rate.

   M Increases muscle contraction.

5. Which of the following actions will restore core temperature after strenuous exercise?

   J decreasing metabolic rate by decreasing the amount of thyroxine in the blood.

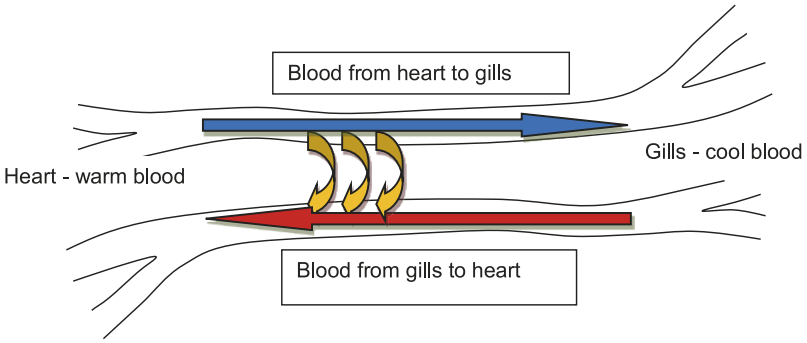
   K increasing sweat production.

   L increasing muscle contractions in skeletal muscles.

   M decreasing the flow of blood in the capillaries close to the skin.

6. *Refer to the diagram below to answer the question that follows. The diagram shows the process of the Counter Current Heat exchange in a fish.*

   As warm blood travels from the heart to the gills an exchange takes place which enables blood returning to the heart from the gills to be warmed.



   The most likely reason that this process increases the chance of survival in cold environments is:

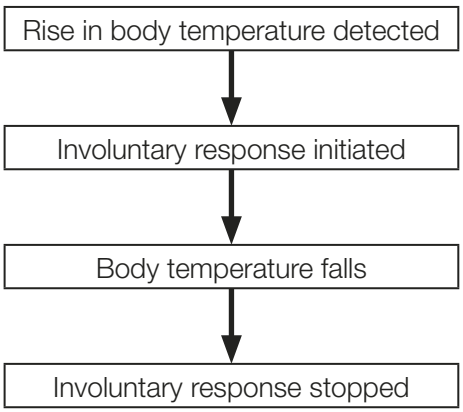
   J An increase in metabolic rate which warms the blood.

   K An increase in vasoconstriction to reduce blood flow to the extremities.

   L A reduction in the exposure of blood vessels to the extreme cold thus limiting heat loss.

   M A reduction in heat loss to the environment by maintaining a low blood temperature flowing to the extremities.

7. *Refer to the flow diagram below, which displays some stages in the control of human body temperature.*



   Which of the following options is an involuntary response that could be initiated as a result of a rise in body temperature?

   J Reduced sweating.

   K Increased secretion of thyroxine.

   L Increased vasodilation.

   M Erection of the hairs on skin.

8. Which of the following physiological changes is not associated with the 'fight or flight' response?
   J Decreased metabolic rate.
   K Dilation of bronchial tubes in the lungs.
   L Increased heart rate.
   M Increased blood pressure.

Free response questions

1. Nerve impulses and hormones both act to transmit information in organisms.
   a) Describe two ways that nervous and hormonal communication are similar.

   b) Describe two ways that nervous and hormonal communication are different.

2. Give one example of homeostasis in humans that involves:
   a) nerve transmission only

   b) hormone transmission only

   c) the nervous and endocrine systems working together.

3. Describe the role of each of the following in the control of blood temperature:
   a) metabolic rate

   b) vasodilation

   c) sweating

   d) increased levels of thyroxine.

4. Complete the following table regarding temperature control in humans. Identify the relevant components of the stimulus-response model.

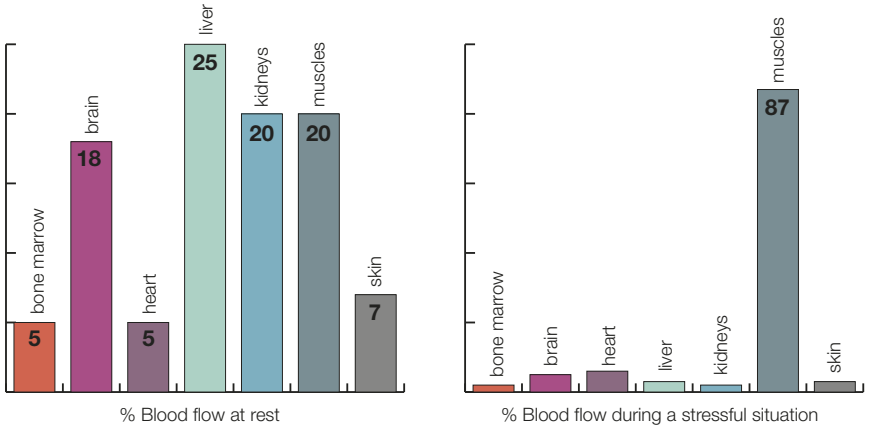
Mechanism	Stimulus	Effector	Response
Shivering			
		Contraction of erector pili muscles	
			Decreased metabolic rate
Vasoconstriction			

5. Describe the role of negative feedback in the homeostatic control of blood temperature.

6. In the fight or flight response, state why it is appropriate for the hypothalamus to initiate its actions via the autonomic nervous system.

7. One of the actions in the fight or flight response is the dilation of the bronchial tubes in the lungs. Explain how this assists in the response.

8. Refer to the *Figure* below to help answer the questions that follow. It compares the percent blood flow at rest compared to a stressful situation.



a) Using data, compare the pattern of results of the two graphs.

b) Suggest a likely hypothesis that could be tested, based on this data.

c) Explain the links between the data and the implications for the 'fight or flight' response.

d) Explain the role of adrenaline in bringing about the differences observed in the two graphs.

9. Explain how nerve impulses and hormones coordinate responses to ensure both work together in the fight or flight response.

10. A reflex action is managed by the nervous system whereas the control of blood glucose levels is achieved by a pair of hormones. Explain why each method of transmission is appropriate for the two different responses.

11. Vasoconstriction of arterioles and the constriction of pre-capillary sphincters are two mechanisms used to reduce heat loss to the environment.

    a) Describe the general mechanism by which each acts to conserve heat energy.

    b) Compare the roles of each method in reducing heat loss.

12. Cortisol is one of the hormones released during the fight or flight response. It is also released as a response to stress and low blood glucose levels. Some of its effects involve partially suppressing the immune system and increasing blood pressure. It has been suggested that stress is sometimes useful but at other times contributes to poor health.

    a) Explain how the effects of cortisol prepare the body for a stressful situation.

    b) Predict how continued exposure to stress may have negative consequences for a healthy lifestyle.

13. Engineers at Johns Hopkins University have recently developed technology called an 'e-dermis' that allows the detection of external stimuli on the fingertips of prosthetic limbs. The technology is revolutionary for amputee patients.

    a) (i) Name the type of receptors engineers would have to replicate into the e-dermis to allow the detection of small stimuli to the skin when it came into contact with an object .

    (ii) Engineers are also developing an e-dermis capable of detecting temperature.

    Explain how specific receptors found in human skin can detect external temperatures.

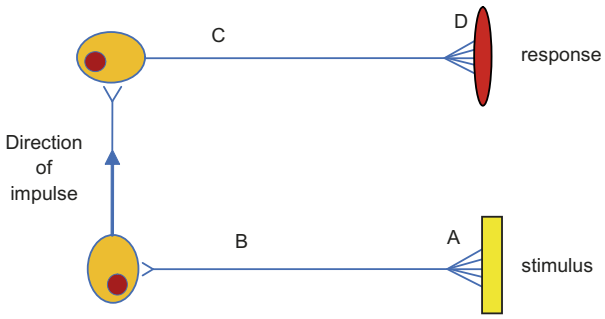
    b) Discuss two possible limitations of the e-dermis.

Topic 3: Review Test

Allocate 80 minutes to complete this Test. These are all SACE exam-style questions. Indicate your choice for each of the multiple choice questions (each worth one mark) and answer all of the other questions in the spaces provided. The number of marks for each free response question is shown in brackets. It is recommended that you compare your answers to the suggested answers section as part of your revision. Please note that the suggested answers are not extensive nor exclusive.

Section 1: Multiple choice questions (10 marks)

1. *Refer to the diagram below of a reflex arc to answer the question that follows.*



Which of the following has the above structures correctly labelled?

	Receptor	Effector	Motor neuron	Sensory neuron
J	D	A	C	B
K	D	A	B	C
L	A	D	C	B
M	A	D	B	C

2. Scientists have proposed a model to explain how homeostasis works to keep a stable internal environment. Which of the following best shows the components of the model in the correct order?

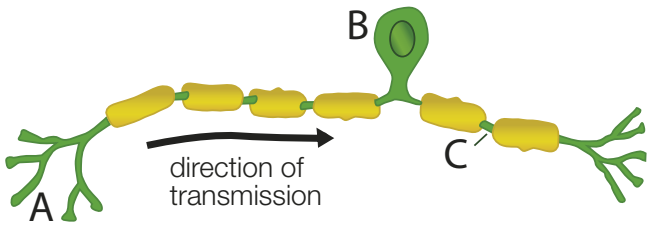
J stimulus, effector, receptor, response, feedback

K stimulus, effector, receptor, feedback, response

L stimulus, receptor, effector, response, feedback

M stimulus, receptor, effector, feedback, response

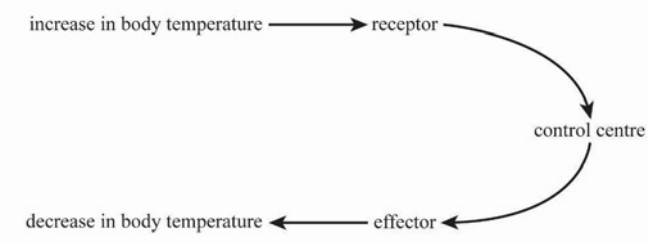
3. *Refer to the diagram below of a sensory neuron and answer the question that follows:*



Which of the following correctly labels the three components of a neuron?

	A	B	C
J	dendrite	axon	cell body
K	cell body	dendrite	axon
L	axon	dendrite	cell body
M	dendrite	cell body	axon

4. *Refer to the diagram below representing the stimulus-response model for an increase in body temperature to answer the question that follows.*



Which one of the following is correct?

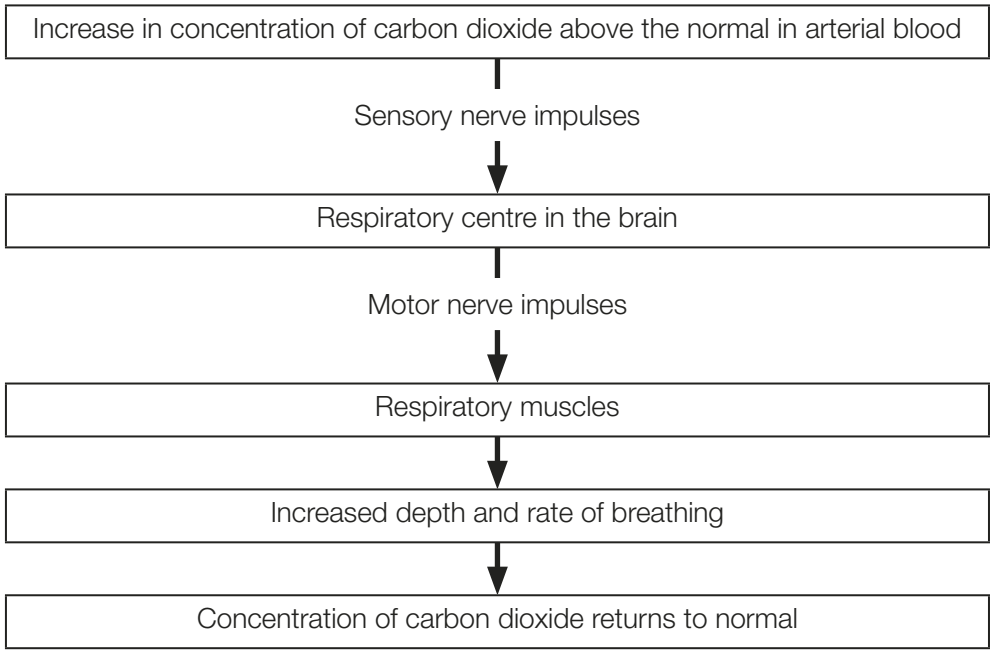
J An example of the receptor involved is a thermoreceptor in the skin.

K This model only involves communication via nerves.

L An example of an effector is smooth muscle in blood vessels.

M This model would not involve negative feedback.

5. *Refer to the flow diagram below which shows the regulation of CO_2 concentration in the blood to answer the question that follows.*



The effector(s) in this diagram is/are the:

J respiratory (intercostal) muscles

K respiratory centre in the brain

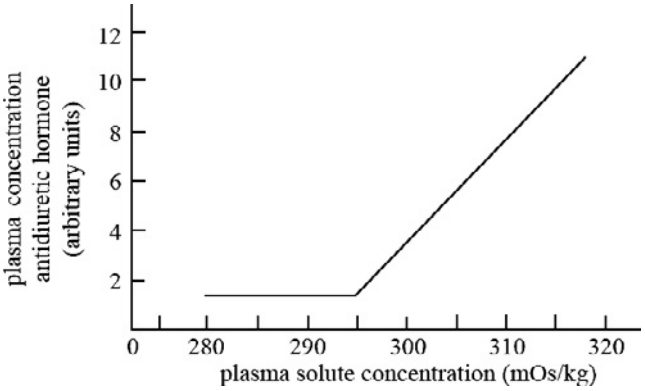
L Increase in the rate and depth of breathing

M motor nerve impulses

6. Antidiuretic hormone (ADH) is an important hormone in maintaining the plasma solute/water balance.

Refer to the graph on the right which shows how changes to the plasma solute concentration affect the concentration of antidiuretic hormone (ADH) to answer the following question.

Normal plasma solute concentration in a human is around 280-295 milli-osmoles per kilogram (mOs/kg).



The most likely way that ADH restores the water/solute balance of blood is to:

J increase the rate of diffusion of solute molecules from the kidney tubule back into the bloodstream.

K increase the rate of diffusion of solute molecules from the blood capillaries into the kidney tubule.

L increase the rate of osmosis from the kidney tubule into the blood capillaries.

M increase the rate of osmosis from the blood capillaries to the kidney tubule.

7. When the hormone cortisol reaches a target cell, it enters the cell and joins with a receptor protein inside the cell. The combined complex enters the nucleus, where it activates the transcription of genes to produce a protein.

What type of hormone is cortisol?

J A lipid soluble amine.

K A lipid soluble steroid.

L A water soluble amine.

M A water soluble steroid.

8. Which of the following is a feature of type 1 diabetes but not type 2 diabetes?

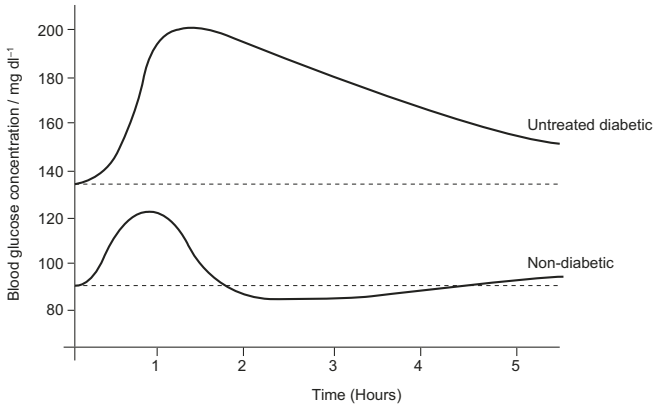
J Type 1 diabetes can be controlled through a low carbohydrate diet.

K β cells are destroyed by immune system.

L Target cells become insensitive to insulin.

M α cells produce excess insulin.

9. The graph below shows the changes in blood glucose concentration of a non-diabetic individual and a type 1 diabetic after consuming a meal.



Which statement correctly describes the events in this untreated diabetic patient immediately after consuming a meal?

J Alpha cells of the pancreas secrete too little glucagon.

K Alpha cells of the pancreas secrete too little insulin.

L Beta cells of the pancreas secrete too little insulin.

M Beta cells of the pancreas secrete too little glucagon.

10. If the core body temperature of a healthy person falls below the normal setting of 37°C

J vasodilation occurs, resulting in an increase in heat production.

K an increased amount of the hormone thyroxine is released, resulting in a decrease in heat loss.

L vasoconstriction occurs, resulting in a decrease in heat loss.

M a decreased amount of sweating occurs, resulting in an increase in heat production.

Section 2: Free response questions (60 marks)

11. Complete the following table comparing the hormonal (endocrine) and nervous systems in the communication between cells and tissues in humans.

Area of comparison	Hormonal	Nervous
Speed of transmission		
Target site(s)		

(4 marks)

12. Hyperventilation is where a person rapidly increases their rate and depth of breathing.

    a) State the effect that this would have on the oxygen levels in the blood.

(1 mark)

    b) A swimmer had her blood pH measured prior to and after a 200m sprint. The results indicated a drop from 7.3 to 7.0. Describe how this might trigger an increase in the rate and depth of breathing.

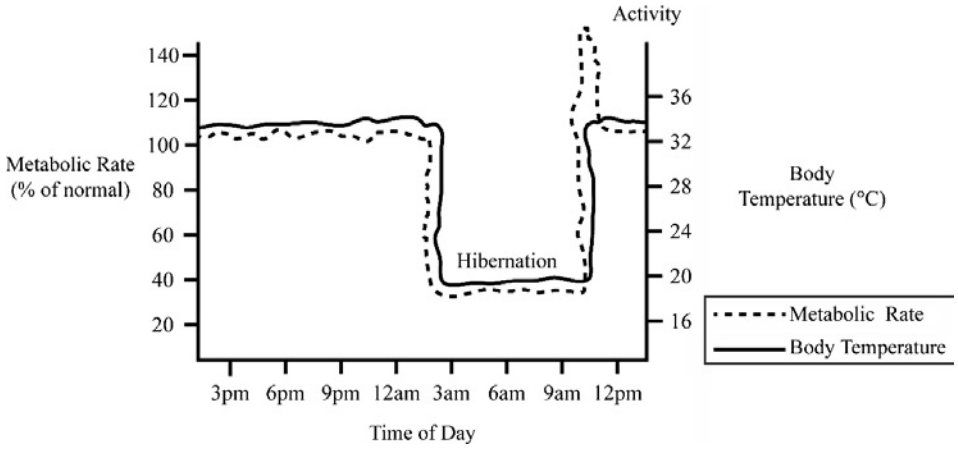
(2 marks)

    c) Name the effectors and explain how they act to lower the carbon dioxide levels in the blood.

(3 marks)

13. The Fat-tailed Dunnart (*Sminthopsis crassicaudata)* is a small carnivorous mammal found quite extensively in inland Australia (refer to the picture below). During winter the animal tends to burrow and enter a mini-hibernation period (torpor).

Refer to the graph below showing the metabolic rate and body temperature of the Dunnart during winter.



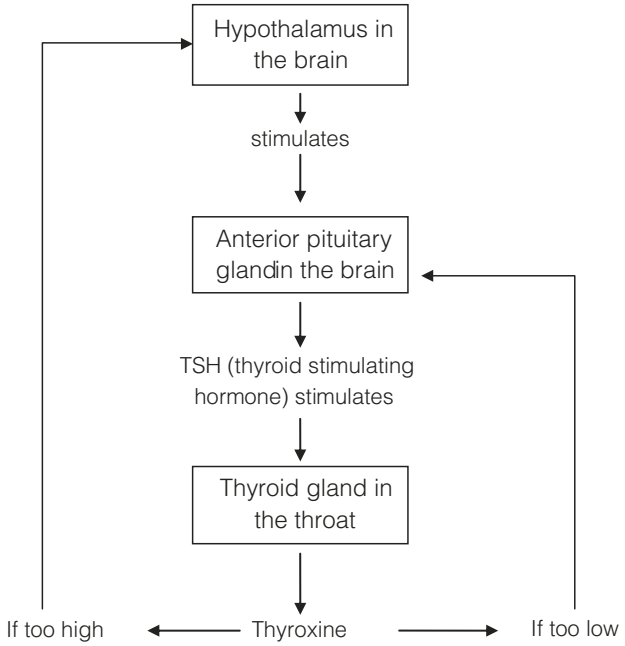
a) Explain how an increase in metabolic rate can give rise to an increase in body temperature.

(2 marks)

b) At approximately 10:30am, there is a period of high activity where the metabolic rate increases to higher levels than normal. Explain why the body temperature does not rise above normal levels even though metabolic rate does..

(3 marks)

14. *Refer to the diagram showing the control of thyroxine production in humans to answer the questions below.*



a) State how TSH travels to the thyroid gland.

(1 mark)

b) If blood temperature falls, thyroxine levels rise. Explain how elevated thyroxine levels can cause a rise in blood temperature.

(2 marks)

c) Discuss how the control of thyroxine production in humans represents an example of one hormone regulating the action of a completely different hormone.

(3 marks)

15. Pseudogenes exist in the genomes of mammals and are known as genes that are unable to function. It has been suggested that they may be the remains of genes that have been lost through evolution or they may be an earlier version of a present functional gene.

Refer to the following table to answer the questions that follow. The table below shows the percentage of smell receptor functional genes and smell receptor pseudogenes in various species.

Smell receptor genes (%)	Organism			
	Humans (%)	Apes (%)	Dogs (%)	Mice (%)
Pseudogenes	50	40	20	20
Functional Genes	50	60	80	80

a) Briefly describe how smell receptor genes enable organisms to differentiate between individual smells.

(3 marks)

b) Write a possible conclusion regarding the importance of smell based on the data in the above table.

(2 marks)

c) Mechanorecptors are another type of sensory receptor. Provide one example of a stimulus detected by such a receptor and a possible location of the receptor.

(2 marks)

16. Botulism is a potentially fatal disease caused by a potent bacterial neurotoxin called botulinum. It acts by preventing exocytosis at nerve cell endings and this prevents the release of the neurotransmitter acetylcholine. One application used in the cosmetic industry is using 'Botox' injections, which are the commercial product of the neurotoxin used in reducing wrinkles in the skin. Another application is found in modifying Botox and using it for pain management.

a) Describe the role of neurotransmitters such as acetylcholine in the transmission of nerve impulses.

(3 marks)

b) Explain how preventing exocytosis at the synaptic cell membrane may give rise to the toxic properties of botulinum.

(3 marks)

17. a) Describe why a gazelle fleeing a cheetah is an example of the "flight or fight" response.

(2 marks)

b) Describe how both nerves and hormones are involved in the "flight or fight" response.

(2 marks)

c) Identify two changes that would occur in the circulatory system to facilitate the "flight or fight" response.

(2 marks)

18. Adrenaline is a hormone released in response to a stressful event. Adrenaline is an amino acid derived hormone that binds with a receptor protein on the cell membrane of muscle cells.

a) Describe two differences between an amino acid derived hormone and a protein hormone.

(2 marks)

b) Adrenaline causes the vasodilation of muscle arterioles. Explain how this response could benefit an individual experiencing a stressful event.

(2 marks)

19. An investigation was conducted to determine the effect of a new form of insulin. Two subjects, both with type 1 diabetes (diabetes mellitus), were asked to drink one litre of glucose solution. Subject A was given an injection of the standard insulin; however, subject B was given an injection of the new form of insulin. Following the injection, their blood glucose levels (BGL) were measured immediately and then every 10 minutes for one hour. The results of the experiment are displayed in the table below:

Table 1: The effect of type of insulin on blood glucose level (over time).

	Blood glucose level (BGL) (mg/100 mL)	
Time (minutes)	Subject A (standard insulin)	Subject B (new form of insulin)
0	90	92
10	110	104
20	122	125
30	126	135
40	105	115
50	96	100
60	90	97

a) State what type of graph would have been constructed to show this dataset.

(1 mark)

b) Discuss the reliability of this experiment.

(3 marks)

c) Using data, compare the results of the two forms of insulin.

(3 marks)

d) Explain why insulin injections work on type 1 diabetics.

(2 marks)

e) Metformin is a drug that is approved to treat type 2 diabetes. Metformin has been shown to lower blood glucose levels (BGL) by reducing glucose released from the liver and from the food we eat, and increasing insulin sensitivity. It is also used off-label (not officially approved for use) for weight loss, gestational diabetes and polycystic ovary syndrome (PCOS). Recently, metformin has been linked to a higher risk (three times) of birth defects in children of men who took the drug in the three months prior to conception (it takes 90 days for sperm development/maturation). However, the solution is not a simple one because type 2 diabetes also affects sperm quality.

Use your understanding of science as a human endeavour to answer the following questions.

(i) Discuss how this research on metformin and birth defects could influence further studies.

(4 marks)

(ii) Discuss why it is important for this information to be communicated to the public and not just medical professionals.

(3 marks)

Total: /70

Topic 4 Evolution

Chapter 4.1 The origin of life on Earth

Science Understanding

Evidence shows that life has existed on Earth for around 3.5 billion years, during which time it has diversified.

Existing cells are the products of evolution.

Membranes may have formed spontaneously and the first simple cells may have used RNA as genetic information. Ribozymes may have played a role in this development.

- Describe the possible roles of RNA and ribozymes in the first simple cells.

There is evidence that prokaryotic cells existed before eukaryotic cells.

- Describe this evidence, including fossil evidence.
- Explain how the ancestry of most existing eukaryotic cells probably involved endosymbiotic events.

Scientific evidence suggests that the Earth was formed around 4.5 billion years ago. As the mass of the developing planet increased, heat generated by the force of gravity and radioactive decay caused the interior to melt, producing a dense metallic core which was surrounded by a cooler, semi-solid mantle. Outside of this was the crust which solidified and formed the continents and the seafloor.

During the cooling of the crust, gases from the hot interior escaped through volcanoes, forming an atmosphere that probably contain hydrogen, water vapour, methane, ammonia and hydrogen sulfide. This early atmosphere lacked oxygen. Refer to *Figure 411*.

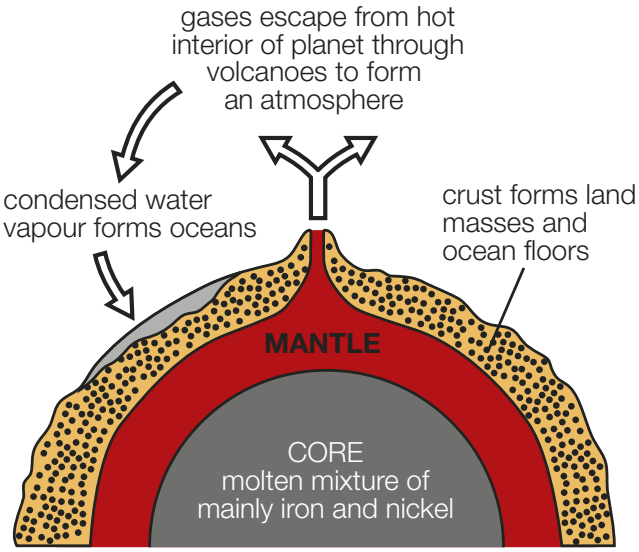


Figure 411 The proposed early structure of planet Earth

There is evidence to suggest that life on Earth originated only once and that the existing cells and organisms are the products of evolution.

The Cell Theory states:

- all organisms consist of cells or the products of cells
- all cells come from pre-existing cells by cell division
- cells are the building blocks of life

This presents scientists with an interesting dilemma; if all cells come from pre-existing cells, where did the first cell come from?

Helpful online resources

TED-Ed: The mysterious origins of life on Earth - Luka Seamus Wright
<https://www.youtube.com/watch?v=de1hiS_XjWg>

As was discussed in Chapter 2.2, the oldest widely accepted fossils are the **cyanobacteria** from rocks in Western Australia dated at about 3.5 billion years old. Refer to *Figure 412*.

These cyanobacteria formed **stromatolites** which consist of layers produced as calcium carbonate precipitated over the growing bacterial filaments. These were important for evolution on Earth as they released oxygen into the atmosphere as a result of photosynthesis. Refer to *Figure 413* for a close-up of stromatolites showing the layers of the build up of mineral deposits.

Figure 412 Stromatolites in the ocean

Figure 413 Stromatolites up close

It is thought that several processes were necessary for life to begin on Earth:

- The synthesis of simple organic molecules e.g. amino acids and ultimately the synthesis of larger organic polymers e.g. proteins.
- The origin of molecules that can self replicate. The only molecules known to do this today are RNA and DNA.
- The packaging of these molecules into membranes with an internal environment different in composition from their surroundings. Closed membrane vesicles are known to form spontaneously from lipids and can maintain different chemical compositions between the intracellular compartment and the extracellular environment.

The beginning of life on Earth

There are limitations to our understanding of the beginning of life with no general agreement among scientists. Some of the early work, in 1953, was conducted by *Stanley Miller* and *Harold Urey* in their famous experiment as shown in the adjacent Information Box. This idea is sometimes called the 'Primordial Soup' theory.

Many scientists doubt that such a natural process on Earth could have given rise to such complex polymers as RNA and DNA. What appears more likely is that because the early Earth was subjected to a lengthy barrage of meteor showers and emissions from volcanoes, the atmosphere contained the precursors needed to make organic molecules. See *Figure 414* for an artist impression of early Earth at this time.

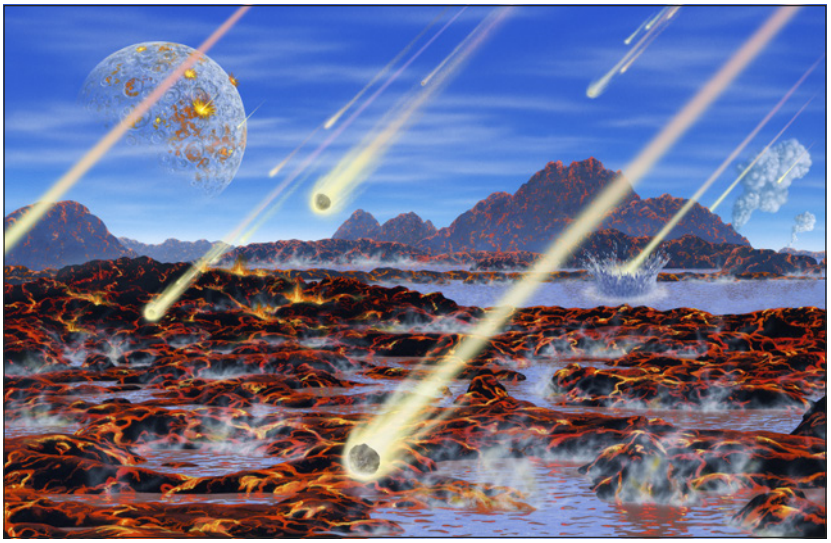
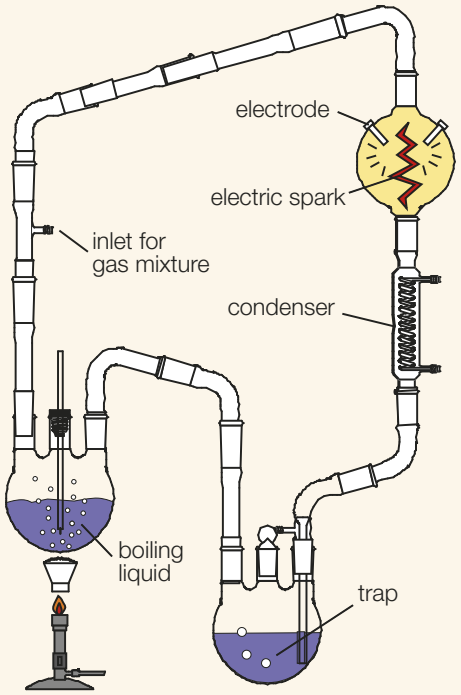


Figure 414 An artist impression of early Earth

Miller and *Urey's* experiment

Many of the chemicals needed as monomers for the synthesis of biological molecules are thought to have been formed in the shallow waters of the oceans as the products of chemical reactions between simple inorganic compounds present in the atmosphere and water. This mixture of chemicals believed to be present in the oceans is known as primordial soup or simply 'chemical soup'.

Miller and *Urey's* experiments conducted in 1953 simulated the conditions, believed at the time, to be present on the early Earth. They attempted to establish whether chemical evolution could occur in primordial soup. Chemical evolution refers to the pre-biological changes that transformed simple atoms and molecules into the more complex chemicals needed for the origin of life. Refer to the Figure.



The experiments used water, H_2O, methane, CH_4, ammonia, NH_3 and hydrogen, H_2. The chemicals were sealed inside sterile glass tubes and flasks connected together in a loop, with one flask containing water and another with a pair of electrodes. The water was heated to produce steam and sparks were produced between the electrodes to simulate lightning. The mixture was cooled so that the water vapour could condense and trickle back into the first flask in a continuous cycle.

At the end of a week of continuous operation Miller and Urey observed that up to fifteen percent of the carbon was present in the form of organic compounds. Thirteen of the twenty naturally occurring amino acids were detected. Later other researchers found that amino acids could be synthesised from hydrogen cyanide, HCN. They also detected a high concentration of the nucleotide base, adenine.

Helpful online resources

Stated Clearly: What Was The Miller-Urey Experiment?

<https://www.youtube.com/watch?v=NNijmxsKGbc>

Deep sea vents

As was discussed in Chapter 2.3, there is evidence that life may have originated at the bottom of the ocean in what are called 'deep sea vents' or **hydrothermal vents**, where there would have been an ideal environment for life to arise. This is because the vents warm ocean water to temperatures conducive to life's processes and release into water hydrogen-rich molecules and minerals that early organisms could have used to obtain energy.

Refer to *Figure 415* showing an artist impression of a hydrothermal vent. This illustration suggests that the first proto-cells are evolving here; does it represent LUCA (last universal common ancestor)?

Figure 415 An artist impression of a hydrothermal vent

With reference to the SACE Stage I syllabus and Workbook Chapter 1.1, life forms can be seen to possess a variety of characteristics including the ability to:

- consist of cells that include a cell membrane and nucleic acids e.g. DNA, RNA
- control the internal environment
- control the exchange of materials
- remove wastes
- respond to stimuli
- utilise energy
- divide, grow and reproduce

RNA and its role in the first cells

Nobel Laureate *H. J. Muller* wrote that genetic material was 'living material, the present-day representative of the first life'. His remark would probably support what has been called the NASA ('*National Aeronautics and Space Administration*' in the USA), definition of life as follows:

'Life is a self-sustained chemical system capable of undergoing **Darwinian evolution**'.

DNA is the main hereditary unit of all forms of life today and it could be hypothesised that it was necessary for DNA to have been present in the first cells. This presents an immediate problem in today's cells. Protein enzymes are required for DNA to be copied and replicated, so which came first - DNA or proteins?

In 1982, **ribozymes** were discovered, which shifted the attention to another nucleic acid, RNA. This is because ribozymes are made up of RNA and are **self-replicating**. The ability of RNA to take the form of a double helix or a single strand allows ribozymes to self-replicate and replicate other RNA molecules. Ribozymes can also **act as enzymes**, catalysing a range of metabolic reactions.

In 1986 Nobel laureate *Walter Gilbert* wrote: 'One can contemplate an RNA world, containing only RNA molecules that serve to catalyse the replication of themselves'. This is referred to as the '**RNA world hypothesis**'. The ability of ribozymes to both self-replicate and perform the current role of proteins to catalyse reactions, is evidence that the first simple cells contained RNA as their genetic code, and not DNA.

Thus there is quite strong evidence that RNA appeared before DNA and proteins in the evolution of life. See *Figure 416* for an artist impression of the first **proto-cells**.

Helpful online resources

Stated Clearly: What Is the RNA World Hypothesis?

<https://www.youtube.com/watch?v=K1xnYFCZ9Yg>

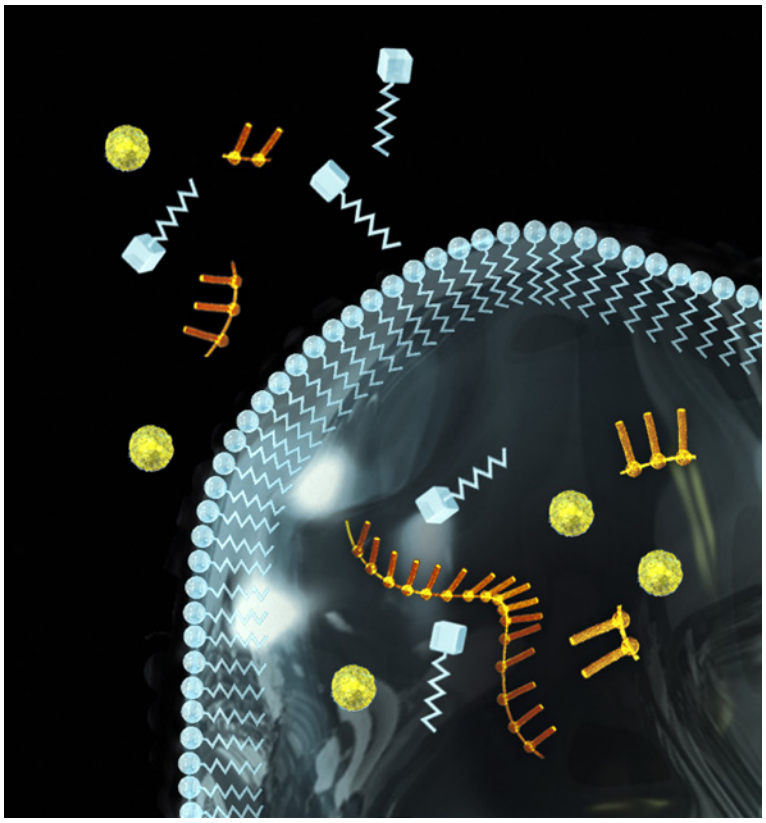


Figure 416 An artist's impression of a single ancient proto-cell

Again, emphasising the limitations of our knowledge in this area of science, many scientists believe that it is highly improbable for RNA to evolve in the first cells. No nucleotides have been reported from the *Miller* and *Urey* type experiments using spark-discharges to simulate lightning, although some amino acids have been shown to form.

Instead many eminent scientists involved in the study of the origin of life suggest more of the 'small molecules' and 'metabolism first' approach where these early cells were then subject to Darwinian evolution.

Prokaryotic cells before eukaryotic cells

The last universal common ancestor (LUCA) is a reference to the most recent common ancestor for all life that exists on Earth today. LUCA is not a reference to the first life on Earth, but a reference to the population from which all existing life is derived from. Refer to *Figure 417* illustrating a suggested evolutionary relationship between the three domains of life descending from LUCA: Archaea, Bacteria and Eukarya.

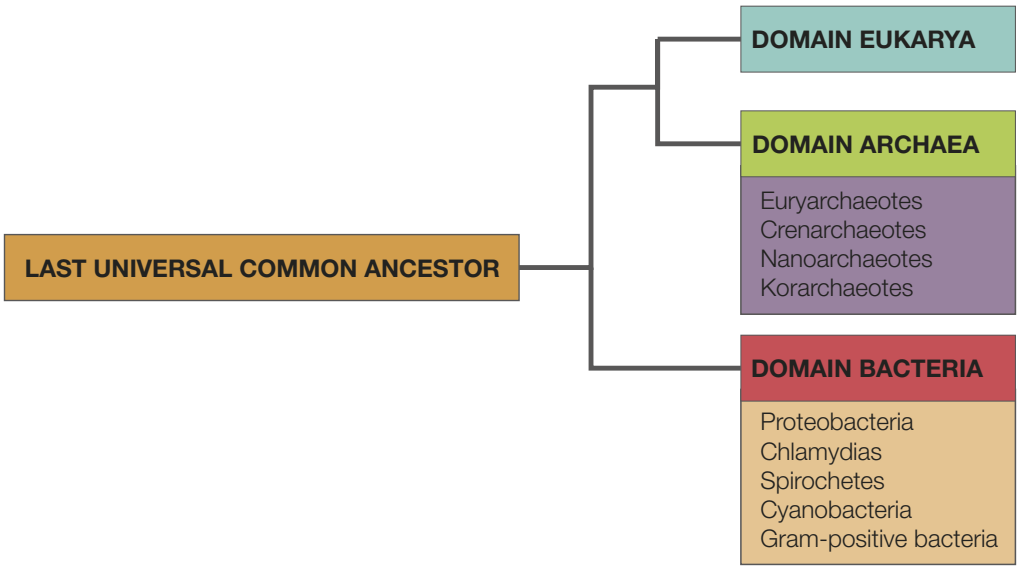


Figure 417 A suggested evolutionary relationship between the three domains of life

The simplest cells are termed prokaryotes (refer back to Chapter 2.2). These lack a nucleus and other membrane-bound organelles and it is thought that they evolved before the eukaryotes. Both archaea and bacteria are made up of prokaryotic cells and as suggested in *Figure 417*, the eukaryotes had a more recent common ancestor with the archaea rather than bacteria.

One of the pieces of evidence that supports this hypothesis is the **fossil record.** As stated earlier in the chapter, the oldest known microfossils are the cyanobacteria found as stromatolites more than 3.5 billion years old. Unicellular eukaryotic cells that are forms of algae (a type of **protist**) have been discovered in rocks around 2 billion years old. The oldest multicellular eukaryotic life yet discovered is a type of red algae which was alive 1.6 billion years ago. See *Figure 418* showing the fossil record.

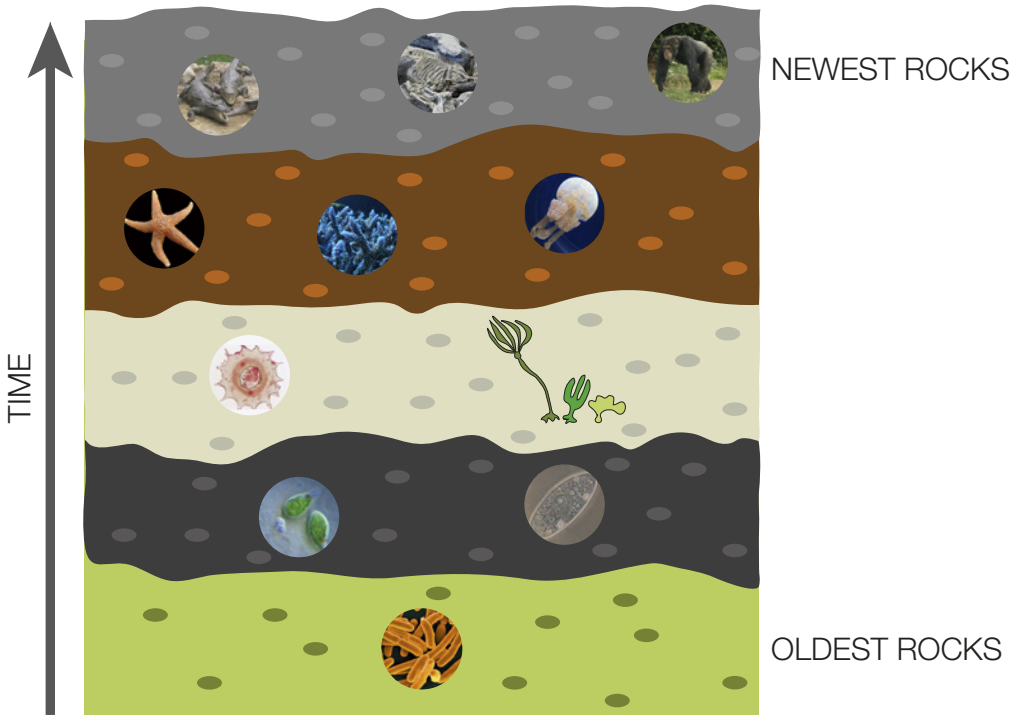


Figure 418 A sample of the fossil record.

Geochemical evidence also supports these approximate dates. Certain carbon compounds are only associated with biotic events or life, and the presence of these at these times supports the existence of life on Earth for around 3.5 billion years.

Ancestry of eukaryotic cells

The oldest and most primitive eukaryotes are the Protists, the main groups being **Protozoa** and Algae. There are many groups of these alive today living mostly in aquatic habitats. *Lynn Margulis* in the 1960s proposed what is termed the endosymbiotic theory to explain the evolution of eukaryotic cells from prokaryotic ancestors.

The term “endo” means within and “symbiosis” refers to the relationship formed between cells living in close association with each other.

The theory of **endosymbiosis** proposes that chloroplasts and mitochondria were once ‘free-living’ prokaryotic organisms that, during evolutionary history, were engulfed by another cell by endocytosis. Instead of being digested, the prokaryotes evolved within the host cell in a symbiotic relationship. The host would have taken in a prokaryotic cell that may have had the capacity to photosynthesise (and thus supply it with organic molecules) or perform aerobic respiration (providing energy for the cell).

The engulfed prokaryotes would have benefited from such a relationship by obtaining shelter and protection from predators. Other endosymbiotic events occurred during the evolution of eukaryotic cells, such as the infolding of the cell membrane to form the endoplasmic reticulum and the nucleus, as shown in *Figure 419*.

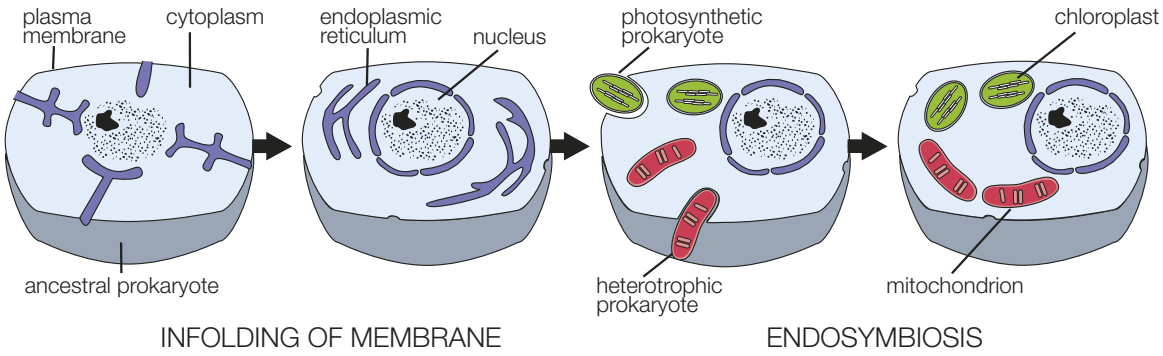


Figure 419 The proposed evolution of eukaryotic cells

Evidence supporting the endosymbiotic theory includes the facts that both mitochondria and chloroplasts:

- have inner membranes that resemble the cell membranes of prokaryotes more than the cell membranes of the eukaryotic cells in which they are found
- divide by binary fission, similar to prokaryotic cells. New mitochondria and chloroplasts are not able to be produced as directed by genes from the nucleus. It is true, however that they rely on nuclear proteins for their division i.e. proteins synthesised under the direction of genes located in the nucleus.
- have circular DNA similar to prokaryotes
- have their own protein synthesis system which includes ribosomes that, incidentally are more similar (in size and structure) to prokaryotic cell ribosomes than eukaryotic cell ribosomes.

Helpful online resources

TED-Ed: How we think complex cells evolved - Adam Jacobson
<https://www.youtube.com/watch?v=9i7kAt97XYU>

Amoeba Sisters: Endosymbiotic Theory
<https://www.youtube.com/watch?v=FGnS-Xk0ZqU>

4.1 Review questions

Multiple choice questions

1. Which one of the following statements is *incorrect* with regards to the cell theory?
   - J All organisms consist of cells or the products of cells.
   - K All cells derive from pre-existing cells by mitosis.
   - L All cells require and use energy.
   - M Cells are the building blocks of life.
2. Which one of the following options is *not* a characteristic of all living organisms?
   - J Responds to stimuli.
   - K Removes waste products.
   - L Are multicellular.
   - M Utilises energy.
3. Which one of the following options is evidence for the theory of evolution of cells?
   All species:
   - J have the same genetic sequence.
   - K replicate DNA in their cytoplasm.
   - L transcribe genes using DNA polymerase.
   - M use the same genetic code.

4. Which of the following statements about the RNA world hypothesis is correct?

   In the proposed RNA world:

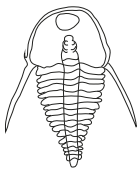
   J ribosomes existed and acted like enzymes but were made of RNA.

   K replication of RNA occurred using RNA polymerase.

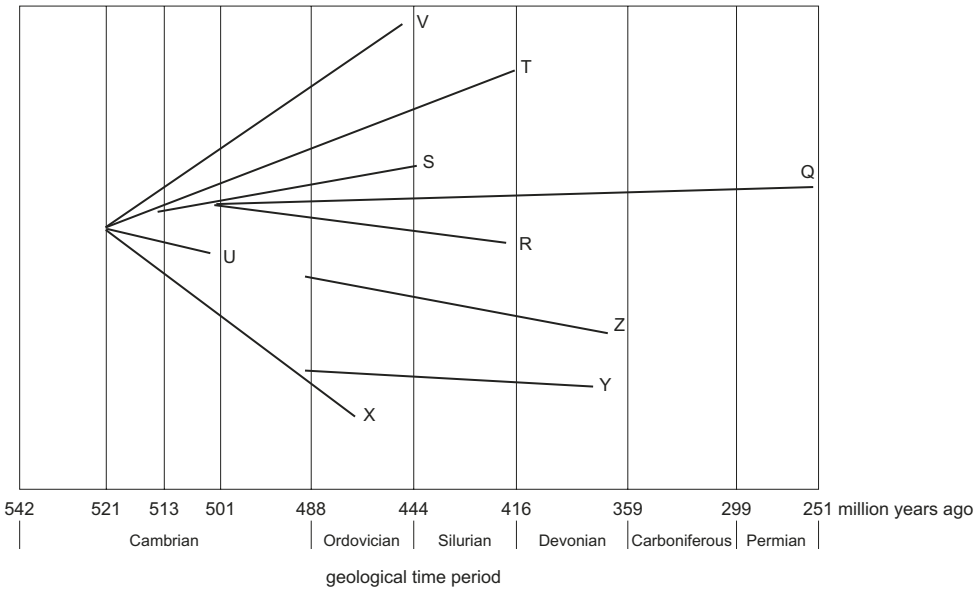
   L it is likely RNA existed prior to both proteins and DNA.

   M RNA could only exist as single stranded molecules.

5. *Refer to the graph below that shows the phylogeny of some trilobite orders that existed in the oceans from the Early Cambrian period to the end of the Permian period based on fossil evidence.*



A trilobite fossil
order: Ptychopariida



   A layer of rock containing some trilobite fossils was uncovered by a palaeontologist who dated the trilobite fossil to approximately 330 to 359 million years old.

   The most likely order of trilobite present in the layer of rock is:

   J Q

   K U

   L T

   M Y

6. *Refer to phylogenetic tree below that illustrates a model of the order and time of appearance (based on fossil evidence) of the major groups of living organisms represented by the letters A to D.*

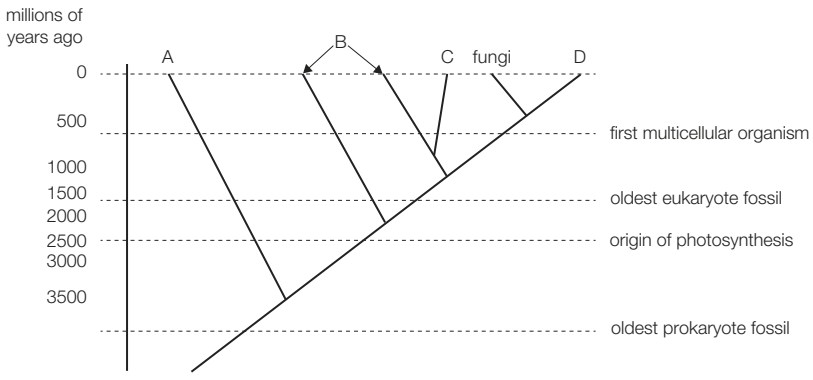
   The correct alignment of organisms on the phylogenetic tree is:

   J A – protists, B – animals, C – bacteria, D – plants

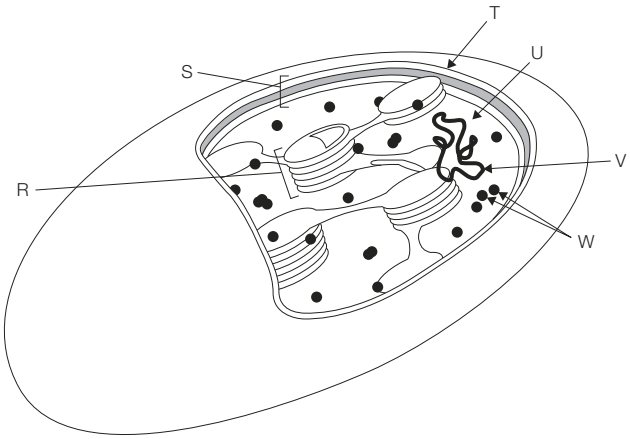
   K A – animals, B – plants, C – bacteria, D – protists

   L A – plants, B – animals, C – bacteria, D – protists

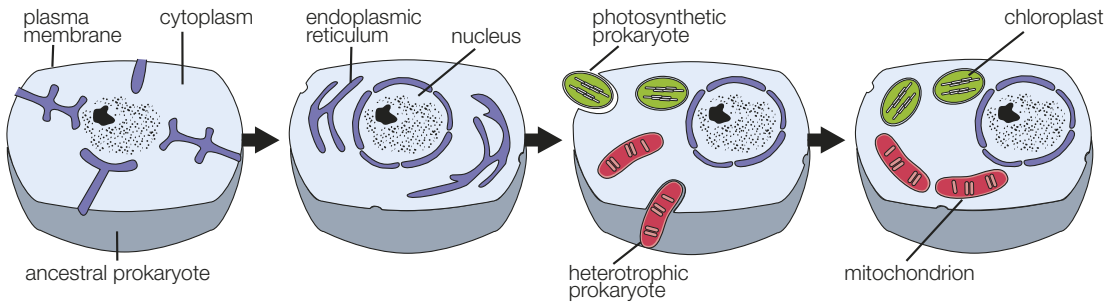
   M A – bacteria, B – protists, C – plants, D – animals



Refer to the diagram below which shows the structures of a chloroplast (labelled R–W), to answer questions 7 and 8.



7. Which of the following combinations could be used as evidence for the bacterial origin of chloroplasts?
   - J U and R
   - K W and T
   - L S and V
   - M V and W
8. Which of the following options do light-independent reactions of photosynthesis occur at:
   - J U
   - K T
   - L W
   - M V
9. *Refer to the diagram below representing a theory for the origin of mitochondria and chloroplasts in present day eukaryotic cells.*



Which one of the following provides strong evidence for this endosymbiotic theory for the origin of mitochondria?

- J Mitochondria can carry out the process of mitosis.
- K Mitochondria possess their own nuclei and are therefore capable of independent replication.
- L Mitochondria have a double membrane surrounding them, the outer membrane with a composition similar to the eukaryotic cell.
- M Mitochondria, when extracted from cells, are capable of independent existence.

10. Which one of the following is an observation that most supports the endosymbiotic theory of evolution.
    - J Bacteria have some DNA that is similar to mitochondria in human cells.
    - K The inner membrane of a chloroplast is similar to the host cells cell membrane in chemical structure.
    - L Eukaryotic cells existed before prokaryotic cells.
    - M Some bacteria contain photosynthetic pigments.

Free response questions

1. Describe evidence that supports the fact that life evolved once, and that existing cells today are the products of evolution.

2. State three processes that scientists propose are necessary for life to begin:

3. Outline how the fossil record suggests that prokaryotic cells existed before eukaryotic cells.

4. It has been suggested that cells with RNA evolved before cells with DNA and proteins.
   a) Describe the main reasons for this suggestion.

   b) Outline a problem many scientists believe is a major hurdle in suggesting that the first cells had RNA in them.

5. Describe the role that endosymbiosis is believed to have played in the evolution of current eukaryotic cells.

6. Explain the advantage for a host cell to engulf a cyanobacterium that could carry out photosynthesis.

7. Using your understanding of endosymbiotic theory, propose how an analysis of the double cell membrane of the mitochondria supports the fact they evolved from a prokaryotic cell.

8. Outline how the ability to replicate and synthesise proteins suggest that chloroplasts were once capable of independent existence.

9. 'Bacteria are simple, from a structural perspective, but not biochemically'.
   a) Explain the evidence that suggests that bacteria are structurally simple.

b) Outline two examples to compare the biochemical complexity of prokaryotic cells with that of eukaryotic cells.

10. There are major limitations to our understanding of the origin of life on Earth. Refer to Miller and Urey's work in 1953 (refer to the Information Box and corresponding video on page 346). Evaluate this experiment by suggesting:
    a) Some useful contributions from this work that have advanced our understanding of how life might have begun.

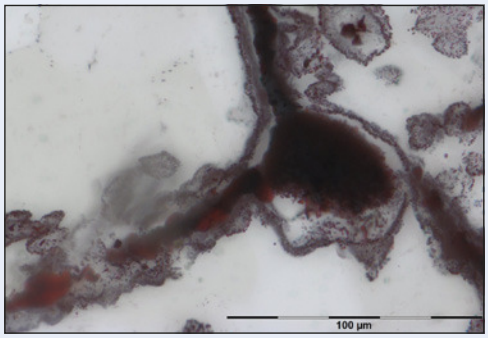
    b) How further research has cast doubts as to how this work can explain how a replicating molecule, such as DNA, might have arisen in the early cells.

11. One hypothesis regarding the origin of eukaryotic cells suggests that the ancestor of these eukaryotes diversified early from the Archaea. In fermentation, Archaean organisms perform the process one way while how it occurs in bacteria is quite different; their genes are quite distinct. The evolution of eukaryotes on the other hand seems to have involved the incorporation of genes from bacteria and others from Archaea. From your understanding gained so far, suggest:
    a) Why Archaea and bacteria carry out fermentation differently.

    b) Suggest two likely explanations to explain the observation that eukaryotes have genes from both bacteria and Archaea.

Science as a Human Endeavour 4.1 – Life on Earth for how long?

Until recently the oldest evidence for life on Earth was in the form of fossilised stromatolites discovered in the Pilbara region of Western Australia. These 3.48-billion-year-old remains were once inhabitants of a shallow sea long since vanished. In August 2016, however, fossilised stromatolites discovered by Australian scientists in Greenland were reported to date to a period 3.7 billion years ago making them 200 million years older.



In March 2017 a report by British researchers in northern Quebec, Canada may push the origins of life on Earth back even further. Their discovery of microscopic tubes of haematite (iron oxide) that contain organic carbon are thought to be the remains of bacteria (see image). If confirmed, these microfossils are significant for two reasons. First, they were found in rocks at least 3.75 billion years' old, and there is some consensus they date to 3.77 billion years or 70 million years older than the Greenland deposits. Second, and perhaps even more ground-breaking, the rocks they were found in were formed near hydrothermal vents at the bottom of an ocean. If this proves to be correct, the little tubes will provide additional support for the hypothesis that life on Earth first originated around hydrothermal vents on the seafloor. *You may need to refer to the online resources below to answer the questions that follow.*

1. The scientists who discovered the microtubes also found they contained carbon that was organic in origin; in other words, it was not a product of a chemical process but was made by a living organism. Describe what they did to confirm this was the case.

2. One of the most exciting aspects of the discovery of the ancient microtubes is that it suggests that life originated at a very early time in the evolution of the Earth; in other words, it got started relatively quickly. Discuss how ongoing geological data collection and analysis is still revealing new evidence, and how this may modify our current timeline of life on Earth and evolution.

Helpful online resources

Quartz: Scientists just discovered the oldest fossils ever found
<https://www.youtube.com/watch?v=FkOm2huZIdo>

UCL: World's oldest fossils unearthed
<https://www.youtube.com/watch?v=rynHqD3Elow>

Chapter 4.2 Comparative genomics

Science Understanding

Comparative genomics provides evidence for evolution and helps establish the likely evolutionary relationship between different species.

- Describe the technique of DNA-DNA hybridisation.
- Describe how evidence from the following techniques may be used:
  - sequencing of common proteins (e.g. cytochromes)
  - DNA–DNA hybridisation
  - DNA sequencing, including rRNA gene sequencing in prokaryotes.

Phylogenetic tree diagrams represent evolutionary relationships.

- Draw and analyse simple phylogenetic tree diagrams to represent evolutionary relationships.
- Mutations accumulate over time. If the mutation rate is known, it can be used as a 'clock'.

More closely related species have fewer differences in their DNA sequences and have separated more recently from a common ancestor than distantly related species.

In Chapter 4.1, some of the basic concepts of evolution were established:

- Life on Earth has evolved once, at least 3.5 billion years ago (LUCA).
- Cellular life has evolved from a single **common ancestor** and existing cells are the products of evolution.
- Prokaryotic cells existed before eukaryotic cells.
- It is likely that the cells with RNA as the replicating molecule evolved prior to cells with DNA.

DNA is the fundamental chemical of all life forms, it enables new cells to be made and directs the synthesis of proteins which are vital for cell metabolism. DNA has great variety which is made possible by the different numbers and order of the four bases A, T, G and C. (Refer back to Chapter 1.1).

Each species uses the same coding system of the four bases, but each species has its own set of DNA, each with their own number and type of chromosomes. The following table illustrates the chromosome numbers of some common organisms.

Name of organism	Chromosome number
human	46
mouse	40
koala	16
pea	14
Chlamydomonas (simple algae)	16
rock dove	80

In this Chapter, some of the different techniques to **compare genetic relationships** and **determine evolutionary relationships between species** will be covered. Fossil evidence can be used to help determine these evolutionary relationships because they provide us with information about the **time in history** that species are first known to have existed (see *Figure 421*).

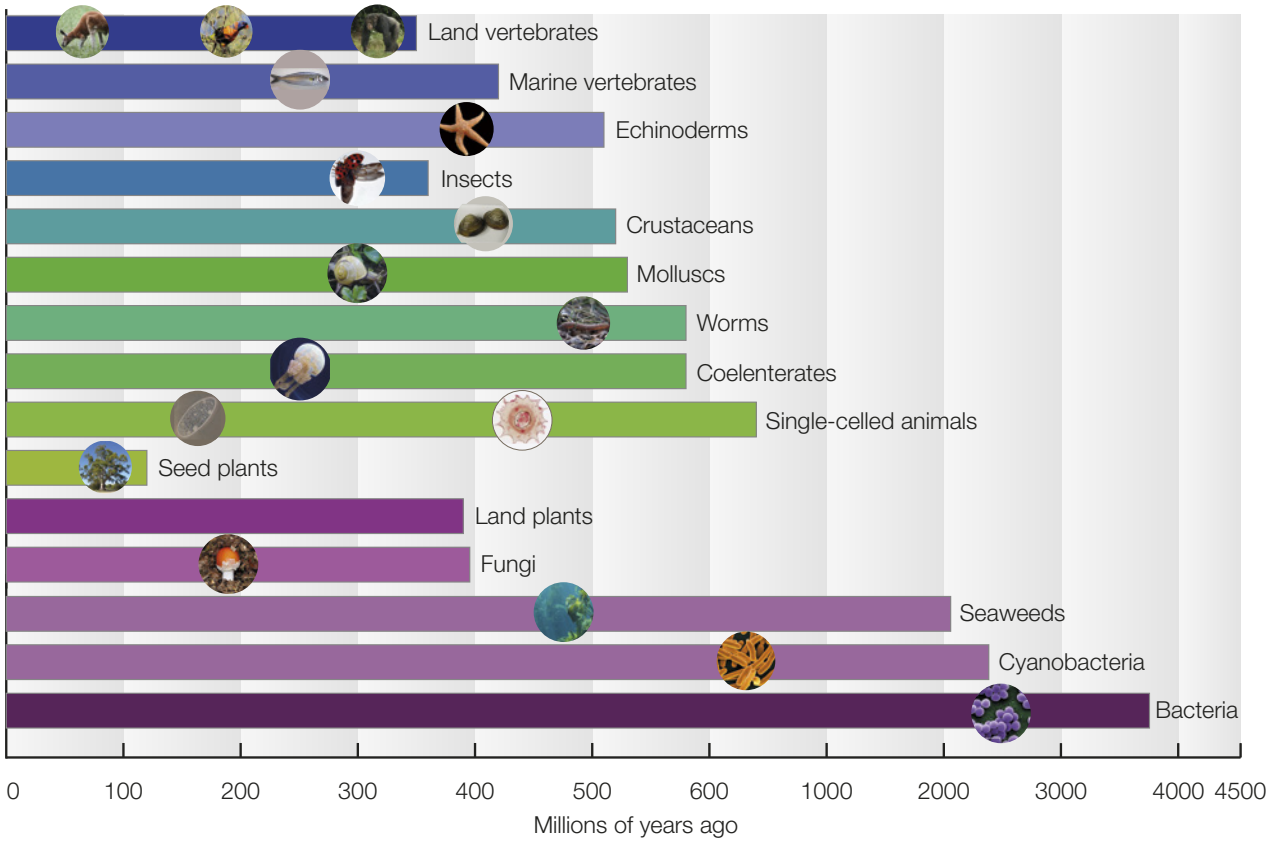


Figure 421 Fossil evidence is used to date and keep record of the earliest time in history species existed

Helpful online resources

Kurzgesagt - In a Nutshell: Everything You Need to Know About Planet Earth
<https://www.youtube.com/watch?v=JGXi_9A__Vc>

Accumulation of mutations and molecular clocks

The **universal** presence of DNA is very strong evidence for the common ancestry of all living things. This evidence suggests that the earliest prokaryotes (bacteria and Archaea) evolved on their own first and then eukaryotic cells appeared around a billion years later, approximately 2.7 billion years ago.

Mutations are **random changes** to the DNA sequence of an organism and can be beneficial, harmful or have no effect at all. Mutations to body (somatic) cells are not passed on to future generations, but mutations that occur in gametes or germline cells that divide into gametes can. If the mutation is **beneficial** to the offspring it is referred to as an **adaptation**, but if the mutation is **harmful**, it is often called **a genetic disease**.

Mutations are the driving force of evolution. Every phenotypical feature across all species has arisen from mutations. Beneficial mutations in gametes that provide an individual with a greater chance of survival are passed on through generations, becoming more abundant over time.

Mutations are generally point mutations to a single gene and may or may not affect one protein only. A single base mutation to a single gene is not the source of all the variation on Earth; however, the **accumulation of point mutations** to different genes, in different populations, over long periods of time, has contributed to the vast array of differences between species.

An example of this, is mutations to the saliva genes. A single point mutation to the genes coding for saliva is unlikely to have a major impact on survival; however, the accumulation of point mutations to the saliva genes gave rise to snake's venom.

Research has shown that the accumulation of mutations occurs at a relatively constant rate. This information has been used to create **molecular clocks**, which is discussed in the next section.

In summary, if populations are separated for long periods of time, it is known that they will **accumulate different mutations in their DNA** and that the larger period of time the groups are separated, the more likely it is that there will be greater differences (see *Figure 422*).

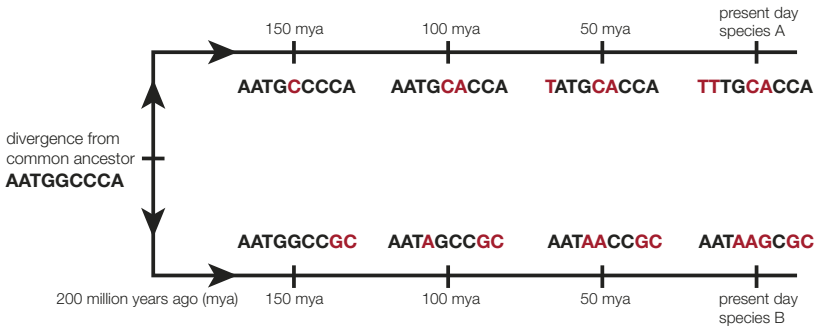


Figure 422 Mutations accumulate in DNA over time at a constant rate

Molecular clocks

A molecular clock, also called a molecular evolutionary clock, is a term used for a technique that compares the **evolution of biological molecules** (generally DNA and proteins), to estimate the time in history that two species **diverged** from a common ancestor. Divergent evolution is covered in Chapter 4.6, but in short, it is when two species evolve from a recent **common ancestor**.

When evolutionary biologists first started analysing the differences in amino acid sequences for specific proteins between species, they discovered that they were **proportional to the time since the two species diverged** from a common ancestor. *Figure 423* shows the rate of amino acid changes for three different proteins: fibrinopeptides, haemoglobin and cytochrome c. All three proteins have different rates of change in their amino acid sequences, but they are all occurring at a **constant rate**. If we assume that this constant rate of change is true for these proteins in all species, then the differences in the amino acid sequences between any two species can be used to determine an approximate time of divergence. For example, if the amino acid sequencing of cytochrome c for two species revealed there was 20 amino acid changes per 100 residues, we could use the graph to extrapolate the number of years since divergence, which would be approximately 500 million years ago (see *Figure 423*).

For a molecular clock to give accurate times of divergence it needs to be **calibrated** properly. There are multiple ways to do this, but biologists generally use **fossil records**, geological evidence and the species samples being analysed. The more samples used from these sources to generate the clock, the more precise the calibration will be.

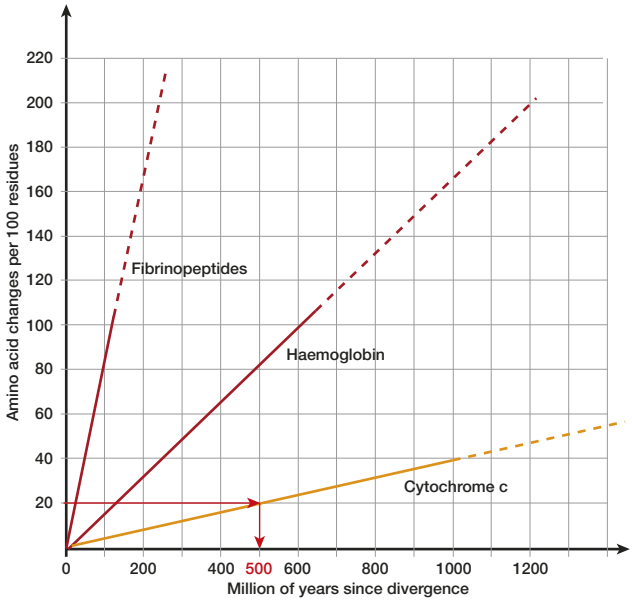


Figure 423 A molecular clock can be used to estimate the divergence of species from a common ancestor

Helpful online resources

Harmony square: Molecular Clocks
<https://www.youtube.com/watch?v=rMSVwWYXljg>

Phylogenetic trees

The branch of biology that deals with finding the evolutionary relationships among organisms is called **phylogenetics**. The principle behind the phylogenetic analysis of **DNA, RNA and protein sequences** is that the greater the similarity between the two sequences, the fewer mutations that were required to convert one sequence to another. Hence, the more recently the organisms being studied must have shared a common ancestor.

A **phylogenetic tree** represents a hypothesis regarding suggested evolutionary relatedness. *Figure 424* shows the likely evolutionary relationships between four primates. The dot points below summarise some of the main features illustrated in this hypothesis:

- There is a common ancestor of each of the four primates located at the 'root' of the tree.
- Each branching point indicates where the species of primate **diverged** from other species.
- The human and chimpanzee share the most recent common ancestor and thus would be expected to have the most DNA in common.
- The orangutan has been separated from the other three primates for the longest period. Therefore, it probably has more differences through mutation due to the greater amount of time that mutations have had to accumulate in the DNA sequence.

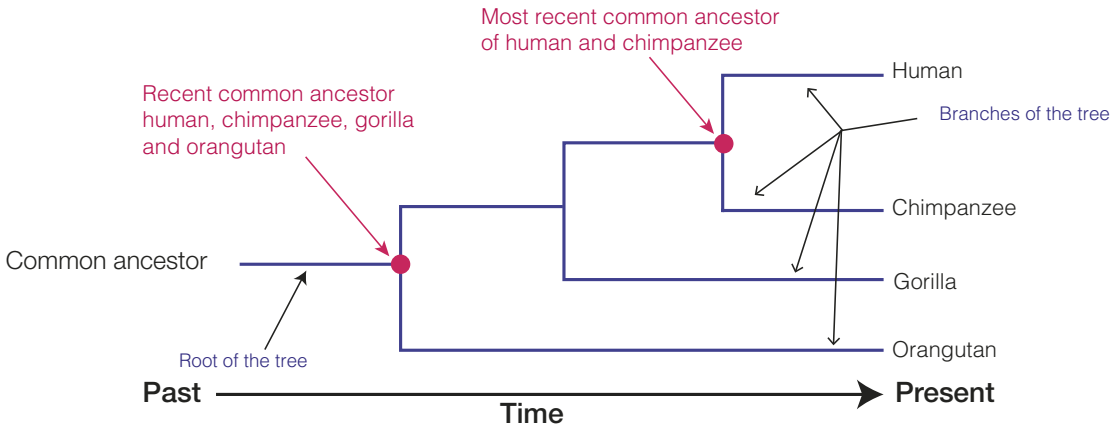


Figure 424 An example of a phylogenetic tree that shows the evolutionary relationships between 4 primates

Helpful online resources

RTHSBiology: Phylogenetic Trees

<https://www.youtube.com/watch?v=OYRYQ6YFsow>

Comparative genomics

Comparative genomics involves scientists using a variety of tools and techniques to compare complete genomes, genes or amino acid sequences of different species. This requires the use of **computer-based analysis** to locate differences in the sequences and regions of similarity. One example of a computer program used for bioinformatics is 'Clustal Omega',which is a global multiple sequence alignment program for **DNA, RNA and proteins**. Computer-based analysis like this has led to an explosion of opportunities aimed at comparing the genome sequences of different species. Some of the benefits of this type of research are summarised below:

- Comparative genomics is a major contributor to the understanding of organisms, including the human genome.
- It is important in identifying genes that are essential to life and contributing to the understanding of how gene signals control gene function across a range of species.
- Comparative genomics is a powerful tool for studying evolution and the evolutionary relatedness between organisms, and humans.
- It has wide ranging applications in agriculture and biotechnology.

As an example, one study highlighted the fact that 60% of genes are shared between fruit flies and humans. In fact, two thirds of human genes known to be linked to cancer have corresponding genes in fruit flies.

DNA sequencing

DNA sequencing was previously discussed in Chapter 1.7 where it was introduced as a technique that can be used to work out the sequence of bases in a specific gene or genome. Samples of DNA from multiple species can be sequenced to compare evolutionary relationships. The **more similar** the genetic code, the **more closely related** a species is because there has been less time for mutations to accumulate. Similarity in DNA sequences therefore also indicates a recent separation from a common ancestor between those species. *Figure 425* shows a comparison of a corresponding base sequence in Neanderthals and humans. There are only three DNA bases that differ in this section of the genome showing high similarity in genetic codes.

Neanderthal 5' TGGTCCTGC**A**GTCCTCTCCTGGCGCCC**C**GGGCGCGAGCGG**T**TGTCC 3'

Human 5' TGGTCCTGC**T**GTCCTCTCCTGGCGCCC**T**GGGCGCGAGCGG**A**TGTCC 3'

Figure 425 A comparison of a segment of a specific gene from humans and neanderthals

Using DNA sequencing to compare evolutionary relationships is now feasible due to **comparative genomics** software. This software can be used to construct a **phylogenetic tree** of related organisms using DNA sequences. '*Clustal Omega*' is a global multiple sequence alignment program for DNA, RNA and proteins. It produces multiple sequence alignments of **divergent sequences** and calculates the best match for the selected sequences. Refer to *Figure 426* of an image prepared using *Clustal Omega* comparing DNA from several spiders. *This is for general interest only and details are not required.*

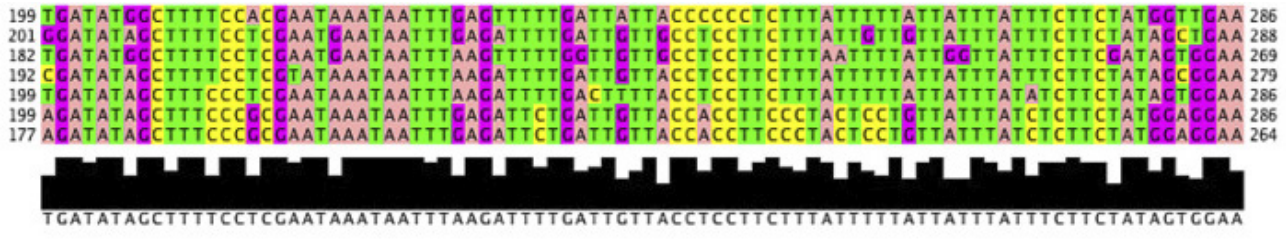


Figure 426 A comparison of base sequences from different species of spiders using Clustal Omega software

Helpful online resources

Clustal Omega Help and Documentation

<http://www.ebi.ac.uk/Tools/msa/clustalo/help/faq.html>

rRNA sequencing

Ribosomal RNA (rRNA) sequencing is a popular technique used to study evolutionary relationships. rRNA is an essential component of **ribosomes**, which are found in all living organisms. This is because all cells require the ability to synthesise proteins. In **prokaryotes** (bacteria and archaea), the **16s rRNA gene** codes for small ribosomal subunit. In **eukaryotes** (fungi, protists, plants and animals), the **18s rRNA gene** codes for small ribosomal subunit.

There are multiple advantages of sequencing rRNA including:

- Because all living organisms require ribosomes to make proteins, the rRNA gene will be present in all species (it's universal).
- The rRNA gene has highly **conserved regions**, where few mutations occur. This allows researchers to synthesise **primers** that will bind in a complementary fashion allowing amplification of the gene by PCR.
- It also consists of multiple highly **variable regions** where mutations occur more readily. This allows researchers to **distinguish** between different species (see *Figure 427*).
- rRNA sequencing can detect multiple species at once in comparison to sequencing the DNA of an individual species. This is very useful as there are over a billion different types of prokaryotic species. Also, DNA sequencing requires the prokaryotic species to be isolated and some cannot be cultured and therefore isolated easily.

Closely related species (same Genus) generally have very **similar rRNA gene sequences**. This information can then be used to create **phylogenetic trees** using computer-based software. rRNA sequencing can also be used as a qualitative method of **determining unknown species and different types of species** in a sample; for example, the variety of species in an individual's microbiome or detecting the species responsible for a food poisoning outbreak. To identify the specie(s) present in a sample, computer-based software is used to compare the results to a known library of species data.

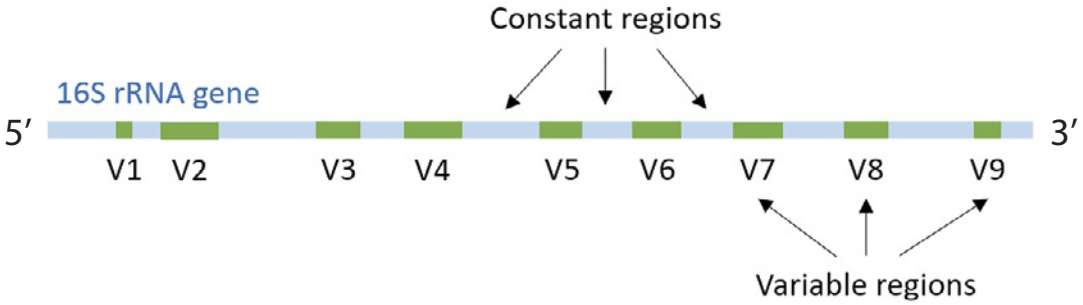


Figure 427 A representation of the 16s prokaryotic gene showing the nine highly variable regions (green) and the conserved regions (blue)

Helpful online resources

YouSeq: What is 16S sequencing?

<https://www.youtube.com/watch?v=EE8JFttYs5k>

4.2

Amino acid sequencing

When comparing proteins of the same type from different species, scientists compare the sequence of amino acids and note any differences. If different species produce proteins with very similar amino acid sequences, it is logical to infer that their DNA is very similar, inherited from a recent common ancestor.

To be able to compare proteins between species, scientists need to identify examples of proteins that have been maintained through evolutionary history, which means they are crucial to survival in most species. Cytochromes, such as **cytochrome c** are proteins that are necessary in the **aerobic respiration** pathway of virtually all living species. This protein varies from one species to another, again the degree of similarity indicating the closeness of the evolutionary relationship.

Refer to the table below showing the differences in the amino acid sequences of cytochrome c in six species. It highlights that the cytochrome c sequence for humans matches for all but one amino acid with monkeys; whereas it differs from rabbit and yeast cytochrome c by 9 and 45 amino acids respectively. It has been found that the evolutionary relationships based on this protein generally align with those from fossil evidence.

	Human	Monkey	Rabbit	Duck	Turtle	Yeast
Human	0					
Monkey	1	0				
Rabbit	9	8	0			
Duck	11	10	6	0		
Turtle	13	14	9	7	0	
Yeast	45	45	15	46	49	0

The assumption is that the first organisms had cytochrome c and that over billions of years, mutations have changed the sequence of bases in the gene coding for the protein. From this table a reasonable conclusion would be that humans and monkeys share a more common ancestor than humans and yeast. Using molecular information obtained from cytochrome c comparisons, phylogenetic trees can be constructed (see *Figure 428*).

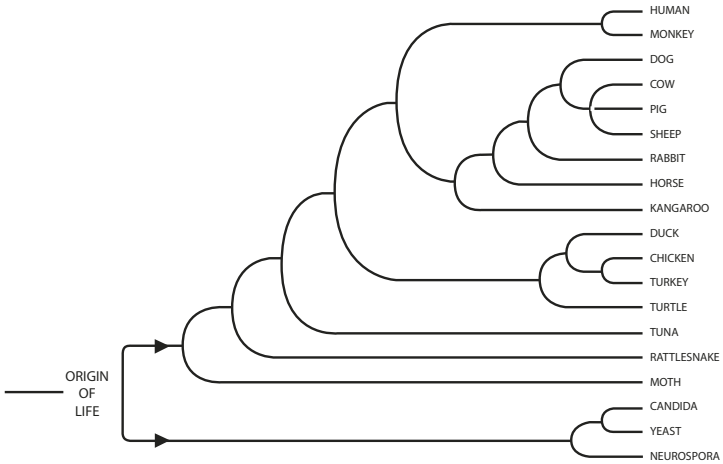


Figure 428 A phylogenetic tree constructed from cytochrome c analysis

Helpful online resources

MinuteEarth: Are We Really 99% Chimp?

<https://www.youtube.com/watch?v=IbY122CSC5w>

Stated Clearly: DNA Evidence That Humans & Chimps Share A Common Ancestor: Endogenous Retroviruses

<https://www.youtube.com/watch?v=oXfDF5Ew3Gc>

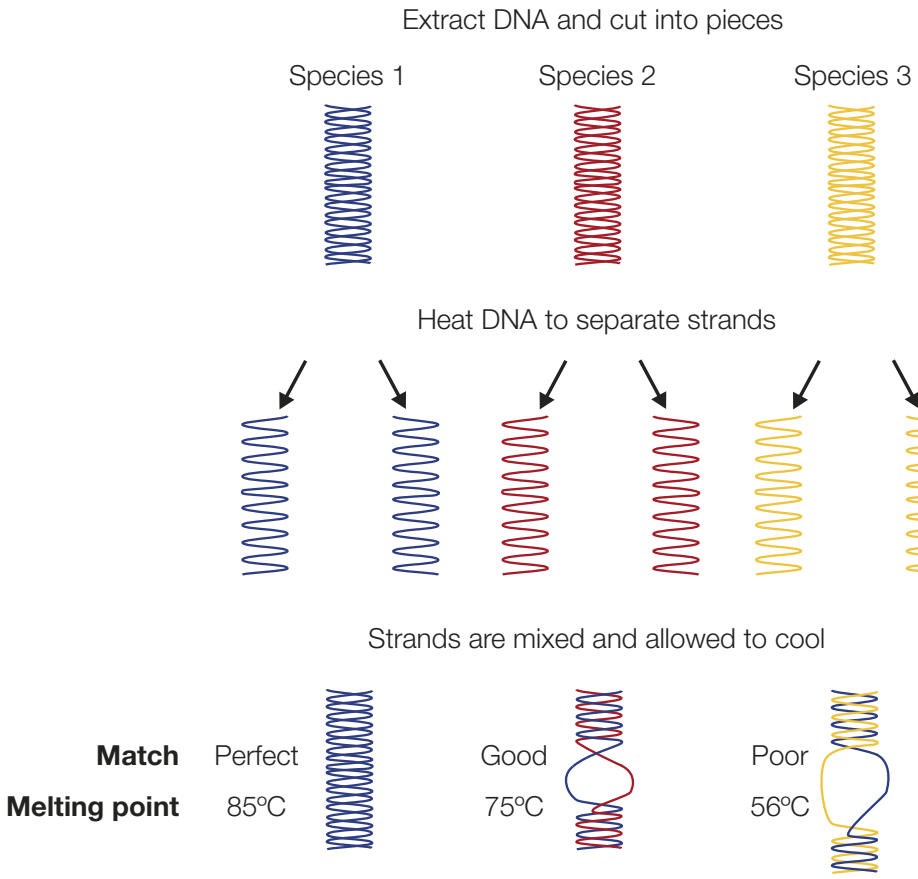
DNA-DNA hybridisation

Another method used to compare the relatedness (or genetic similarity) of different species is the process of **DNA-DNA hybridisation**. Heating a solution containing DNA disrupts the hydrogen bonding between the two complementary strands (measured as the **melting point**) and when the mixture is cooled they will recombine to form the double helix once again. The process operates by heating a solution of DNA from different species and allowing 'hybrid' DNA (i.e. a mix of DNA from separate species) to form. The degree of hydrogen bonding between one species DNA and another gives a measure of how similar the sequence of nucleotides (bases) is and as such an indication of how closely related the two species are.

The process is briefly presented below:

1. The particular gene sequence to be compared between the two species is isolated using a gene probe and enzymes.
2. The DNA of the two species is heated to 95°C to separate the strands.
3. The strands are mixed together and allowed to cool, enabling hybrid DNA to form.
4. The strands are re-heated to work out the 'melting point' of the hybrid DNA. The melting point is defined as the temperature at which 50% of the DNA is single-stranded and 50% is double-stranded. Essentially the higher the melting point, the more bonding between the DNA molecules and the more in common the two sequences of DNA are.
5. In summary the **higher the melting point, the greater similarity** between the DNA sequences and the more likely it is that they shared a **more recent common ancestor**.

Figure 429 shows three species DNA being subjected to the process of DNA-DNA hybridisation. In the diagram it is noted that species 1 and species 2 have a relatively good match whereas species 1 and species 3 have a relatively poor match. It is reasonable to conclude that species 1 is more closely related to species 2 than it is to species 3. As a result, it is more likely that species 1 has a more recent common ancestor with species 2 compared with species 3.



Conclusion: Species 1 is more closely related to 2 than to 3

Figure 429 The process of DNA-DNA hybridisation

The simple phylogenetic tree in *Figure 4210* would indicate a possible hypothesis that the data from *Figure 429* would support.

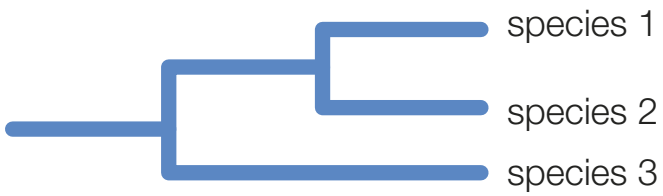


Figure 4210 A possible phylogenetic tree for the data obtained through DNA-DNA hybridisation shown in Figure 429

Helpful online resources

Mr i Explains: How DNA Hybridization works
<https://www.youtube.com/watch?v=hJA_86H-XK4>

4.2 Review questions

Multiple choice questions

1. DNA-DNA hybridisation is used:

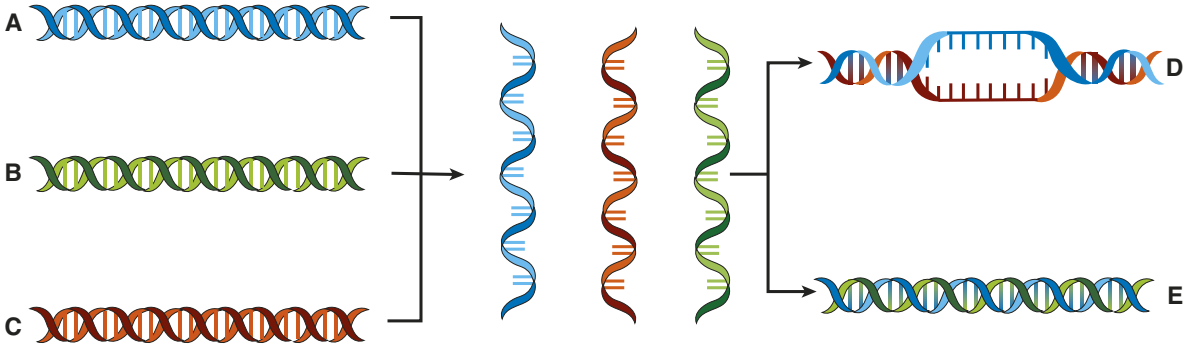
   J to fuse two species' DNA together to genetically modify an organism.

   K instead of DNA sequencing because it is more accurate.

   L to compare the amino acid sequence of a protein between two or more species.

   M instead of DNA sequencing because it is quicker than sequencing a whole genome.

2. *Refer to the image below to answer the following question.*



   Which of the following options is correct regarding the DNA-DNA hybridisation process shown above?

   J There are more hydrogen bonds formed between the DNA strands of species A and B when compared to DNA strands of species A and C.

   K A higher temperature is required to heat the molecule E compared to molecule A

   L There is a higher percentage of base pairs matching for molecule D than there is for molecule E.

   M Species B and C would have a greater similarity of DNA base pair matching than species A and B.

3. Some proteins like cytochrome C are present in almost all living organisms and therefore the similarity can be compared across species. The presence of cytochrome C in almost all living things suggests that:

   J cytochrome C passes from cell to cell through mitosis.

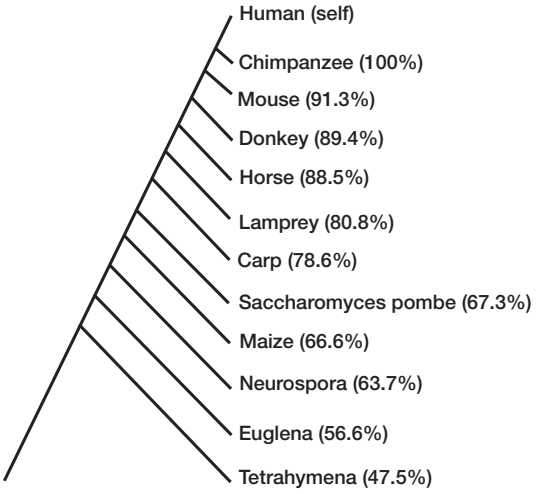
   K cytochrome C plays an important role in the survival of all organisms.

   L cytochrome C is a protein found in cell membranes as every cell has a membrane.

   M all living things have independently evolved genes that code for cytochrome C.

4. *Refer to the diagram to the right showing the percentage similarity of cytochrome C protein sequences between various species.*

   Based on the information presented, which of the following statements is most correct?



   J Humans and chimpanzees have 100% similarity in the gene coding for cytochrome C protein.

   K Mice and donkeys have a closer common ancestor than donkeys and carp.

   L There is a greater percentage difference in amino acid sequence for cytochrome C between mice and donkeys than there is between donkeys and horses.

   M There is a greater percentage difference in amino acid sequence for cytochrome C between neurospora and euglena than there is between neurospora and maize.

5. Comparative genomics:

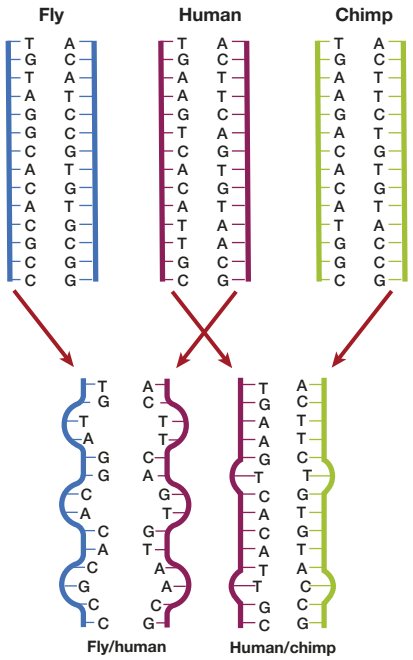
   J uses computerised data to analyse the molecular structure of a species.

   K allows the genetic comparison of criminal suspect's by comparing STR loci.

   L can involve the use of two or more species' complete DNA sequences.

   M only uses data from the human genome project.

6. *Refer to the diagram below of a process involving DNA from three different species. Sections of the DNA results are shown below.*



   Based on the results of this process, a likely conclusion is:

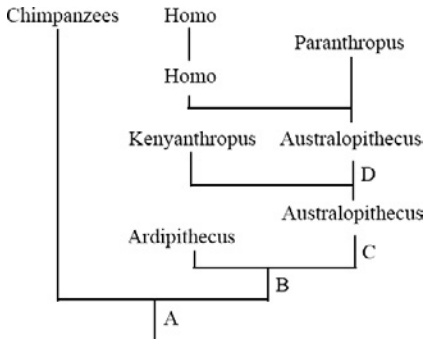
   J There are only 7 bases different in the whole genome between the fly and a human.

   K Humans are more closely related to chimps than flies because humans and flies have a more recent common ancestor

   L The differences in the DNA code shown between humans and chimps arose from two frameshift mutations.

   M Human and chimps have separated more recently from a common ancestor than humans and flies.

7. *Refer to the diagram below of the suggested evolutionary relationships between humans (Homo) and chimpanzees.*



   The most recent common ancestor of Chimpanzees and Homo is:

   J A

   K B

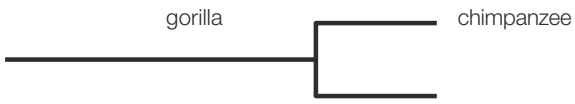
   L C

   M D

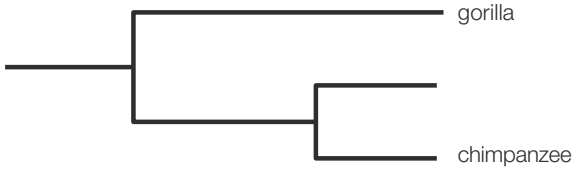
8. The common ancestor of modern apes and humans lived around 8 million years ago. The evolutionary line leading to Gorillas diverged from the common ancestor about 7 million years ago. The most recent common ancestor of the chimpanzee and humans occurred about 2 million years ago.

   Which one of the following diagrams best represents the evolution of the three species?

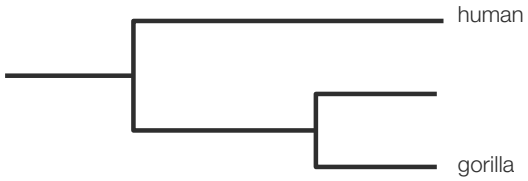
J



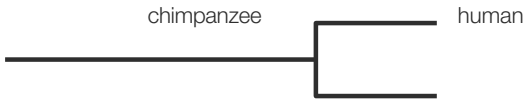
K



L



M



9. Refer to the table below that shows six examples of genes containing DNA sequences unique to humans and not found in chimpanzees, along with their general function.

Gene with sequence unique to humans	Functional role of the gene
AMY1	Facilitates digestion of starch.
HAR1	Is active in the brain and necessary for the development of the cerebral cortex.
FOXP2	Facilitates formation of words by the mouth.
HAR2	Drives gene activity in the wrist and thumb during development.
ASPM	Controls brain size.
LCT	Permits digestion of milk sugar in adulthood.

   With reference to the table above, a possible conclusion is:

   J Chimpanzees have more-opposable thumbs than humans.

   K Humans can walk on two feet.

   L All human adults can digest milk sugar but not all adult chimpanzees can.

   M Chimpanzees cannot process and remember more complex information than humans.

10. The rRNA gene is a good target for sequencing because:

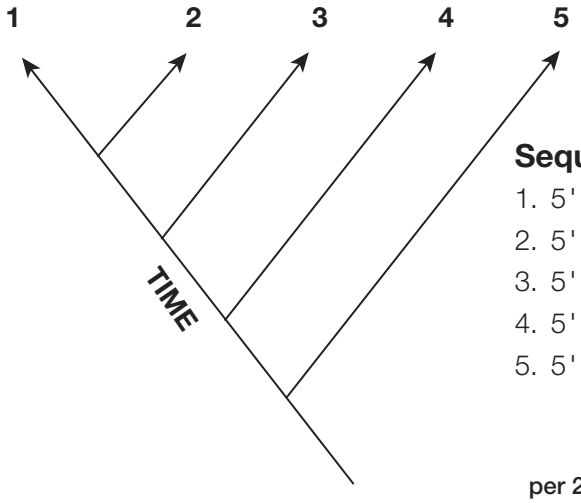
   J it is found in all living organisms and is highly variable throughout the whole gene.

   K it is found in all living organisms and consists of highly variable and highly conserved regions.

   L it is only found in bacteria and allows researchers to distinguish between bacterial species.

   M it is found in all bacteria and makes up the small subunit of the mitochondria.

11. *Refer to the diagram below showing 5 species and a corresponding section of DNA sequence for each species to answer the following question.*



Sequence of species 1 to 5:

1. 5'...atccgattattgcacgatat...3'
2. 5'...atccgatttttgcacgatat...3'
3. 5'...atcccatttttgctcgatat...3'
4. 5'...ttcccaattttgctcgatat...3'
5. 5'...ttcccaatttacctgcatat...3'

Substitution rate:
2 substitutions
per 20 nucleotides in 1.5 million years

Which of the following options correctly identifies how long-ago species 1 and 4 diverged from a common ancestor?

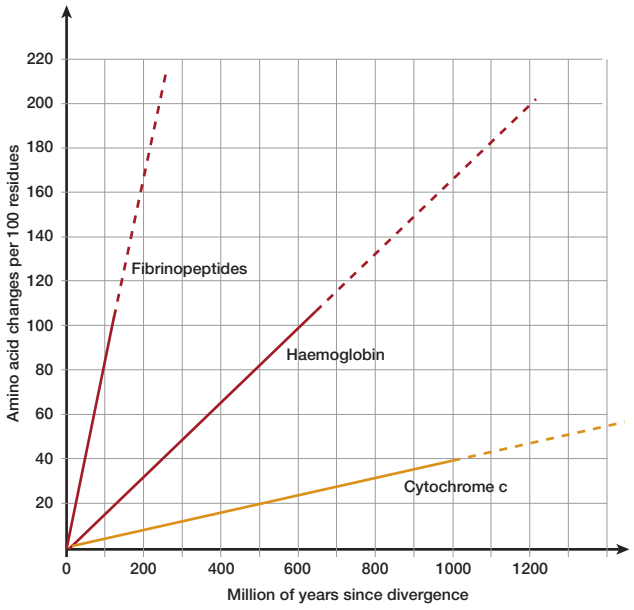
J 3 million years ago.

K 5 million years ago.

L 3.75 million years ago.

M 7.5 million years ago.

12. *Refer to the diagram below to answer the following question.*



How many amino acid changes per 100 residues would you expect to find when sequencing the haemoglobin protein of two species that were known to diverge from a common ancestor approximately 250 million years ago?

J 1200

K 218

L 40

M 10

13. Identify the statement below about comparative genomics that is **not** true.

    Comparative genomics can involve:

    J whole genomes from different organisms being sequenced.

    K computer-based techniques that can alter sequences of DNA in common between different species.

    L a comparison of gene loci, the number of genes, and their content.

    M techniques that provide greater insight into the evolution of genomes.

14. An experiment was conducted to test the effect of age on the accumulations of mutations in mitochondrial DNA. The samples were taken from three-month-old and thirty-month-old mice for observation.

    The correct conclusion based on the results in the table to the right is:

    J The average increase in mutations between the three and thirty-month-old mice was 11.4 per 10^6 base pairs. This has a greater consequence for females as mitochondria are inherited from the ovum.

    K The average increase in mutations between the three and thirty-month-old mice was 11.4 per 10^6 base pairs. This has a greater consequence for males as mitochondria are inherited from sperm.

    L The average increase in mutations between the three and thirty-month-old mice was 9.2 per 10^6 base pairs. This has a greater consequence for females as mitochondria are inherited from the ovum.

    M The average increase in mutations between the three and thirty-month-old mice was 9.2 per 10^6 base pairs. This has a greater consequence for males as mitochondria are inherited from sperm.

	Number of mitochondrial mutations in 10^6 base pairs	
Mouse	Three-month-old mice	Thirty-month-old mice
A	2	
B	1	
C	2	
D	2	
E	4	
F		10
G		14
H		10
I		13
J		10

15. Which of the following statements is correct with regards to molecular clocks?

    J They can be used to estimate the age of individual animals and plants.

    K Molecular clocks estimate the age of fossils.

    L All genes have the same rate of molecular evolution and therefore the same calibration for a molecular clock.

    M They can be used to estimate when two species evolved from a common species.

Free response questions

1. Comparative genomics involves comparing the DNA of different organisms.

    a) State three possible benefits from the study of comparative genomics.

    b) Outline three techniques that can be used to establish evolutionary relationships between species.

2. Describe how the DNA of different species is:
   a) similar
   b) different
3. Describe why the universal presence of DNA provides strong evidence for evolution.

4. Evolution is defined as the change in heritable characteristics of biological populations over successive generations. Describe how scientists can obtain a measure or indication that evolution has occurred.

5. The DNA sequence in early prokaryotes has been modified and diversified over billions of years to give rise to the biodiversity of organisms seen today.
   a) Explain the role of endosymbiosis in this process.

   b) Describe how mutations play a role in the modification of the DNA sequence.

   c) Explain why mutations in tissue cells of an organism will not impact on the next generation.

6. Explain how a comparison of the amino acid sequence in haemoglobin molecules can provide an indication of how recent a common ancestor existed between two species.

7. Haemoglobin is a protein found in many organisms and is involved in transporting O_2 around to the tissues. The amino acid sequence varied between different species.

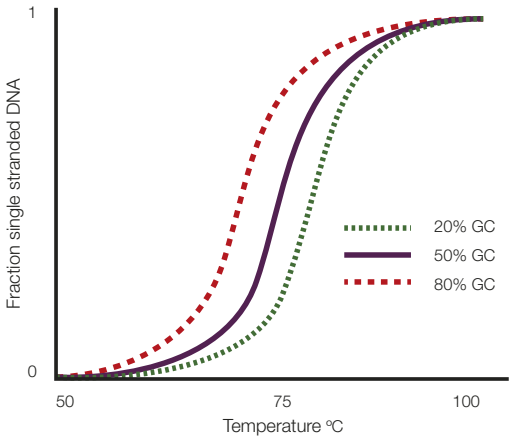
   Refer to the table below which shows the numbers of differences in the amino acid sequences of haemoglobin in 3 different species A, B and C to answer the question that follows.

Species	A	B	C
A	0	10	9
B	10	0	2
C	9	2	0

   Using this information, in the space below, draw a possible hypothesis in the form of a phylogenetic tree that could represent a possible evolutionary relationship between the three species.

8. Explain the basis for the following scientific statement: "*the greater the similarity between the sequences of nucleotides in the DNA of two species, the more recent the separation from their common ancestor*."

9. *Refer to the adjacent graph to answer the questions that follow. The graph shows the melting point curves for three strands of DNA with different levels of the bases C-G.*

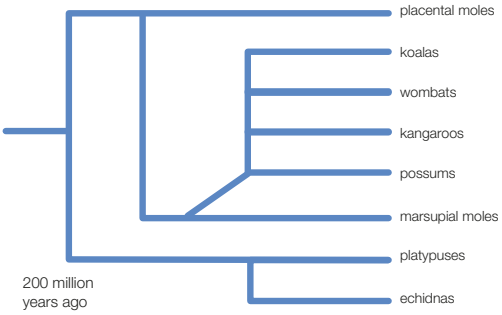


   a) State how the melting point of DNA is defined.

   b) Suggest a logical hypothesis relating the G-C content in DNA and the melting point of the DNA.

   c) Explain how the melting point of hybrid DNA formed between two species can be used to give an indication of the evolutionary relatedness of the two species.

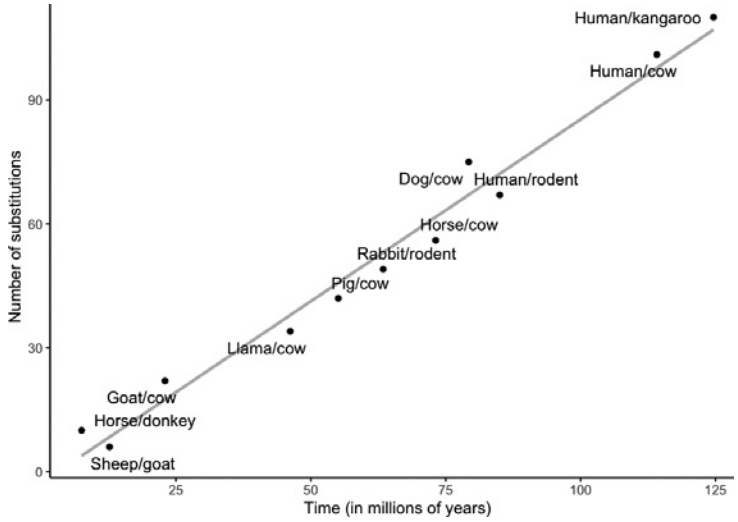
10. *Refer to the simple phylogenetic tree on the right to answer the following questions.*



   a) Explain how scientists compare the cytochrome c molecules in different species.

   b) Identify and explain the evidence in the phylogenetic tree above that would support the idea that placental moles and marsupial moles possess significant differences in their genetic make up.

11. *Refer to the molecular clock below showing the number of substitutions in the cytochrome c gene for different pairs of species.*



a) State what the slope of the line in the molecular clock represents.

b) Explain why each plotted point on this molecular clock has two species associated with it.

c) State one other way that this data could be used to illustrate evolutionary relationships.

d) Plot a line on the molecular clock that represents a gene with a mutation rate that is slower than cytochrome c's.

e) Explain why each gene requires a separate calibration of its molecular clock.

f) (i) Explain why the most important component of a molecular clock is its calibration.

(ii) Describe how the effect of calibration errors could be reduced.

12. rRNA sequencing is a popular technique used for studying evolutionary relationships.

    a) The rRNA gene consists of both conserved and variable regions. Discuss the importance of these two regions to researchers.

    b) Researcher's use rRNA sequencing to identify the species of microorganisms residing in individuals' guts.

        i) Explain one reason why researchers prefer rRNA sequencing over DNA sequencing for the identification of microorganisms.

        ii) Explain why using 16s rRNA sequencing alone, is not a valid technique for identifying all microorganisms in the intestines.

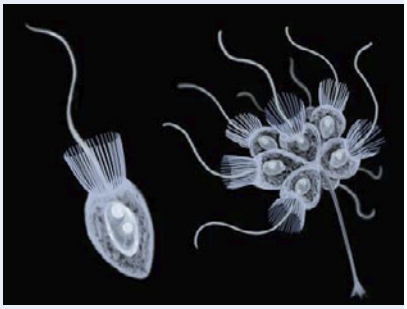
        iii) Describe another limitation of using rRNA sequencing for the analysis of microorganisms in the intestines.

Science as a Human Endeavour 4.2 - Why is there multicellular life?

As discussed in Chapter 4.1, the first life on Earth was unicellular and dates back to at least 3.5 billion years. According to a report by *New Scientist* in March 2017 the oldest known multicellular life appeared in the fossil record about 1.6 billion years ago. This means that for about 2 billion years the only life on Earth was unicellular. What happened to change that?

The answer it seems is related to the origin of mitotic division. For cells to divide this way the mitotic spindle must be orientated so it points to opposite ends of the cell. In animal cells this is done by the protein GK-PID (Guanylate Kinase Protein Kinase Interaction Domain). Once the mitotic spindle has been correctly orientated by GK-PID, mitotic division occurs.

A team of scientists at the University of Chicago published a paper in 2016 that proposed that GK-PID first appeared about a billion years ago due to a mutation of a gene that previously coded for an enzyme. The timing is important because at that time colonies of unicellular organisms called choanoflagellates had evolved (see image). The team's work suggests choanoflagellates that experienced the mutation gained the ability to divide mitotically, vital to being multicellular. These subsequently evolved into complex multicellular organisms, the descendants of which have given rise to all multicellular life and populate Earth today.



You may need to refer to the online resources below to answer the questions that follow.

1. Explain the importance of comparative genomics to determine our evolutionary past.

2. Discuss one other way that comparative genomics could be applied to be benefit society's understanding of our evolutionary past.

Helpful online resources

Bioinformatics: What is Comparative Genomics?

<https://www.youtube.com/watch?v=Irs65GAu1YM>

Be Smart: Why Are You Multicellular?

<https://www.youtube.com/watch?v=jdVc2J_OwDc>

Chapter 4.3 Reproductive isolation

Science Understanding

Different criteria are used to define a species depending on the mode of reproduction.

A species that reproduces sexually can be defined by the ability of its members to actually or potentially interbreed to produce fertile offspring.

Other criteria used to define a species include::

- morphological similarity
- biochemical similarity
- sharing a common gene pool.

Reproductive isolating mechanisms act to maintain distinct species.

- Describe pre-zygotic mechanisms (prevention of zygote formation) including:
  - temporal isolation
  - behavioural isolation
  - mechanical isolation
  - gamete isolation.
- Describe post-zygotic mechanisms (prevention of fertile hybrids) including:
  - hybrid inviability
  - hybrid sterility

Defining species

As was discussed in the SACE Stage 1 Biology course, the principal groups for classifying organisms are: Domain, Kingdom, Phylum, Class, Order, Family, Genus and Species. Refer to *Figure 431*.

Figure 431 the principal groups for the classification all living things.

Naming species

Over the last few hundred years, a system for naming species has developed. In 1753 a Swedish naturalist, *Carl Linnaeus*, developed a binomial system where all species were given two names, the first one of which refers to its genus and the second its species name. For example, two eucalypt trees, *Eucalyptus camaldulensis* (River Red Gum) and *Eucalyptus leucoxylon* (Blue Gum) both belong to the same genus, Eucalyptus, as they have certain common characteristics, but they belong to separate species as they do not cross pollinate and thus do not interbreed. Refer to *Figures 432 (a) and (b)*.

Note: The name of the genus usually begins with a capital letter whereas the first letter of the name of the species is lower case and both are usually written in italics as shown above.

Figures 432 (a) Eucalyptus camaldulensis and (b) Eucalyptus leucoxylon

An example of classifying two organisms

The classifications of *Taraxacum officinale* (a dandelion) and *Homo sapiens* (a human child), are shown in this table and are illustrated in *Figures 433 (a) and (b)*.

Taxa (=level of hierarchy)	Dandelion	Human
KINGDOM	Plantae	Animalia
PHYLUM	Tracheophyta	Chordata
CLASS	Angiospermae	Mammalia
ORDER	Asterales	Prima
FAMILY	Asteraceae	Hominidae
GENUS	Taraxacum	Homo
SPECIES	*Taraxacum officinale*	*Homo sapiens*

Figure 433(a) Dandelion (Taraxacum officinale)

Figure 433 (b) A human child (Homo sapiens)

Biochemical similarities

DNA is a biochemical molecule found in all species, no matter how different they look, and is therefore universal. **Biochemical similarities of DNA and proteins** can therefore be used to determine between asexually reproducing species such as bacterial species. However, there are many other biochemical molecules that are very similar between species. Because transcription, translation, cellular respiration and photosynthesis are essential processes in organisms, the biomolecules associated with these processes are very similar. One example is **cytochrome C**, which is required for cellular respiration. Because all organisms require energy, they all have cytochrome C. Therefore, the similarity of these biomolecules can be compared to determine evolutionary relationships (see Chapter 4.2 for more information).

Species concepts

Defining a species is not easy. A definition that works for a simple prokaryote that reproduces asexually may not work for a more complex eukaryotic organism that reproduces sexually. Additionally, the reproductive isolation associated with sexually reproducing species is on a continuum and therefore, not always easily recognisable.

Methodologies for defining whether individuals from two different populations are separate species have been developed; they are called **species concepts**. There isn't a 'one size fits all' species concept that can be applied across all species. In fact, there are at least 26 accepted species concepts that could be applied in different situations, each having their own **limitations**. In this course, two species concepts are covered:

- Biological species concept, and
- Morphological species concept

Biological species concept

The biological species concept is the **most widely used** concept to define species and is based on the concept of **reproductive isolation**. The concept states that the members of one species are a population where the members have **similar characteristics** (biochemical, morphological and genetic) and the **capacity to interbreed and produce fertile offspring**. The mechanisms that can result in reproductive isolation are studied later in this Chapter.

Recall that a population is a group of individuals of the same species that interbreed together in a particular community. Species will usually consist of **several populations** that are **geographically isolated** from one another. Even though the populations are physically isolated, they are still considered one species if they can contribute to the **gene pool** by producing fertile offspring. The term gene pool refers to the total set of genes that are found in an interbreeding population. All members of the species thus contribute to the genetic make-up of this gene pool. The gene pools of different species remain isolated as the members of different species do not interbreed and have fertile offspring.

There are many **limitations** when applying the biological species concept. The table below summarises a few main limitations.

Limitation	Explanation
Asexually reproducing species	Many organisms reproduce by asexual means and as such, this species definition of interbreeding simply does not apply. Bacteria, bees, hydra, sea stars, and many types of plants all have the ability to reproduce asexually. **Biochemical comparisons** of DNA and proteins (see Chapter 4.2) help to establish relatedness in these circumstances.
Lack of data on breeding behaviour	Many species have not had extensive research conducted on their breeding patterns and ability to produce fertile offspring with other groups of organisms. More research would have to be funded and completed to gain the necessary data before applying this species concept.
Fossils	The DNA in fossils has generally degraded for species that have been extinct for a long time. This rules out the ability to compare breeding behaviours and **comparative genomics**. There is also no evidence available regarding interbreeding and behaviour of the fossilised organisms. However, fossils can still show the structural (**morphological**) features of organisms, which can be compared.
Overlap of populations and hybrids	Sometimes it is difficult to apply the species concept because it is difficult to examine the extent of interbreeding. An example that illustrates this involves three groups of rosellas; the Crimson Rosella, the Adelaide Rosella and the Yellow Rosella. Refer to *Figure 434* which shows a distribution of the three groups of rosellas across eastern and southern Australia. On first appearances it could be suggested that these three types of rosellas are different species, but observations reveal overlap in their distribution areas and also the presence of **hybrids** or intermediate forms. If the different rosellas interbreed to give rise to intermediate forms they are of course considered to be **one species**. Scientists may classify three groups of rosellas as three separate **sub-species**. Groups of populations such as these rosellas may be in the process of gradual divergence into separate species.

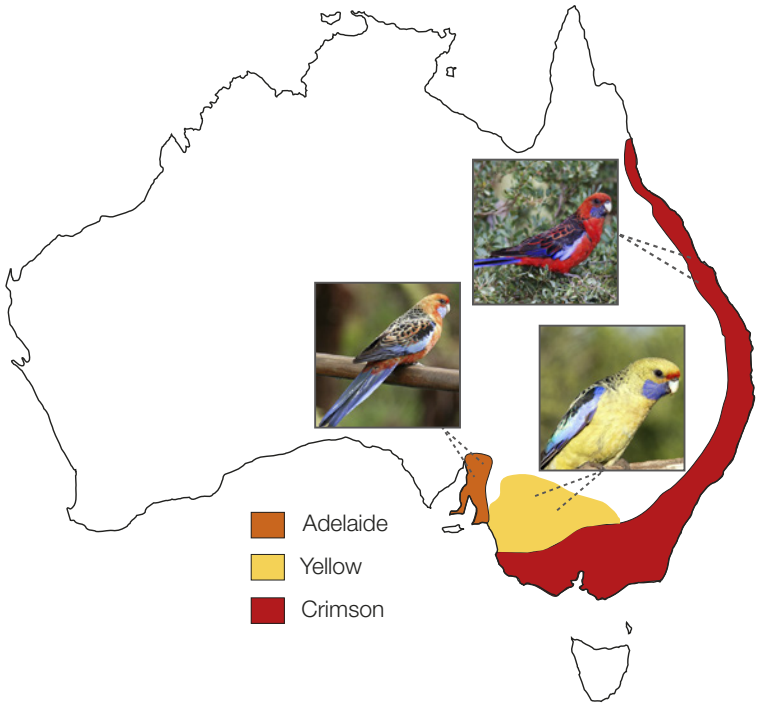


Figure 434 The distribution of rosellas in Australia

Morphological species concept

The morphological species concept groups species according to **structural (morphological) features** that are unique to the particular group of organisms. This species concept can be applied to any group of organisms on Earth but is particularly useful when classifying **fossil remains**. The DNA in fossils has generally degraded for species that have been extinct for a long time. This rules out the ability to compare breeding behaviours and **comparative genomics**. There is also no evidence available regarding interbreeding and behaviour of the fossilised organisms. However, fossils can still show the structural (**morphological**) features of organisms, which can be compared.

A **limitation** of the morphological species concept is that different species can have similar structural features, making it hard to differentiate between organisms. It is therefore only used when the biological species concept cannot be used. Species that have similar structural features due to **convergent evolution** (see Chapter 4.6) is a good example of this concepts limitations. Sharks and dolphins are **not closely related**. Sharks are classified as a fish and dolphins are classified as a mammal. These two species both live in marine environments and have been exposed to similar selection pressures that acted on the variation in their populations, resulting in these similar structures (see *Figure 435*).

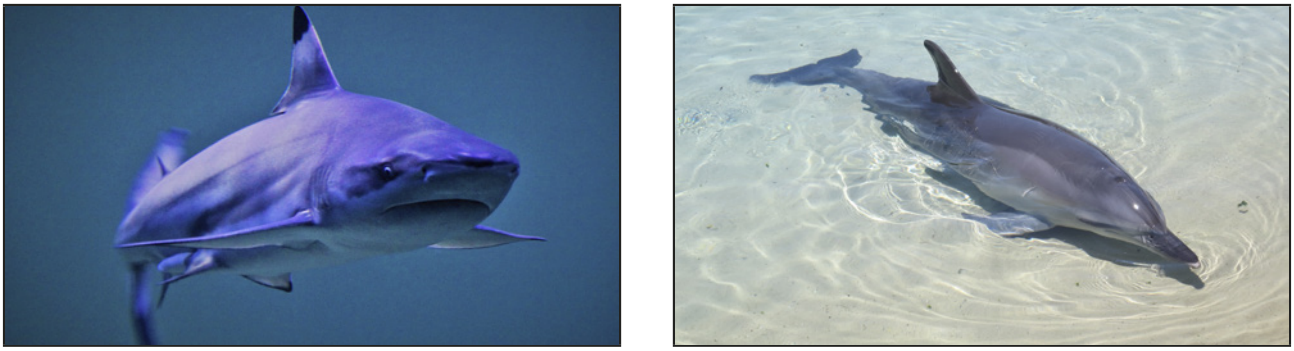


Figure 435 Sharks and dolphins have similar structural features but are not closely related

Helpful online resources

SciShow: What Makes a Species a Species?
<https://www.youtube.com/watch?v=dnfaiJJnzdE>

Fossils

Trying to classify fossil remains into particular species also will not fit with the current definition of species as no evidence is available regarding interbreeding. In these instances, biologists will tend to use morphological features, species grouped according to structural features that are unique to the particular group of organisms. Refer to *Figure 436* showing a fossil of a small flying dinosaur; with a real size about that of a raven, 50 cm in length.

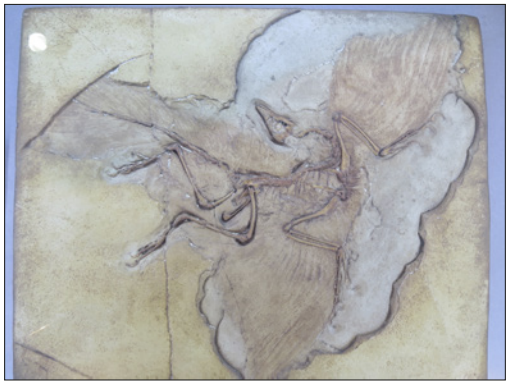


Figure 436 An Archaeopteryx fossil

Reproductive isolating mechanisms

An important feature of an individual species is that members of the species can interbreed with other members of the same species but are **reproductively isolated** from members of other species. Essentially, members of separate species cannot interbreed and have fertile offspring.

This reinforces the concept just discussed in this chapter, concerning the gene pool which is the set of genes in a population of the one species.

The genetic isolation of the populations of one species from populations of another species is achieved by reproductive isolation mechanisms. These isolating mechanisms are essentially grouped into two main types: **pre-zygotic** and **post-zygotic.**

Pre-zygotic mechanisms

Pre-zygotic mechanisms prevent reproduction before the zygote is formed i.e. prior to fertilisation. There are a number of these mechanisms:

Temporal (time) isolation

Temporal isolation is where the breeding cycles or time of fertility differs from one population of species to the next. Plants are good examples where some species of eucalypt will only flower and thus be pollinated in the summer months whilst others only in the winter. Species of mammals that are nocturnal are highly unlikely to mate with species that are active during the day. *Figure 437* illustrates the timing of the mating activity of the populations of four species of frogs, indicating a mechanism that would be achieving partial pre-zygotic isolation.

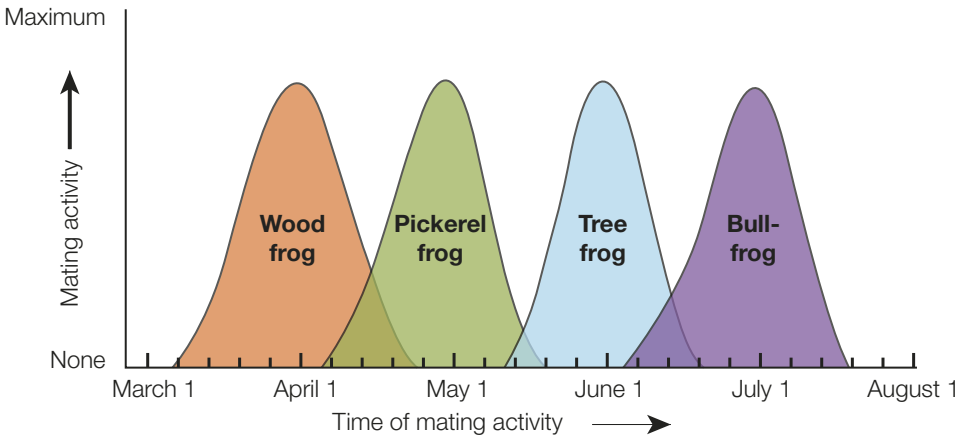


Figure 437 An example of temporal isolation.

Behavioural isolation

Behavioural isolation involves the development in populations of highly specific calls or rituals that are directed and responded to only by other members of a particular population. The Blue-Footed Booby has a very unique courtship dance display that the female can respond to. The female will not respond to males from different populations that cannot replicate this courtship ritual. *Figure 438* illustrates the Blue-footed booby courtship dance ritual.

Male frogs have very specific mating calls that only members of the population will respond to. Refer to *Figure 439*.

Figure 438 Blue-footed boobies' courtship

Figure 439 A frog's mating call

Mechanical (morphogical) isolation

This type of isolating mechanism is essentially related to incompatible sexual organs (genitalia) whereby significant anatomical differences act as a very powerful mechanism to ensure that different populations remain reproductively isolated. Bats, for example, show remarkable diversity in penis structure that makes this is a good example of **mechanical (morphological) isolation**.

This also applies to plants where populations of different species of plants may use different pollinators e.g. insects/birds/bats and again, no cross pollination and thus no fertilisation will occur.

Gamete isolation

Gamete isolation refers to the incompatibility of sperm and eggs from populations of different species. There are a range of mechanisms and chemicals in species to ensure that sperm can fertilise and fuse with an egg from a member of the same species only.

Isolating mechanisms that can operate here include where the sperm do not respond to chemical signals from the egg or cannot penetrate the egg of a member of an unrelated species. Refer to *Figure 4310*.

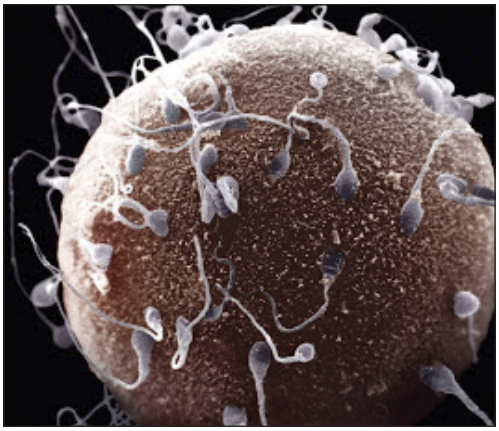


Figure 4310 Sperm attempting to penetrate an egg.

Post-zygotic mechanisms

The post zygotic mechanisms usually prevent a zygote, which was formed from the union of sperm and egg from different species, from developing into a viable, fertile adult hybrid.

Hybrid inviability

When hybrid zygotes are formed and begin to develop, there are many instances where these individuals are weak and compete only poorly for resources. Consequently, they are unlikely to reach reproductive age and contribute to the gene pool, this is called **hybrid inviability.**

Hybrid sterility

Hybrid sterility can be seen as an extension of the previous isolating mechanism. In this instance the hybrid formed is sterile and as a consequence, once again, reproductive isolation between the two species is maintained. An example to illustrate this can be seen when a female horse mates with a male donkey and a sterile mule offspring is the result. Refer to *Figure 4311*.

Figure 4311 A mule

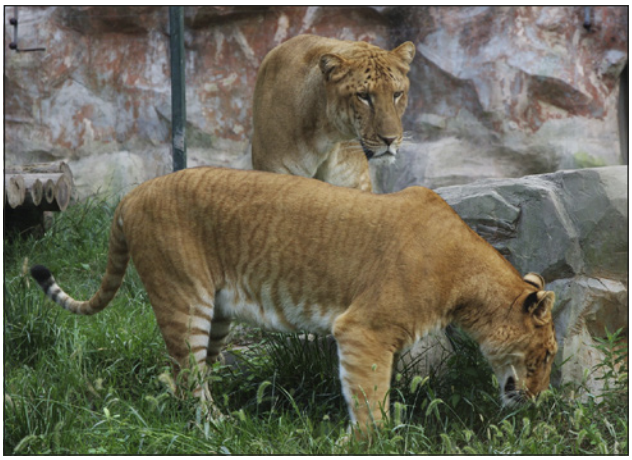


Figure 4312 Two ligers

This can be understood when an examination of the chromosomes reveals that horses have a diploid number of 64 and donkeys 62. As a result, the mule will have 63 chromosomes in each of its cells; without a complete set of homologous pairs, meiotic division fails to proceed in a normal fashion and the organism, in this case the mule, is sterile and unable to produce gametes.

A 'liger' (refer to *Figure 4312*) is a hybrid formed by the mating of a male lion with a female tiger (tigress). In this instance, however, while the male ligers have never been known to reproduce, in some very rare cases the female ligers have.

Helpful online resources

Khan academy medicine: Reproductive isolation | Biomolecules | MCAT | Khan Academy
<https://www.youtube.com/watch?v=vmgKC2lJjOI>

4.3 Review questions

Multiple choice questions

1. Identify the statement that mentions one species:
   - J *Panthera tigris* and *Panthera pardus.*
   - K *Mangifica indica* and *Rosa indica* plants.
   - L Two populations of *Panthera pardus* and cougars.
   - M Three different populations of *Gorilla gorilla*.
2. Which of the following options is *not* a limitation of the biological species concept?
   The biological species concept:
   - J cannot be applied to asexually reproducing species.
   - K requires geographical barriers between species
   - L cannot be applied to fossils.
   - M is limited when complex patterns of reproductive connectivity is encountered.
3. A limitation of the morphological species concept is:
   - J Individuals from the same species can look very different.
   - K It can only be used with fossilised organisms.
   - L It cannot be applied to sexually reproducing species.
   - M Individuals from different species can sometimes look similar.

4. Starting from a single wild canine species, humans have developed hundreds of breeds of domestic dogs.

The two dogs shown to the right are:

J members of the same species.

K members of the same breed.

L not members of the same species.

M not members of the same species or the same breed.

5. A pre-zygotic barrier prevents which of the following?

J A zygote from developing into viable offspring

K An egg from being fertilized

L Animals from interacting with one another

M All of the above options.

6. Which one of the following statements describes an example of a mechanism that would best help to maintain reproductive isolation?

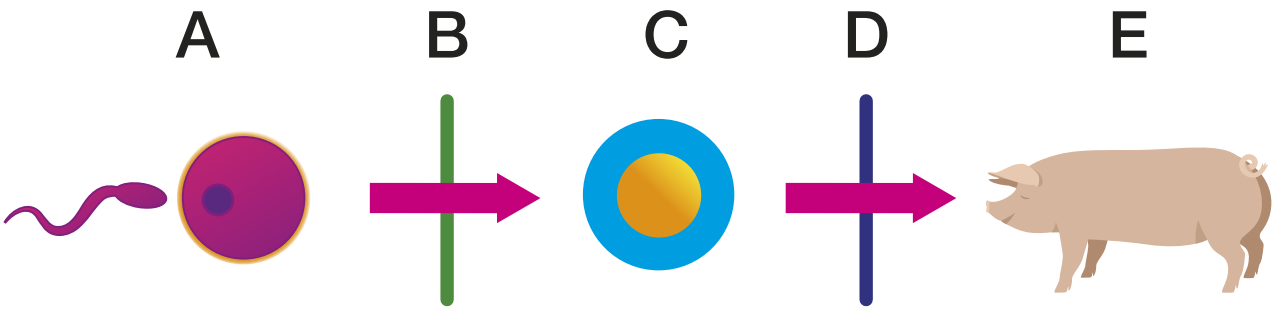
J The production of similar mating calls by two species of frog.

K The production of gametes during the same season by two species of pine tree.

L The mating and production of infertile offspring by two individuals.

M The separation of two populations of the same species by a geographical barrier.

7. *Refer to the following diagram to answer the question that follows:*



Which of the following options does not represent stages where post-zygotic mechanisms can occur?

J B and C

K C and D

L C and E

M D and E

8. Which one of the following is *not* a pre-zygotic reproductive isolating mechanism between two species?

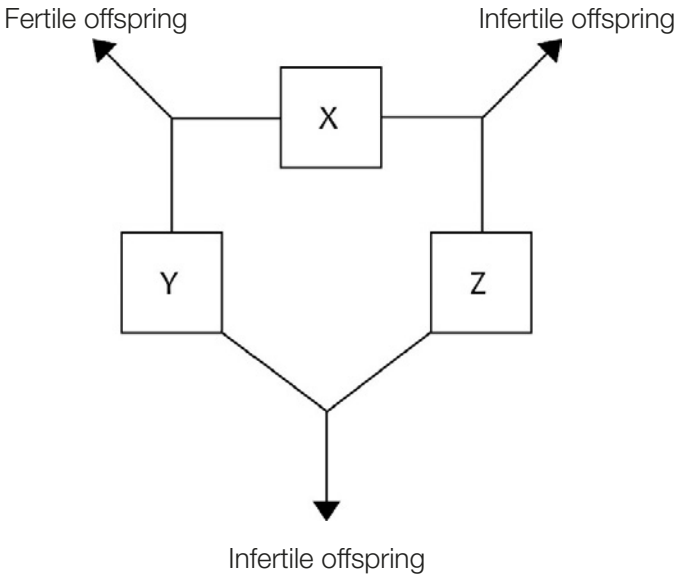
J Species-specific female preference for male plumage colour.

K The production of pollen at different times of the year.

L The failure of hybrid offspring to develop into adults.

M Incompatible morphological structures required for reproduction.

9. Refer to the diagram below which shows the fertility of the offspring *produced when 3 populations of rosellas X, Y and Z interbreed.*



How many species of rosella are there?

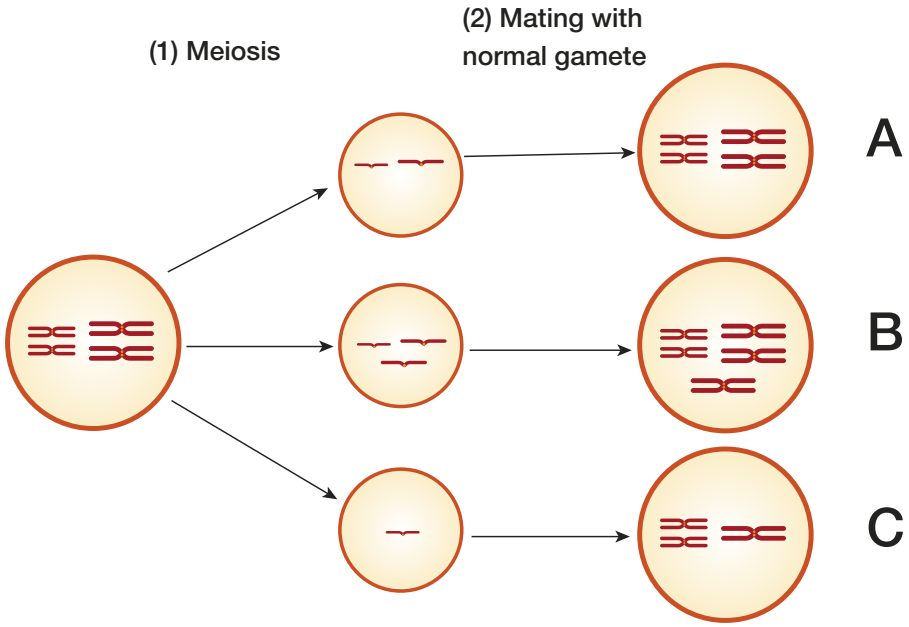
J 0

K 1

L 2

M 3

10. *Refer to the diagram below illustrating the formation of gametes in an organism (1) and some possible gametes produced from mating with a normal gamete (2).*



With reference to the diagram, which of the following zygotes is most likely *not* to grow into a sterile adult?

J A

K B

L C

M None of the above.

Free response questions

1. Explain the difference between the terms population and species.

2. The definition of a species is effectively 'a group of organisms that interbreed to produce fertile offspring'.
   a) Give two examples of populations where the above definition is difficult to apply.

   b) Describe how scientists attempt to place such groups of individuals into species.

3. Describe what it means to say that 'the members of a species are genetically isolated from other species'.

4. Name examples of reproductive isolating mechanisms that might prevent gene flow between:
   a) two groups of flowering plants
   b) two groups of closely related frogs
   c) horses and donkeys
5. Outline three pre-zygotic reproductive isolating mechanisms and give an example of each.
   a)
   b)
   c)
6. The hybrid formed between two species, horses and donkeys, is termed a mule.
   a) State which type of reproductive isolating mechanisms keeps the species from interbreeding.

   b) Explain how incompatible chromosome numbers between the species renders normal gamete production impossible.

7. Outline the link between gene pool and the concept of a species.

8. A biochemical analysis of protein molecules could be used to determine if two different types of bacteria were different species.
   a) Suggest why this analysis can be used to determine relatedness between organisms.

   b) Outline a likely procedure that could be used to compare differences in the proteins.

9. *Eucalyptus camaldulensis* and *Eucalyptus leucoxylon* are very similar eucalypt trees. Describe the evidence that would have enabled scientists to determine that these, do indeed, belong to different species.

10. Explain why reproductive isolation between two populations is essential if they are to be regarded as separate species.

11. Suggest a possible hypothesis to explain how members of two closely related species living in close proximity and mixing together might be reproductively isolated.

12. Eucalyptus flowers produce male gametes (pollen) and female ova (eggs). There are some groups that flower in summer, others in winter. On closer examination it is noted that different pollinators are involved in the two groups.
   a) Name the type of reproductive isolation seen here.
   b) Suggest how the method of pollination can also act as a reproductive isolating mechanism.

13. Refer to *Figure 434*, indicating the distribution of three groups of rosellas, in the south and eastern parts of Australia .
   a) The map tends to suggest that the three groups might belong to separate species. State two pieces of evidence that suggests they are indeed, separate species.

   b) On close examination, hybrid rosellas are found. Given this information, suggest why scientists are more inclined to name the three groups as separate sub-species rather than separate species.

Chapter 4.4 Genetic variation

Science Understanding

Mutation is a permanent change in the sequence of DNA nucleotides and is the ultimate source of genetic variation in a species.

In a species that reproduces sexually there are additional sources of genetic variation.

- Explain the sources of genetic variation in a species that reproduces sexually.

A gene pool comprises all the genetic information in a population.

- Recognise that a large gene pool indicates considerable genetic diversity and is found in populations that are more likely to survive selection pressures.

Natural selection is a process in which organisms that are better adapted to their environment are more likely to survive and produce offspring.

- Explain how natural selection results in evolution by causing a change in the frequency of alleles in a population.

Mutations

Mutations are permanent changes in the sequence of nucleotides of DNA and are the ultimate source of genetic variation in the species. Mutations are the source of new forms of a particular gene (**alleles**) in populations of a species.

Recall that Chapter 1.6 presented a range of different types of mutations, from base substitution, insertion or deletion mutations to large-scale chromosomal mutations. An important distinction was made with regard to what types of cells mutations occur in.

Mutations in somatic (non-germline) cells can cause serious disease but will not be passed on to future generations. On the other hand, mutations in germline cells (tissues that give rise to sperm or ova) can be passed on to the next generation. When the DNA replicates in the new embryo, the mutated gene is also replicated and appears in all new cells that are subsequently produced.

Mutations accumulate over time and the rate of mutation is relatively constant; this enables the number of mutations to be used as a 'clock' in estimating the time elapsed since various events.

Generally, mutations can be placed into four groups: lethal, disadvantageous, neutral or beneficial.

Helpful online resources

Khanacademymedicine: The effects of mutations | Biomolecules | MCAT | Khan Academy
<https://www.youtube.com/watch?v=JxC2phkdY8Y>

Lethal mutations

To understand lethal mutations, a brief reminder of gene inheritance is required, as discussed in Chapter 2.7. A zygote inherits half of its genetic material from its father (paternal) and half from its mother (maternal). Genes act in a variety of ways; some act according to a **dominant** and **recessive** pattern of inheritance. Since individuals have two alleles for each gene of a characteristic, they will either be **homozygous** (i.e. two dominant alleles or two recessive alleles of the gene) or **heterozygous** (one dominant allele and one recessive allele).

Dominant and recessive inheritance is characterised by alleles that are either dominant (i.e. the feature is expressed when at least one dominant gene is in the genotype) or recessive (i.e. when two copies of the gene are required for the character to be expressed).

Cystic Fibrosis

Cystic Fibrosis (CF) (studied in Chapter 1.6) is a genetic disease caused by a faulty recessive allele of a gene. The normal allele(C) is dominant over the recessive mutant allele(c). Three genotypes and consequent phenotypes can be identified:

CC Normal (does not carry the cystic fibrosis allele)

Cc Normal (but carries one cystic fibrosis allele)

cc cystic fibrosis sufferer (has two cystic fibrosis alleles)

As seen, if an individual inherits two faulty alleles (c) , one from each parent, the child will suffer from the disease.

Sickle-cell anaemia

Another genetic condition relates to the disease sickle-cell anaemia (*refer back to Chapter 1.6*). The cause of the disease is a change of one base which leads to a protein with one amino acid changed. An A changes to a T in a substitution mutation occurring in the codon for the sixth amino acid in the beta (β) chain; the codon changes from GAG to GTG and consequently glutamic acid (glu) is replaced by valine (val).

Two alleles can be identified here:

Normal haemoglobin HbA and the mutant (abnormal) variety HbS; therefore:

- homozygous individuals could be HbA HbA or HbS HbS
- heterozygous individuals will be HbA HbS as illustrated in *Figure 441*

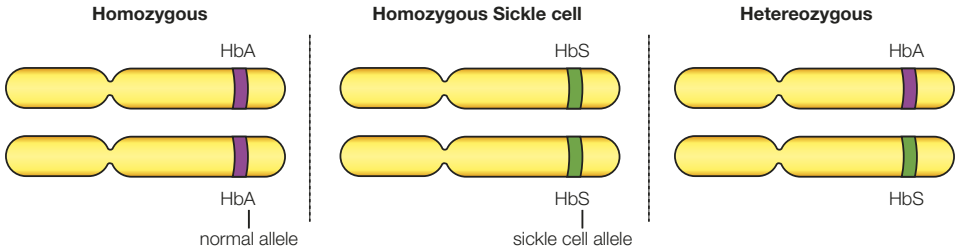
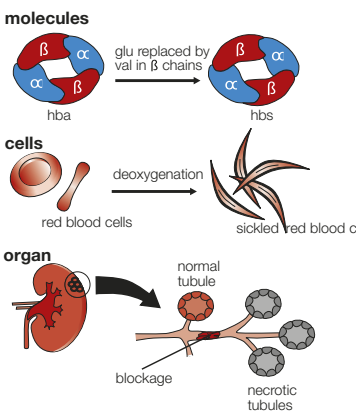


Figure 441 Alleles for haemoglobin

In this situation, the genes HbA and HbS exhibit a form of **co-dominance** (or incomplete dominance) where the heterozygous form i.e. HbA HbS) exhibits features from both alleles i.e. normal and abnormal haemoglobin are both made.

In the individuals with the mutant gene and consequently the mutant haemoglobin, the red blood cells will change from the normal bi-concave shape into a sickle-cell shape. The resultant disease is called sickle-cell anaemia and will often cause death in homozygous individuals. Refer to *Figures 442 (a)* and *(b)*.



Figures 442 (a) and (b) Illustrating sickle-cell anaemia

There are a range of lethal mutations, some of them causing the embryo to stop growing (abort), others that usually lead to death after birth to pre-reproductive age. Many humans carry single lethal recessive alleles of genes that would be fatal if the offspring was to inherit another copy of the lethal allele of the same gene from their other parent.

Disadvantageous mutations

Some mutations are disadvantageous; they cause disease in those who have the mutant gene but generally this is not fatal. Osteoporosis is a disease that affects over one million people in Australia. Sufferers display symptoms such as brittle bones that are subject to a higher rate of fracture. The gene 'low-density lipoprotein receptor related protein 5' (LRP5) is involved in bone density and mutations in the gene can give rise to osteoporosis. The bones of affected individuals tend to lose or 'leak' minerals such as calcium into the blood, giving rise to low bone density. Refer to *Figure 443*.

Figure 443 Osteoporosis

Neutral mutations

A neutral mutation would normally be described as one which will have no effect on either the appearance (i.e. **phenotype**) of an organism or its function. It is thought that the majority of mutations are neutral. Some scientists take issue with this definition of neutral and argue that they are still mutations because they change the **genotype** and will be passed on to future generations (if in the 'germline' cells). These changes, perhaps in 'non-coding regions' of the DNA may, in fact, cause unknown changes to function.

Beneficial mutations

The disease sickle-cell anaemia was established as a lethal condition caused when individuals are homozygous for the sickle-cell gene. It has been noted however, that heterozygous individuals (HbA, HbS) have some HbS-derived haemoglobin but more normal haemoglobin and suffer from mild anaemia. The advantage in being a carrier is found in malaria-infested areas as the protist that causes the disease cannot reproduce in red blood cells with haemoglobin that is a product of the HbS allele. Thus individuals who are heterozygous for the sickle-cell condition have a reduced chance of contracting malaria.

It has also just been noted that mutations in the LRP5 gene can give rise to the disease osteoporosis. An interesting case was discovered when a boy was involved in a serious car crash in the Midwest of USA and doctors were astonished that none of his bones were broken. On further investigation, it was found that no one in his immediate family had ever broken a bone. It turns out that a completely different mutation in the same LRP5 gene had conferred a completely different outcome i.e. increased bone density and increased resistance to fractures.

Sexual reproduction

Chapter 2.7 presented aspects associated with species that reproduce sexually and use meiotic division to produce sperm and ova (eggs). Reproducing by sexual means introduces variety into the offspring so that they do not look the same as their parents. This variation expresses itself as different genotypes (pairs of alleles of genes) and consequently different phenotypes (appearance).

Whilst mutations represent the only source of new alleles of genes, sexual reproduction essentially 're-shuffles' alleles of genes from parents to give rise to new combinations in their offspring. Refer to *Figure 444*.

Mutations

- source of new alleles

Sexual reproduction

- meiosis
  - independent assortment
  - crossing over
- fertilisation

Figure 444 Sources of genetic variation

A brief revision of how variation is introduced in sexual reproduction is given below:

In meiosis

Crossing over

This is a process that introduces new combinations of alleles of maternal and paternal genes.

Independent assortment of chromosomes

This refers to a process that gives rise to new combinations of maternal and paternal chromosomes in the gametes through random alignment of the homologous chromosomes on opposite sides of the equator of the cell (during meiosis 1).

In fertilisation

Fertilisation is the random fusion of an ovum and sperm each with their own unique collection of chromosomes and alleles.

As will be seen later in this chapter, this genotypic and phenotypic variation within a species is important for the processes of natural selection and evolution. Populations of sexually reproducing species show variation between individual members of the population.

Refer to *Figure 445*, note variations in colour.

Figure 445 A colony of Australian seals

Gene pool

A population is a group of individuals of the one species that breed together in a particular habitat. In Chapter 4.3, three groups of rosellas were all described as belonging to the one species as there was interbreeding between the three populations. The **gene pool** of a population is the **sum of all of the alleles** (and thus all of the genetic information) of all of the individuals in that population. In the situation with the rosellas, three gene pools could be described but they are not completely separate, with some gene flow occurring between the groups.

The genotype of an organism, along with the effects of the environment on it, determine the appearance or phenotype of the individual. The term **allele frequency** refers to the relative proportion of a particular allele in the population; this is usually expressed as a fraction or a percentage.

As will be explained later in this chapter, populations with **large gene pools** and possessing large diversity of alleles will be more robust and **more likely to survive** changing or harsh environmental conditions. Populations with reduced genetic diversity are at greater risk of extinction. Refer to *Figure 446* which shows a black footed rock wallaby, the genetic diversity of which has reduced so much that it is considered a threatened species.

Figure 446 A wallaby

Changes in the gene pool

Changes in the gene pool of a population can be brought about by several factors.

Mutations

These permanent changes to DNA sequences are the only way for new alleles of a gene to appear.

Gene flow

Gene flow is the movement of alleles **between different populations** of the same species. This can occur when individuals move in and out of populations, or **migrate**, which can change the frequency of alleles found in the gene pool.

Increased flow of alleles of genes between populations tends to reduce differences between the populations whereas limited gene flow tends to lead to populations evolving and developing in their own environment. Refer to *Figure 447*.

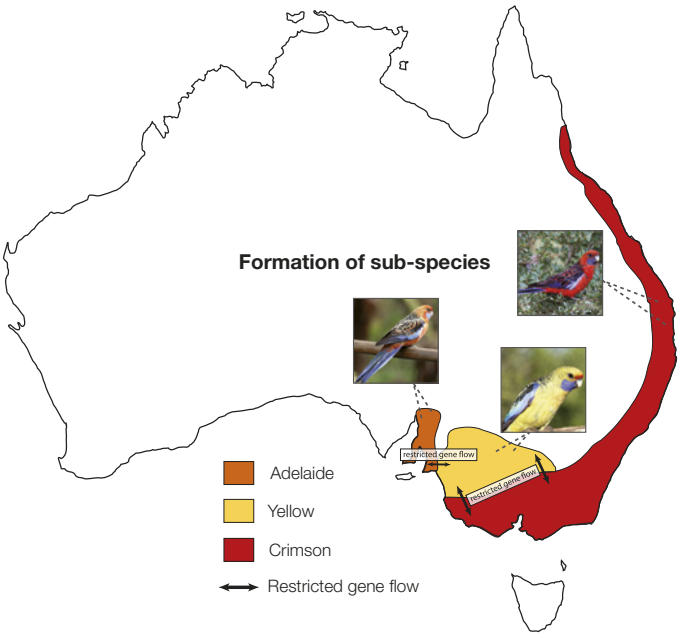


Figure 447 The distribution of rosellas

Genetic drift

Genetic drift refers to **random changes** in the frequency of alleles and tends to have more pronounced effects on small populations. If any individuals do not contribute their alleles to the next generation (i.e. reproduce) then this can have a major impact on the gene pool. Genetic drift can be seen in populations when effects such as the **bottleneck effect** occur.

The population of Mallee-Emu wrens (see *Figure 448*) is an example of a species that is endangered as a result of bushfires which act in a random manner to kill individuals within the population.

Genetic diversity, when measured, is found to be low and is thought that the bottleneck effect and genetic drift are at least partially responsible. The bottleneck effect refers to the impact of random factors, such as bushfires on the population. Reduced population size **reduces variation in the gene pool** often leading to reduced genetic biodiversity which may last for many, many generations.

Figure 448 A Mallee-Emu wren

Helpful online resources

Amoeba Sisters: Genetic Drift

<https://www.youtube.com/watch?v=W0TM4LQmoZY>

Natural selection

One of the most influential scientists in the history of biology was *Charles Darwin* who provided the first explanation for how the process of evolution takes place. In 1831 Darwin left England on a sea voyage on board the ship the 'Beagle' touring the coast of South America. It was here, particularly in the Galapagos Islands, that he was fascinated by the variety between individuals in a population and also between closely related species. Refer to *Figure 449* showing Darwin's voyages on the Beagle.

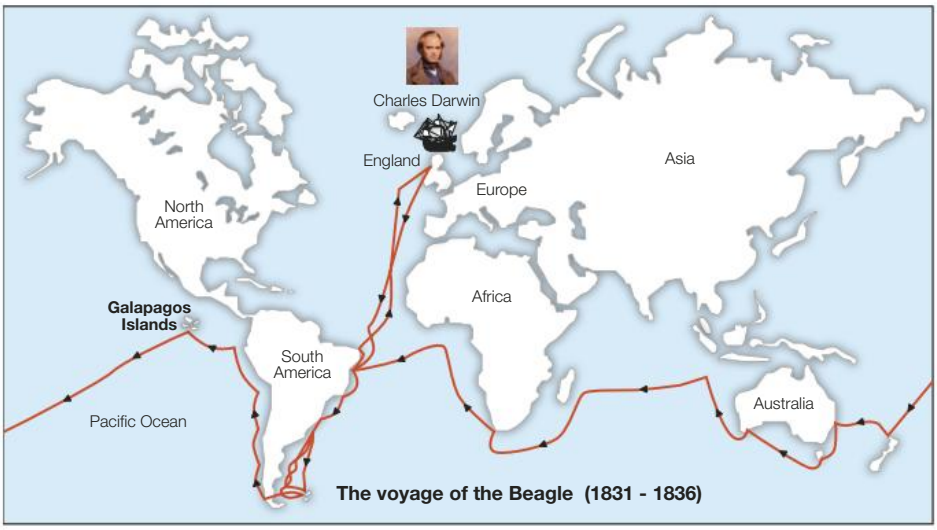


Figure 449 Charles Darwin's journey aboard the 'Beagle'

Darwin hypothesised that for each population, more individuals were born and survived to reproduce and that environmental factors hold all populations in check. In his book, "On the Origin of Species " published in 1859, Darwin suggested a process of **natural selection**, in which nature, or the environment, selected those individuals who were best adapted or "fittest". He proposed that variation between individuals gave some reproductive advantage which would enable the organism to leave more offspring to survive in the next generation. Refer to *Figure 4410* of Darwin's finches.

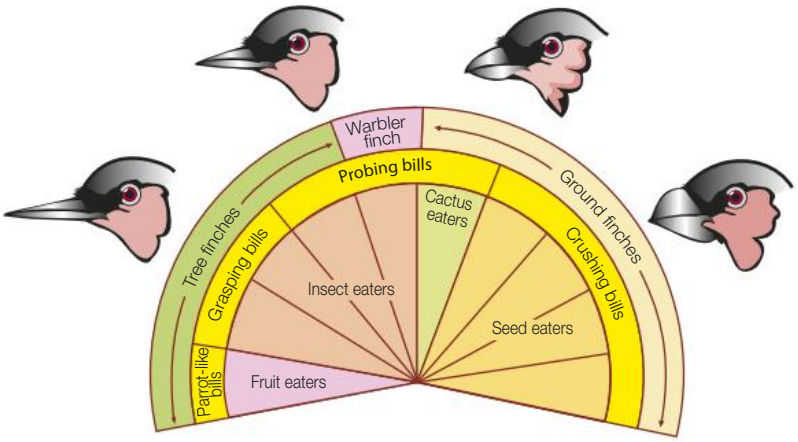


Figure 4410 Darwin's finches

As can be seen in the different shaped beaks, each one provides a unique **adaptation** for the type of food predominantly found in its particular environment on different islands. Darwin's thinking, which was both revolutionary and controversial for the time, was that natural selection, over a series of generations was the main driving force for evolution. He proposed that life had evolved from a common ancestor and due to natural selection, populations were modified over time according to the different environments and thus different selective pressures they were exposed to.

Helpful online resources

FuseSchool - Global Education: Charles Darwin's Observations | Evolution | Biology | FuseSchool
<https://www.youtube.com/watch?v=WAKppAtleh8>

Selective pressure

Natural selection is a process in which environmental or **selective pressures** act on the phenotypes of individuals in a population and thus lead to **changes in allele frequency;** certain alleles are favoured, others are selected against. This is where the term "survival of the fittest" arose from; alleles of the favoured traits in the population's gene pool increase in frequency over time whilst alleles selected against will decrease in frequency. Different selection pressures can lead to **divergent evolution** or **adaptive radiation.**

Selection may be by biotic or abiotic factors

Biotic factors include:

- predators
- disease-causing organisms
- competition from members of the same or different species
- symbiotic relationships with other organisms
- human activities

Abiotic factors include:

- rainfall
- temperature
- nutrient levels
- light intensity
- medical drugs like antibiotics, or chemicals like pesticides

A good and very famous example of the effects of natural selection on populations of a species is seen in the industrial melanism in peppered moths (*Biston betularia*). Refer to the information box below.

Case Study - Natural selection in 'Peppered moths'

Industrial melanism in moths *Biston betularia* (peppered moth) is found in forests near Manchester, England and elsewhere in the UK. Before the Industrial Revolution, trees on which the moths rested were covered with off-white lichen. The moths were white (light form) and speckled and therefore camouflaged from predation by birds. Occasionally a black (dark form) peppered moth would grow and develop. It, of course, was highly visible on the lichen-covered trees and would have a very high chance of being eaten by a bird before reproducing.

Due to (coal-based) industry, the trees became covered with black soot and the naturally white moths were thus easily spotted and eaten. The black (melanic) variant now had the advantage and became predominant (95%) in certain areas by around 1850. This phenomenon has been named 'industrial melanism'. The subsequent reduced use of coal in the later part of the 20th century made the trees green (covered in algae) and today both forms of the moths are common. This is an example of what is called 'balanced polymorphism'.

The environment before 1850 was such that the white moth phenotype was the best adapted. However, when the environment changed, the black moth became the better adapted. This is a simple and short-term example of evolution. Refer to the *Figures 4410 (a) and (b)* below. It has also been observed that in more recent times, with tighter environmental regulations about factory emissions, there has been a gradual change back to the lighter form.

Figure 4410 (a) The dark form

Figure 4410 (b) The light form

A brief summary of evolution by natural selection is given below:

- Individuals in populations show phenotypic variation that is the result of the environment and differences in genotype, which are inherited by the next generation
- There is a 'struggle for survival' between individuals of a population due to the action of selection pressures that can be biotic or abiotic.
- Those organisms that are best adapted to environmental conditions are more likely to survive to a reproductive age and pass on their favourable alleles of genes to the next generation.
- Over many generations, the population may evolve, showing changes in the gene pool. The effects of natural selection can be measured by changes in the frequency of alleles in the gene pool, evidence that evolution is occurring. It is important to note that it is populations or the species that evolves rather than individual organisms.
- Environmental selective pressures determine the reproductive success of the population; the population **does not "adapt"** to the conditions.

Helpful online resources

Amoeba Sisters: Natural Selection
<https://www.youtube.com/watch?v=7VM9YxmULuo>

Kurzgesagt - In a Nutshell: The Antibiotic Apocalypse Explained
<https://www.youtube.com/watch?v=xZbcwi7SfZE>

TED-Ed: Why are some people left-handed? - Daniel M. Abrams
<https://www.youtube.com/watch?v=TGLYcYCm2FM>

4.4 Review questions

Multiple choice questions

1. Which of the following statements about variation is most correct?
   - J Mutations are the only source of permanent variation for cells.
   - K Mutations to smooth muscle cells in genitals results in variation to offspring.
   - L Mutations can give rise to permanent advantageous alleles.
   - M Mutations are the only source of variation in acacia trees.
2. The Gros Michel banana virtually went extinct in the 1960s as it was susceptible to a fungal disease called Tropical Race 1 (TR1). The Cavendish bananas were not susceptible to TR1 and took over as the prime banana crop grown and sold. However, a new strain of the fungal disease called TR4 is now able to infect the Cavendish crops and is threatening our global banana supplies.

   With reference to the information above, which of the following statements is true?
   - J The Cavendish banana is susceptible to TR4 because of its large gene pool.
   - K Mutations to TR1 accumulated giving rise to TR4.
   - L Mutations to the Cavendish banana resulted in the development of TR4.
   - M The Cavendish banana was not susceptible to TR1 because of its small gene pool.
3. Gene flow:
   - J occurs when species migrate to new geographical locations.
   - K arises from sexual reproduction between closely related individuals.
   - L arises from the exchange of genes during fertilisation.
   - M occurs when individuals migrate to new geographical locations.

4. Which one of the following situations would most likely result in the highest rate of evolution by natural selection?

   J reproduction of organisms by asexual means in an unchanging environment.

   K reproduction of a species with a low mutation rate in a changing environment.

   L reproduction of organisms in an unchanging environment with little competition and few predators.

   M reproduction of organisms with genetic differences due to mutations in a changing environment.

5. The increasing global temperatures associated with global warming are applying selection pressures on many species, such as African elephants. Fortunately, variation exists within the population of African Elephants, so there is greater chance of some individuals being more suited to the increasing temperatures.

   Which of the following examples is the best suited to survive the increasing temperatures?

   J Large elephants that have a smaller surface area to volume ratio for heat release.

   K Small elephants that have a smaller surface area to volume ratio for heat release.

   L Large eared elephants providing a greater surface area to volume ratio for heat release.

   M Small eared elephants providing a greater surface area to volume ratio for heat release.

6. In some professional sports, left handers make up about 30% of the athletes. This is greater than the 10% of left handers that make up the general human population.

   Which of the following statements best describes this disproportionate ratio?

   J Left handers are better at professional sports than right handers.

   K Left handedness is a beneficial mutation in athletes only.

   L Left handedness is a favoured trait in professional sport and not selected against.

   M Left handers are always better competitors than right handers.

7. Antibiotic resistance has been noted in bacterial populations not long after antibiotics were first discovered and used for medicinal purposes.

   Which of the following statements best explains how a species of bacteria can accumulate multiple resistance to several antibiotics?

   J There have been separate mutations to different genes in the bacteria.

   K Some genes confer resistance to several antibiotics.

   L Some bacteria can develop resistance to multiple antibiotics when they are exposed to them.

   M Antibiotics cause mutations in bacterial genes when bacteria are exposed to the antibiotics.

8. In 1942 when penicillin was introduced, 99% of Staphylococcus aureus bacterial infections were successfully treated with it. Today a large proportion of these infections cannot be treated with penicillin because this species of bacteria is resistant to the drug.

   Which of the following is **not** a likely explanation for this observation?

   J Natural selection has occurred.

   K There has been an increase in the mutation rate of the gene that confers resistance to penicillin.

   L The bacteria that are resistant to penicillin have greater chance of surviving and passing on the gene for resistance to the next generation.

   M The staphylococcus aureus population has evolved over time.

Refer to the following information for questions 9 and 10.

In 2018, scientists discovered that fluoxetine, a key component of some common antidepressants, induced antibiotic resistance. For some antibiotics, the resistance was greater by up to 50 million-fold. They also noted that the higher the concentration of fluoxetine the bacteria were exposed to, the greater the mutation rate of bacteria was over time. Fluoxetine's presence in the environment is well documented. Approximately, 11% of fluoxetine in medication is not metabolised and passes though the body unchanged.

Use your understanding of the interaction between science and society to answer questions 9 and 10.

9. Identify the statement below that is **not** a limitation of this study's conclusion.

   J It is unclear how fluoxetine affects the native gut microbiome.

   K Does fluoxetine have the same effect on all species of bacteria?

   L The sales of antidepressants containing fluoxetine could decrease as a result of this study.

   M The study was completed in vitro (outside the human body); would the findings be replicated in vivo (inside a human body)?

   In a separate study conducted in 2016, it was estimated that superbugs will be killing 50 million people by 2050.

10. Identify the statement below that is most likely to help reduce the development and/or spread of antibiotic resistance

    J Using last resort antibiotics in the livestock industry.

    K An increased popularity in tourism packages for cosmetic surgeries in developing countries with large populations.

    L The use of antibiotics for viral infections.

    M The careful use of last resort antibiotics for humans with multi-resistant bacterial infections.

11. In 1820, fluffy field mice from England were introduced onto an island off Scotland that already had a population of another species of field mice, the sodden field mouse. In 1820, both species of mice had similar body sizes and fed on similar diets. By 1990, the body sizes of the two species on the island had changed so that the fluffy field mice were smaller and the sodden mice were larger. This situation was most likely a result of which of the following?

    J Sexual reproduction in isolation.

    K Pre-zygotic isolation of individuals.

    L Competition–leading to exclusion, and natural selection.

    M Different mutation rates between the two species.

    Use the following information to answer Questions 12 and 13.

    The woodland strawberry (*Fragaria vesca*) has a very small genome of just 206 million base pairs. *F. vesca* is a relative of apples and peaches and is an ancestor of the garden.

12. The genome of *F. vesca*:

    J is comprised of all the genes of *F. vesca*.

    K includes all the proteins made by *F. vesca*

    L is the same as the genome of the peach.

    M is only found in the stem cells of woodland strawberries.

13. Offspring resulting from the sexual reproduction of *F. vesca* would be expected to:

    J grow delicious strawberries all year long.

    K receive half their genome from the female parent.

    L have half the DNA encoded by Adenine and the other half by Thymine.

    M have all 206 million base pairs translated.

14. Genetic diseases can be screened due to the advancements made in DNA technology. Genetic screening results can influence peoples' decision to have children or not.

    The decision not to have children based on genetic results:

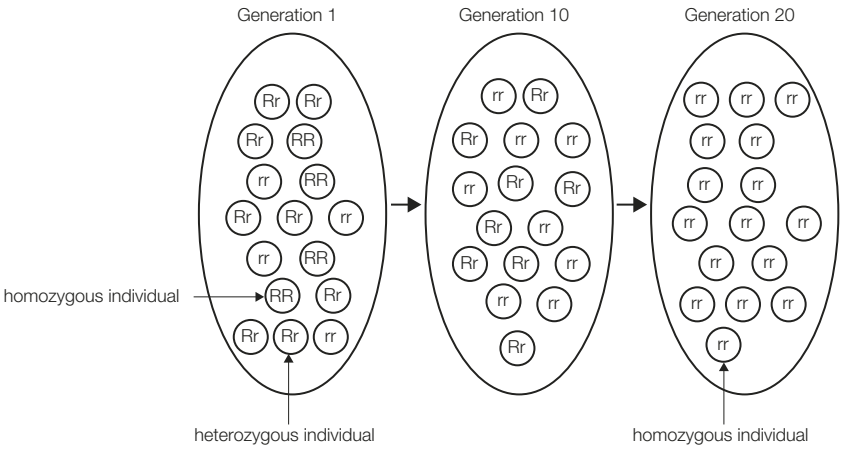
    J will impact future human evolution by eliminating alleles that are not passed on.

    K will impact future human evolution by increasing variation in the human population.

    L will impact future human evolution by altering the frequency of an allele.

    M will not have any impact on the gene pool.

15. *Refer to the diagram below showing the gene pool of a population over 20 generations.*



Over the 20 generations:

J there is an increase in genetic diversity.

K new alleles were introduced that were advantageous.

L there was a selective advantage for individuals with the genotype RR.

M the diversity of the gene pool decreased.

Free response questions

1. Describe how mutations in gametes can increase variation in the offspring of individuals.

2. Briefly outline the ways in which sexually reproducing species introduce variation into their offspring.

3. Natural selection is one of the main driving forces for evolution. Various factors can act to provide 'selective pressure' on individuals in a population.

   a) Name three abiotic factors which can exert such selective pressure.

   b) Name the three biotic factors which also can exert such selective pressure.

   c) Explain why not all individuals in a population have the same chances of surviving such selective pressure giving an example to illustrate your answer.

4. Describe the advantage to a species in having only some individuals in the population reach reproductive age.

5. Describe possible effects of each of the following in changing the gene pool of a population:
   a) non-random mating

   b) a favourable mutation

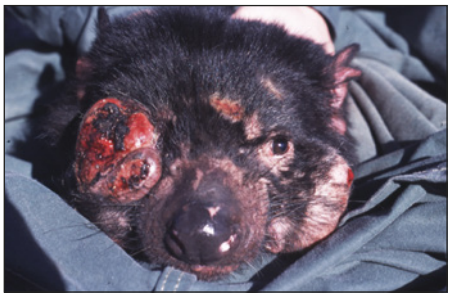
   c) continuous gene flow from populations of the same species in overlapping zones

   d) genetic drift leading to a bottleneck effect

6. Genetic variation in a population is essential for the forces of natural selection to act in shaping the evolution of the population.
   a) Explain the following statement: 'variation provides the potential for natural selection to act'.

   b) Explain why species that reproduce sexually might have a better chance of surviving environmental change compared to a species that reproduces by asexual means.

7. The Tasmanian devil (*see Figure*) population on mainland Tasmania is at severe risk of being wiped out by Devil facial tumour disease (DFTD) that is a type of cancer that can be transmitted between individuals by physical contact (e.g. biting). One of the contributing factors appears to be linked to reduced diversity in the major histo-compatibility complex (MHC) set of genes which are involved in the immune response.



   a) Suggest likely factors that might have contributed to this reduced diversity in the MHC genes.

   b) Explain how this reduced diversity may impact on natural selection and how this has led to the species becoming classified as endangered.

8. 'The amount of gene flow between populations is an important factor in the accumulation of differences between the populations'. Explain the meaning of the above statement using an example to illustrate your answer.

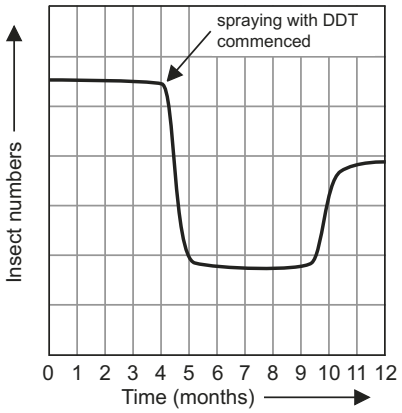
9. Use the example given earlier in the chapter regarding the peppered moth (*Biston betularia*) , to answer the questions that follow:

   a) Name the selective pressure driving changes in the gene pool.

   b) Point out the likely changes to the frequencies of alleles related to moth colour during the Industrial Revolution.

10. Refer to the graph of a treatment used to control the numbers of a particular crop-insect pest by spraying with DDT. Spraying continued at regular intervals after the five-month period.

   a) Describe the pattern of results as indicated by the data.



   b) Explain the pattern of results with regards to insect numbers from 3-12 months.

   c) Describe how the data suggests using a spray such as this has limitations.

11. Antibiotic resistance is one of the biggest threats to global health. Two of the most worrying strains are methicillin-resistant *Staph. aureus* and multi-drug resistant strains of *E. coli*. Much of this problem has been exacerbated (made worse) by either misuse or over-prescription of antibiotics by humans.

   a) Bacteria have a short generation time. Suggest how this might impact on the effects of natural selection on bacteria as a result of the use of antibiotics by humans.

   b) Briefly explain the role of natural selection in giving rise to strains of bacteria that are resistant to antibiotics.

   c) Relate each of the following practices by humans to possible increases in antibiotic resistance:

- Taking antibiotics for viral infections (Note: viruses are not destroyed by antibiotics).

- The overuse of antibiotics to treat animals in the agricultural industry.

- Not finishing a course of prescribed antibiotics.

Science as a Human Endeavour 4.4 - Antibiotics

Antibiotics are drugs that are used to kill harmful bacteria that have entered the body. Some antibiotics prevent bacteria from making new cell walls which renders them incapable of dividing by binary fission to form daughter cells e.g. penicillin that is used to treat tonsillitis.

The first antibiotics were developed in the early 1940s and the subsequent global use of them revolutionised medicine. Today antibiotics are used to treat patients with life-threatening diseases like pneumonia, tuberculosis and cystic fibrosis as well as ailments that include ear and urinary tract infections, appendicitis and skin conditions like psoriasis (a red scaly rash).

The effectiveness and ease of access of antibiotics, particularly in Western countries, has led to over-use of them. Over-using antibiotics is a selection pressure that leads to the emergence (evolution) of antibiotic-resistant bacteria. These cannot be killed using existing antibiotics and thus the disease or condition they cause becomes more difficult (or impossible) to treat.

You may need to refer to the online resources below to answer the questions that follow.

1. The use of antibiotics in countries like Australia is influenced by cultural considerations. We all expect to be able to visit a doctor when sick and be prescribed an antibiotic if doing so will help us to recover. Discuss some of the cultural and ethical considerations associated with the ongoing use (and over-use) of antibiotics.

2. There is now real international concern about the threat antibiotic-resistant bacteria pose. According to a United Nations report published in late 2016 antibiotic-resistant bacteria now claim 700, 000 lives a year worldwide. Discuss how international communication and collaboration is required to help combat the spread of antibiotic resistant superbugs.

Helpful online resources

TED-Ed: What causes antibiotic resistance? - Kevin Wu
<https://www.youtube.com/watch?v=znnp-lvj2ek>

TED-Ed: How can we solve the antibiotic resistance crisis? - Gerry Wright
https://www.youtube.com/watch?v=ZvhFeGEDFC8

Chapter 4.5 Evolutionary change

Science Understanding

Evolutionary changes are affected by other factors besides selection, including:

- sexual reproduction
- genetic drift.

Speciation may result from an accumulation of genetic changes influenced by different selection pressures or genetic drift in geographically isolated populations.

- Describe the process of allopatric speciation.

The process of evolution suggests the following:

- all life forms have evolved from a single, simple common ancestor (LUCA)
- species change through time
- evolution in a species can be recognised by the changing frequency of alleles in a population.

Sexual reproduction

It has been well established (Chapters 2.7, 4.4) that organisms that reproduce by sexual means produce offspring that have greater variation compared with those that reproduce by asexual means.

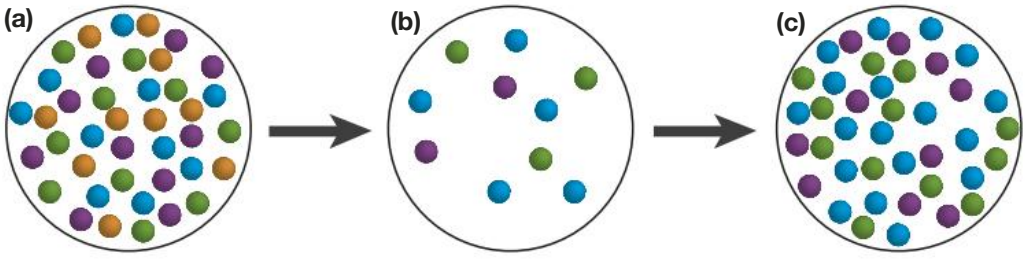
Chapter 4.4 introduced the concept of natural selection, where variation was seen to provide the potential for natural selection to act. Sexual reproduction is then seen as a process that facilitates evolution, compared to asexual reproduction.

Evolution in **asexually reproducing species** tends to happen quickly if there is a **favourable mutation.** An example of this can be seen with the recent rapid rise in the number of species of bacteria resistant to antibiotics.

Genetic drift

This concept was introduced in Chapter 4.4 where it was shown to be a mechanism in which allele frequencies of a population may **change over generations due to chance** (i.e. mutations occurring randomly). Unlike natural selection, **genetic drift** is not driven by the benefit or harm caused by the allele.

The **bottleneck effect** is an example of genetic drift that occurs when the size of a population is reduced dramatically, for example with the Mallee Emu-wren discussed in Chapter 4.4. Here it is proposed that bushfires have reduced the population size, randomly killing individuals and leaving behind a smaller, less genetically diverse population. The allele frequencies in this reduced group may be very different to those of the original population. Refer to the model using coloured marbles shown in *Figure 451 (a), (b) and (c)*.



Original population

Allele	Number	Percentage
●	10	25%
●	10	25%
●	10	25%
●	10	25%
Total	40	100%

New surviving population

Allele	Number	Percentage
●	5	50%
●	0	0
●	2	20%
●	3	30%
Total	10	100%

New population

Allele	Number	Percentage
●	18	45%
●	0	0
●	10	25%
●	12	30%
Total	40	100%

Figure 451 (a), (b) and (c) An illustration of the bottleneck effect leading to reduced genetic diversity

Figure 451(a) represents the original population with the number of marbles and their allele frequencies as shown. After a random sampling event, such as a bushfire, the remaining individuals are represented in *Figure 451(b)*. This type of event is an example of the bottleneck effect. Note the reduced population size and changed frequencies (e.g absence of yellow allele). When the individuals in (b) interbreed and have offspring, the new population is indicated in *Figure 451(c)*.

Note the dramatic **changes seen in the allele frequencies** caused by a chance or random event. The genetic composition in (c) is now the genetic composition of the entire population.

The **founder effect** is another example of genetic drift and is observed when a small group of individuals may separate or move away from the original population (e.g. to live on an island). These new founding populations may be **very different in their genotype** to the original population. Refer to *Figure 452*. There is reference to the founder effect in the Helpful Online Resource on genetic drift and the bottleneck effect in Chapter 4.4.

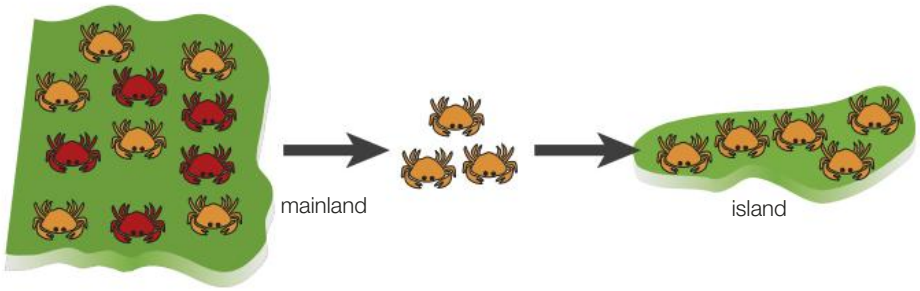


Figure 452 An illustration of the founder effect

Along with natural selection, genetic drift is a factor in giving rise to changing **allele frequencies** in populations and is an important element that influences evolutionary change.

Speciation

Speciation is the process that gives rise to new species. This was the mechanism used to explain the appearance of several finch species from a common ancestor on the Galapagos Islands (refer to Chapter 4.4).

The birds, described by Charles Darwin, had many structural similarities but did have beaks that were different in shape and size that could be related to the food source on each island.

Refer to *Figure 453* showing a group of Darwin's finches from the collection of the *Charles Darwin Research Station* on the Galapagos Islands. The different shaped beaks, ideally suited to different feeding habits, are clearly visible.

Figure 453 Examples of Darwin's finches.

Figure 454 summarises a suggested sequence of changes involved in the formation of two new species from an original population. The isolating mechanisms will be explored in greater depth later in this chapter.

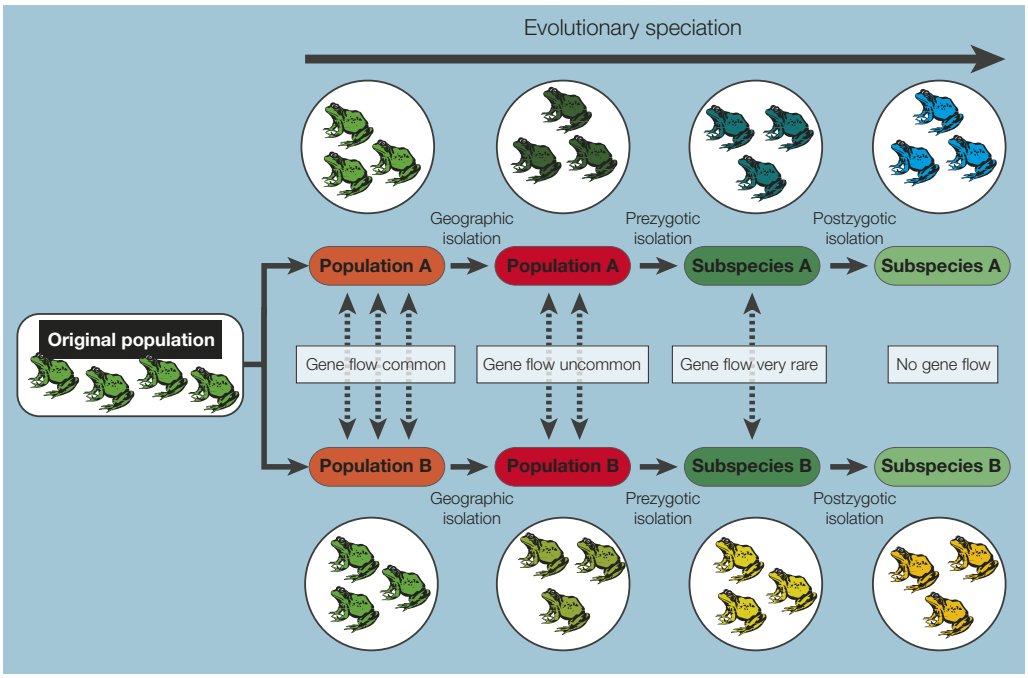


Figure 454 The process of speciation

The evolution of the modern day horse (*Equus)* has occurred over about 50 million years and is thought to have given rise to around 138 different species, seven of which still exist today. A brief summary of these changes is shown in *Figure 455*.

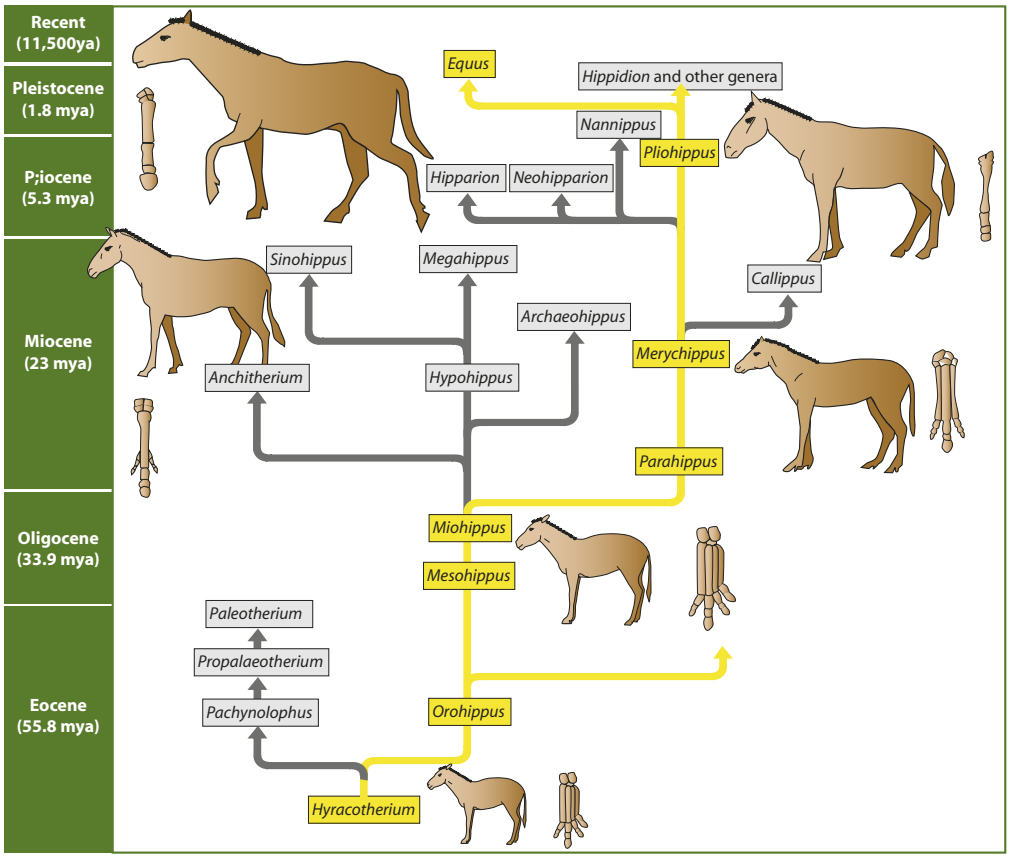


Figure 455 The evolution of the 'modern day' horse

Allopatric speciation

Allopatric speciation involves members of the original population being separated by a geographical barrier. In most cases, the factor which initiates the evolution of these separated populations into different species is **geographical isolation**. This is where some type of geographical barrier (e.g. the formation of an ocean, lake, mountain range, river, desert) separates populations in such a way that **gene flow** between them is prevented.

If the environments the separated populations end up occupying have different biotic or abiotic factors, it is likely that 'the forces of natural selection' or other **selective factors will act differently** in each new location. Referring to the finches on the Galapagos Islands, it was observed that different islands had different food sources and that the finches with the beak shapes, that were best adapted, were more likely to find food, survive and reproduce. Refer to *Figure 456* showing speciation of finches on the Galapagos Islands.

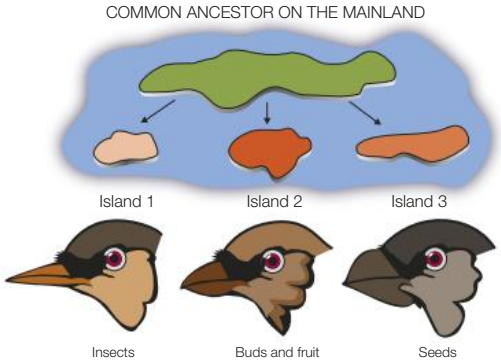


Figure 456 Allopatric speciation in 'Darwins's finches'

As a result of the different natural selective pressures, **genetic differences may begin to accumulate** in the isolated populations. If the gene pools of the two populations are separated and no gene flow occurs between them for a long enough period of time, then significant differences in the gene pool can occur. At first, what was originally geographical isolation may evolve to **reproductive isolation**. This was discussed as a reproductive isolating mechanism in Chapter 4.3. If this situation arises between separated populations then **speciation has occurred by divergent evolution.** *Figure 457* summarises allopatric speciation using an example of frogs in Australia.

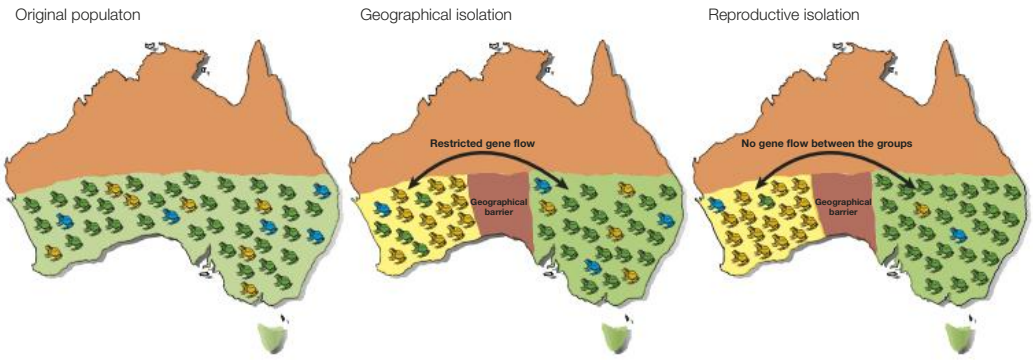


Figure 457 Allopatric speciation in Australian frogs

Refer to the diagram and the summary steps below:

- There is evidence that suggests that in the past the conditions across the Nullarbor Plain were much cooler and wetter and that the frogs were once a part of a single original population.
- As Australia drifted north, the climate changed and the area became hotter and drier. As a result, a desert gradually formed through the region, which effectively isolated the frogs into two groups.
- There were different habitats and selective pressures between the frogs in the west compared to the east. Differences began to accumulate in the separate gene pools.
- Over the long period of geographical isolation, the groups now differ in appearance and mating behaviours. They are effectively reproductively isolated into two different species meaning speciation has occurred by **divergent evolution**.

Another interesting case of evolution can be seen with the Australian marsupials. Until about 250 million years ago, the continents on Earth were joined in one huge landmass called **Pangaea**. This 'super-continent' began to break into two around 200 million years ago the southern part of which was called **Gondwana**. Over 150 million years ago, Gondwana itself began to fragment into the continents of Africa, South America, India, Antarctica and Australia. Around 40 million years ago Australia separated from Antarctica and has remained isolated from the other continents ever since. This idea is supported by geological and fossil evidence and the fact that satellite tracking has confirmed that the continents are still slowly moving. Refer to *Figure 458* showing the movement and separation of the continents over hundreds of millions of years.

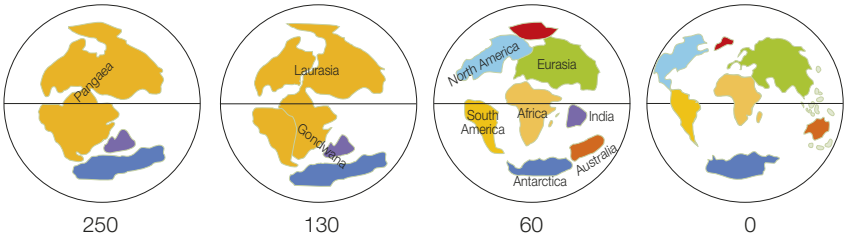


Figure 458 The movement of the continents

The **marsupial** order of mammals consists of approximately 240 species including wombats, kangaroos, koalas and wallabies, most of which are found exclusively in Australia. It is accepted by many scientists that marsupials originated in North America and migrated to land masses including Australia. When Pangaea and subsequently Gondwana began to break apart, ancestral populations of marsupials survived and underwent **adaptive radiation** (divergent evolution of related species from a common ancestor) in Australia. Refer to *Figure 459* illustrating several Australian marsupials. The speciation of marsupials in Australia was facilitated by the fact that there have never been any large Australian placental land mammal predators and the fact that dingoes only arrived with the 'sailing hunter-gathers' from Indonesia about 4000 years ago.

Figure 459 (a) A bilby (b) A numbat and (c) A yellow footed rock wallaby

Sympatric speciation

Sympatric speciation is where one population gives rise to two or more new species while still inhabiting the same region (**there is no geographical isolation**). The same pre-requisites for any form of speciation still apply, meaning gene flow needs to be prevented or at least reduced and, ultimately, reproductive isolation must arise.

There are several different ways in which this can occur.

Occupying different micro-habitats

Sometimes, particular members of one population tend to occupy a specific **niche** or **microhabitat**. One case that has been observed from around the 1860s is that of the apple maggot fruit fly. Hawthorn trees grow throughout North America and produce a small fruit which is eaten by fly larvae. In 1864 apples were growing in the same areas as the Hawthorn trees and it was soon noticed that unknown maggots started to feed on apples.

What was happening was that groups of the original population that fed on Hawthorn fruits were now feeding almost exclusively on Apple fruits. This feeding habit set up distinct micro-habitats and reduced gene flow.

As a result, the following observations are made;

- Attachment or feeding on different fruits acts as a strong barrier to gene flow between the apple maggot fly and the Hawthorn maggot fly.
- There is only a 4-6% hybridisation rate between the two groups.
- There are noticeable genetic differences between the two groups of flies.

Refer to *Figure 4510* showing an apple maggot fly.

Figure 4510 An apple maggot fly

Helpful online resources

Amoeba Sisters: Speciation

<https://www.youtube.com/watch?v=udZUaNKXbJA>

Polyploidy

Polyploidy is a condition where organisms possess more than two sets of chromosomes. This is a common condition in many plants as well as certain groups of fish and amphibians. Refer to *figure 4511*.

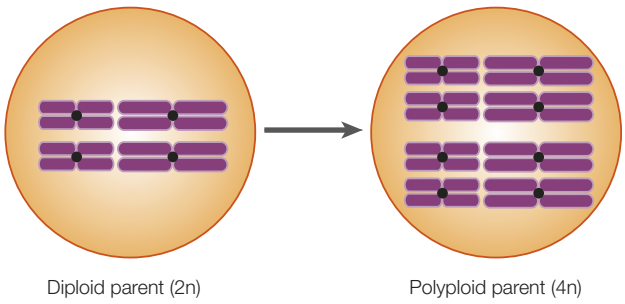


Figure 4511 The chromosomes of diploid and polyploid individuals

Polyploidy happens as a result of a malfunction during a process such as meiosis where chromosomes fail to separate properly (non-disjunction). This is an example of instantaneous speciation because the **polyploid organism cannot interbreed** with an organism with the normal diploid number so gene flow is immediately stopped. Polyploidy is thought to have played a major role in the evolution of flowering plants, most of which are polyploid.

Helpful online resources

Alex Lee: Polyploidy leads to speciation (IB Biology)

<https://www.youtube.com/watch?v=odL631acMC0>

SciShow: Why Do Strawberries Have Eight Copies of Their Genes

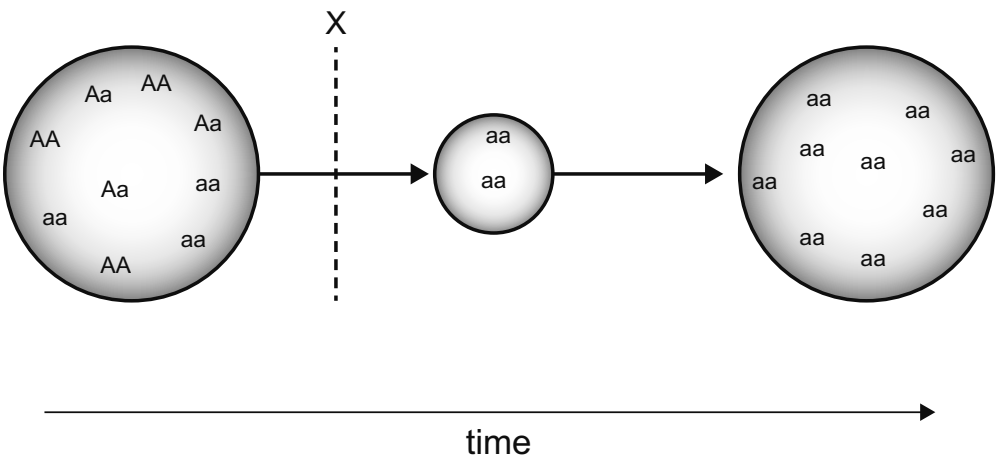
<https://www.youtube.com/watch?v=exA6-wrqOGQ>

4.5 Review questions

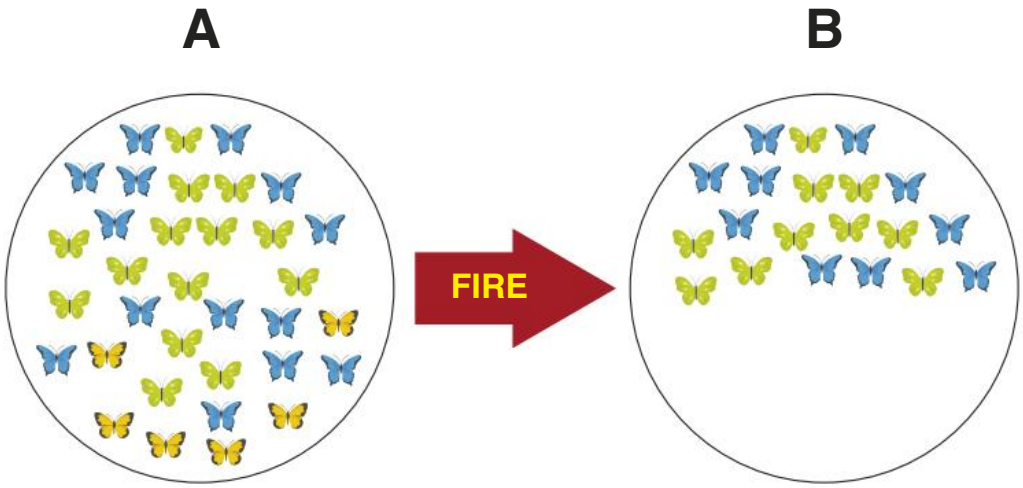
Multiple choice questions

1. The theory of evolution was proposed by Charles Darwin and Alfred Wallace in the late 1850s. The theory was formulated with help of an observation made by Darwin, which was:
   - J that evolution occurs in an individual's lifetime.
   - K populations exhibit inherited variation.
   - L individuals lose traits that are not being used.
   - M variation occurs in animals by mutation only.
2. Which of the following is not a cause of the bottleneck effect?
   - J Too much genetic variability.
   - K Too much hunting.
   - L Floods.
   - M Habitat destruction.
3. Genetic drift is a:
   - J decrease in gene frequency in the gene pool due to differential survival.
   - K gradual decrease in gene frequency due to disadvantageous genes in a population.
   - L a change in the makeup of a population's collection of genes due to a random event.
   - M a change in variation in the gene pool based on the fitness of alleles.
4. Which of the following options is least likely to result in evolution through allopatric speciation?
   - J An island range consisting of 5 islands forms from a single land mass.
   - K A mountain range rises due to tectonic plate movement in the middle of a population of wild horses.
   - L A cave collapses completely separating a population of beetles.
   - M A trench forms between a population of birds.
5. Identify the example of sympatric speciation.
   - J The ability of different breeds of dogs living in different parts of the world being able to produce fertlile offspring.
   - K The production of a sterile mule from a horse and donkey interbreeding.
   - L Two plant species hybridise, doubling chromosome number, resulting in the creation of a third species.
   - M Three species evolve due to adaptation to different habitats and reproductive isolation.

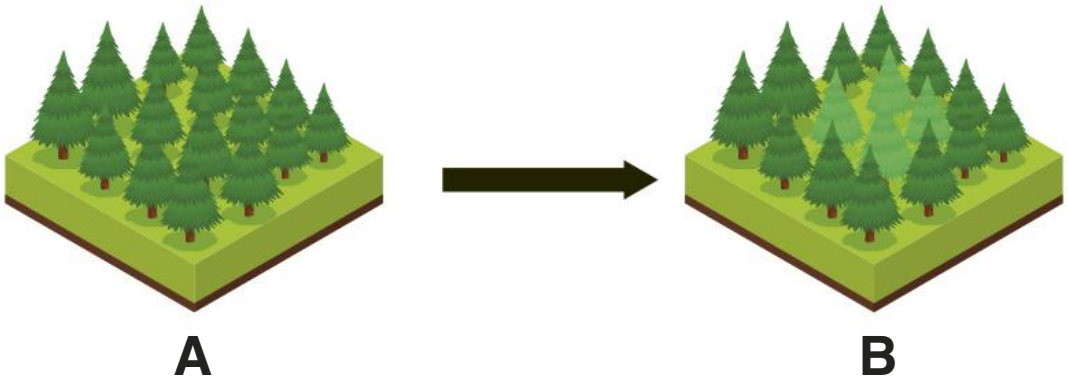
Refer to the diagram below which illustrates a population's change in gene frequency for a particular trait over two generations (from left to right), to answer questions 6 and 7.



6. Identify the event that has occurred at X.
   J Bottleneck effect.
   K Allopatric speciation.
   L Founder effect.
   M Adaptive radiation.
7. Identify the cause of the event at X.
   J increase in gene flow.
   K a bushfire.
   L random generation of alleles.
   M migration.
8. *Refer to the diagram below to answer the following question:*



   The event occurring from A to B is most likely an example of:
   J Founder effect.
   K Speciation.
   L Natural selection.
   M Genetic drift.
9. *Refer to the diagram below to answer the following question.*



   Which of the following options best explains the cause of the event seen from A to B?
   J The geographical separation of the two species.
   K A prevention of gene flow due to a malfunction in meiosis.
   L Natural selection acting on the variation in a species.
   M The evolution of a species caused by the bottleneck effect.

10. Tristan da Cunha is an island in the Atlantic Ocean where no natural disasters have occurred since being colonised by a few hundred British individuals in the early 1800s. The gene frequency for Retinitis pigmentosa (RP) is four times greater than the population it was colonised from. RP causes progressive blindness in humans and is an autosomal recessive trait.

    Identify the process responsible for this change in gene frequency.

    J Speciation.

    K Bottleneck effect.

    L Natural selection.

    M Founder effect.

11. Select the option representing the prevention of gene flow.

    J The production of sterile offspring between two populations.

    K Populations breed at different times of the year.

    L Different numbers of chromosomes between individuals of two populations.

    M All of the above.

12. Molecular clocks are a tool that biologists can use to determine the point in time where:

    J species arrive in an ecosystem through succession.

    K species experienced genetic drift.

    L a specific gene frequency increases in the gene pool for a species.

    M species diverged through speciation.

13. Identify the correct statement regarding genetic drift.

    J Large populations lose genetic diversity more quickly than small populations as a result of genetic drift.

    K Genetic drift can result in individuals breeding with close relatives.

    L Disadvantageous genes can never increase in frequency as a result of genetic drift.

    M Small populations have a lower risk of extinction following a genetic drift event.

14. It has been suggested that the human population was almost completely wiped out around 75,000 years ago. This is called the 'Toba catastrophe theory'. It is based on the belief that a 10-year global volcanic winter was caused by the eruption of a super-volcano near Lake Toba in Indonesia. It is theorised that the human population was decimated, with approximately 40 breeding pairs surviving to repopulate.

    Assuming the 'Toba catastrophe theory' is true, the repopulation of humans following the eruption would be an example of the:

    J founder effect.

    K boomerang effect.

    L bottleneck effect.

    M testing effect.

15. The 2019-20 Black Summer bushfires killed a very large number of Australian flora and fauna. It is estimated that 3 billion animals were impacted by the fires, including the death of 64,000 koalas. Since the bushfires, many species have established themselves in the community. The mix of species is not he same as it was prior to the bushfires.

    Which of the following processes would explain the impact of the bushfires on the koala population's gene pool?

    J Secondary succession.

    K Natural selection.

    L Primary succession.

    M Genetic drift.

Free response questions

1. Explain the importance of each of the following processes in the evolution of a species.
   a) Meiosis

   b) Mutation

   c) Natural selection

2. The 'bottleneck effect' and the 'founder effect' are both types of genetic drift that influence evolution.
   a) Describe one similarity between these effects.

   b) Describe one difference between these effects.

   c) Explain how *either* of these effects may give rise to reduced genetic diversity in a population.

3. In the natural world it is often difficult to establish whether populations of very similar organisms are members of one species or a different species.
   a) State reasons why scientists may find it difficult to determine if groups belong to the same or different species.

   b) Describe the circumstances where the term "sub-species" could be used to describe two separate groups of closely related organisms.

4. 'Geographic isolation is an important step in most cases of speciation'. Briefly summarise the steps that lead to speciation, using an example, to support the above statement.

5. State why it is necessary for the gene pools of populations to be separated for the process of speciation to occur.

6. 'Allopatric speciation was involved in the evolution of Australian marsupials'. Discuss support for the above statement using your knowledge of the past history of the Earth and the location of its continents.

7. Compare the effects of genetic drift and natural selection on the process of evolution.

8. Two similar groups of tortoises were found on islands that were separated by about 3 km of ocean. One of the groups had necks that were significantly longer than the other, but apart from this, they were very similar in appearance. It is highly likely that the two groups evolved from a common ancestor.
   a) State one possible explanation for one of the populations having longer necks.

   b) Describe the evidence that would be required to determine if these two groups belong to the same or different species.

   c) Outline likely differences between the gene pools of the two groups.

9. Explain why the frequency of alleles of genes in populations will change in those groups that are evolving.

10. Refer to the example in this chapter regarding the apple and Hawthorn maggot fly to answer the questions that follow:
    a) Outline how this is a form of sympatric speciation.

    b) Identify evidence in favour of the two populations being regarded as a separate species.

    c) Identify evidence in favour of the two populations being regarded as the same species.

11. Compare the roles of geographic isolation and reproductive isolation in the process of speciation.

Chapter 4.6 Convergent and divergent evolution

Science Understanding

Similar selection pressures on unrelated species may lead to convergent evolution.

- Recognise and give examples of convergent evolution.

Different selection pressures may lead to divergent evolution or adaptive radiation.

- Recognise and give examples of divergent evolution and adaptive radiation.

Succession is the gradual change in the mix of species in an area over time, following a disturbance.

- Describe the processes of primary and secondary succession.

Species or populations that have a reduced genetic diversity have a higher risk of extinction.

- Give examples of species with low genetic diversity.

Convergent evolution

Convergent evolution occurs when different species of organisms develop similar (analogous) features with similar functions. This makes sense when considered in the light of the process of natural selection (Chapter 4.4) where different groups of organisms, often in similar habitats with similar selective pressures, end up with similar structures and/or behaviours to be able to carry out life's processes. In other words, species that have evolved in particular environments in similar ways and evolve similar features are said to have undergone convergent evolution.

Refer to *Figure 461* indicating the evolution of distinct flowering plants with leaves termed **sclerophyll** (sclero- meaning hard, and -phyll meaning leaf); a Eucalypt and Banksia. These leaves evolve in species living in sclerophyll woodlands in response to dry, harsh conditions and are often exposed to fire events.

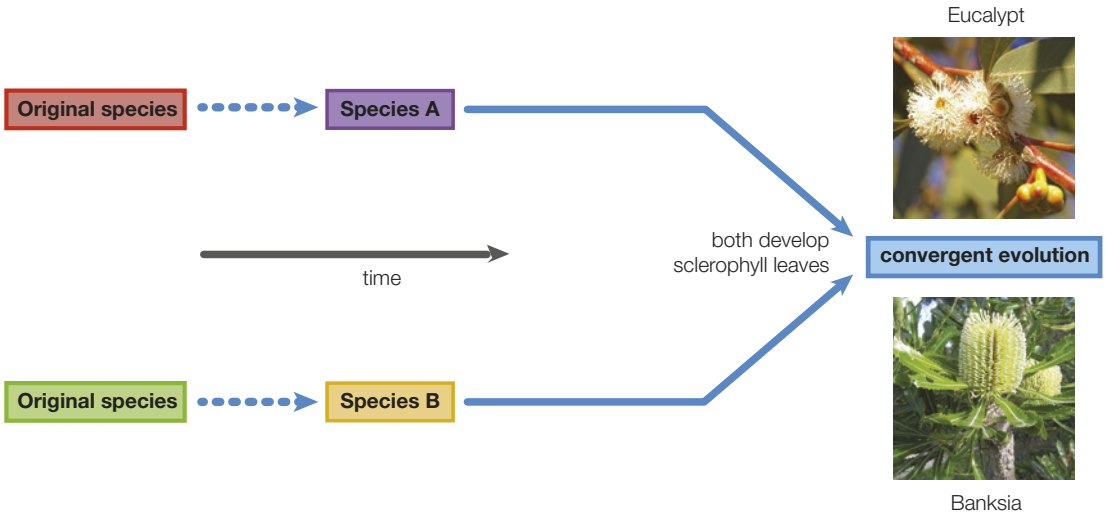


Figure 461 Convergent evolution in leaf structures

Analogous features are those that have evolved separately in different lines of evolution. They effectively serve the same function in different species but have evolved separately. Convergent evolution has occurred when such features **evolve independently in unrelated groups** or separate species.

Wings and eyes are two of the most stunning products of evolution. These two features have evolved many times in different species throughout evolutionary history.

Wings

The ancestors of birds, bats and butterflies (which are quite unrelated) have all evolved wings for flight independently of each other.

Eyes

The emergence of eyes in a variety of quite different groups of organisms is another good example of convergent evolution. The most important gene in the evolution of the eye is an ancestral master gene 'Pax6' that was originally probably responsible for the development of collections of simple light-sensitive cells. Like many other master genes, the Pax6 gene is found across an incredibly diverse set of organisms ranging from birds to bees, squid and humans. This fact indicates that the Pax6 gene was probably part of the genome of a very early common ancestor of animals that lived approximately 500 million years ago.

Cephalopods, which include squid, cuttlefish and the octopus have evolved a 'camera eye' that has the same features as the vertebrate camera eye, but arose by convergent evolution over some 500 million years. Refer to *Figure 462 (a) and (b).*

Figure 462 (a) A squid eye

Figure 462 (b) A human eye

A recent study has uncovered a likely source of variation from the original 'Pax6' gene. In Chapter 1.2, RNA splicing was discussed as a process in which the original mRNA strand synthesised during transcription is 'cut-and-re-joined' in a way that only certain sections are translated to produce the required polypeptide while others are omitted or not translated. It appears that Pax6 RNA splicing has been a process that has occurred throughout evolution, resulting in the development of various sophisticated eyes many times.

Helpful online resources

TED-Ed: The evolution of the human eye - Joshua Harvey
<https://www.youtube.com/watch?v=qrKZBh8BL_U>

Figure 463 shows a range of animals where convergent evolution has occurred, giving rise to analogous features.

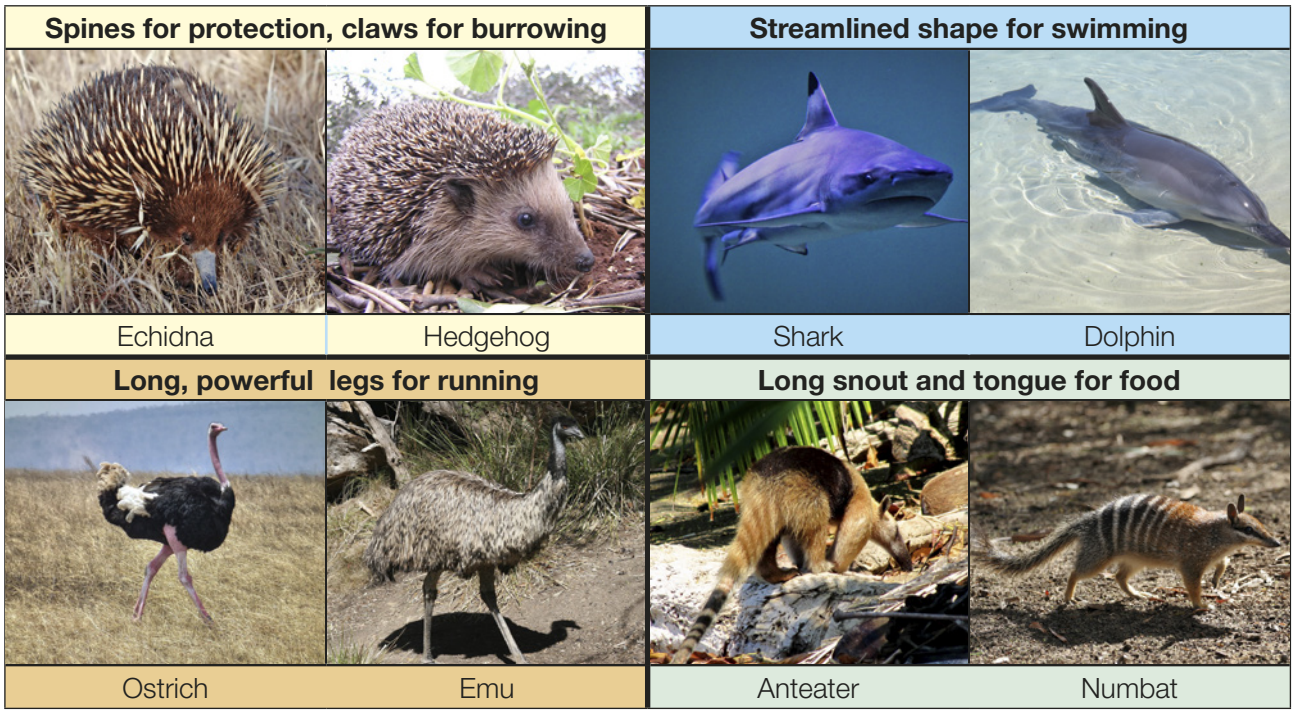


Figure 463 Examples of convergent evolution

Divergent evolution

All of the previous chapters in this topic have introduced and built on the principles underlying evolution and forces driving change over time. In contrast to convergent evolution, **divergent evolution** is evolution of species from a common ancestor; each group separating from others by speciation and accumulating differences in their genome by mutations. These groups, as has been noted, **evolved from a common ancestor** but since they have been subjected to **different selective pressures,** there is **no gene flow** and hence are reproductively isolated. Evolution that takes place in this way is known as divergent evolution.

Adaptive radiation is the term that refers to the divergent evolution of related species from a common ancestor; an example of this has been studied in Chapter 4.4 and 4.5 with Darwin's finches in the Galapagos Islands. A common ancestral finch population ended up spreading to the various islands where, under different selective pressures and because of subsequent reduced gene flow, evolved into different species of finch, each with unique adaptations to the food source on each island.

Limbs in such creatures as bats, monkeys, birds, frogs, humans and dolphins have been modified for long periods of time throughout evolutionary history. It appears as if these modifications have occurred from a common ancestral limb, the pentadactyl limb, which has been subjected to the processes of evolution to bring about the highly specialised roles in each vertebrate. Such features with a fundamental similarity based on common ancestor are called **homologous features**. Refer to *Figure 464*.

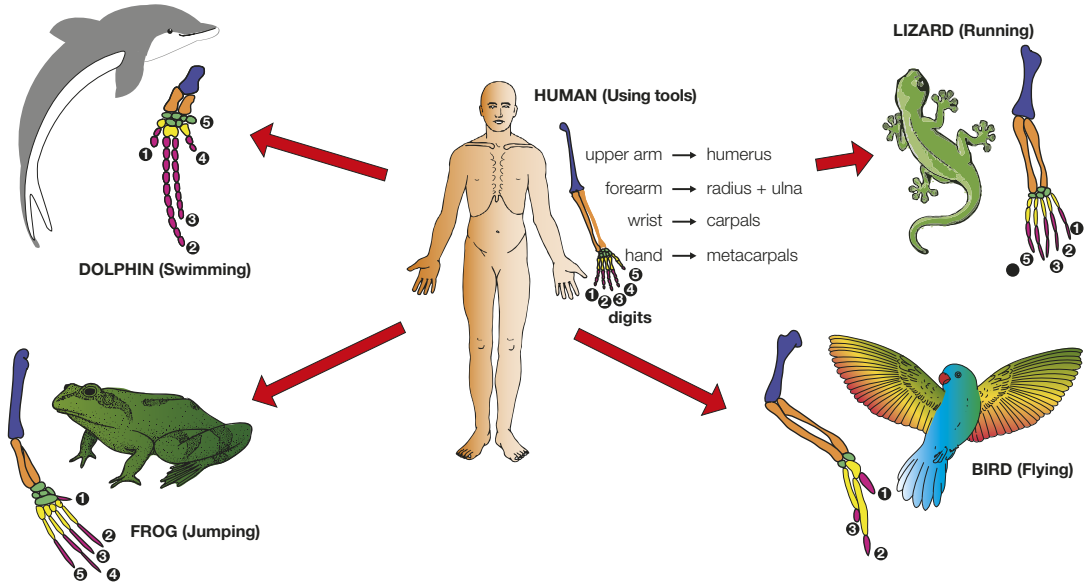


Figure 464 Examples of divergent evolution in animals

Adaptive radiation is the process responsible for the development of the three different groups of **mammals** i.e. **monotremes** (egg-laying), marsupials (young develop in a pouch) and **placentals** (young develop in the female uterus with a placenta).

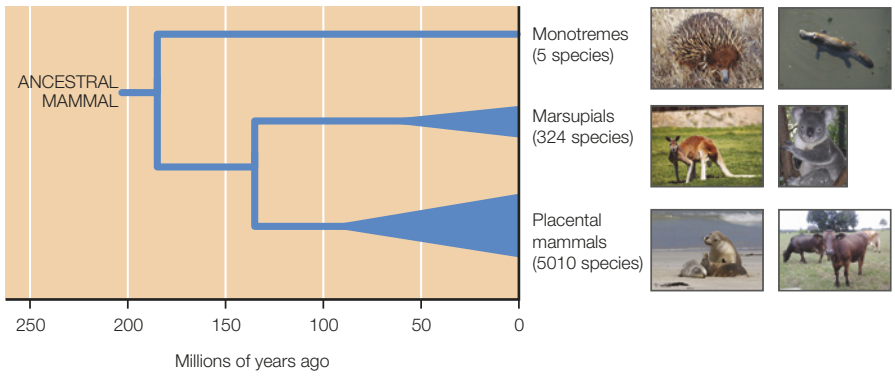


Figure 465 The evolution of mammals

As seen in *Figure 465*, mammals are thought to have evolved from an ancestral mammal about 190 million years ago. After the dinosaurs became extinct, some 65 million years ago, it is believed that a range of new niches become available to the mammals and this, along with the separation of the continents, provided ideal opportunities for evolution to occur.

As previously noted (Chapter 4.5), Australia has very few **endemic** placental mammals, compared to the unique array of marsupial species and several species of monotreme. Refer to *Figure 466* which illustrates the adaptive radiation of marsupials in Australia.

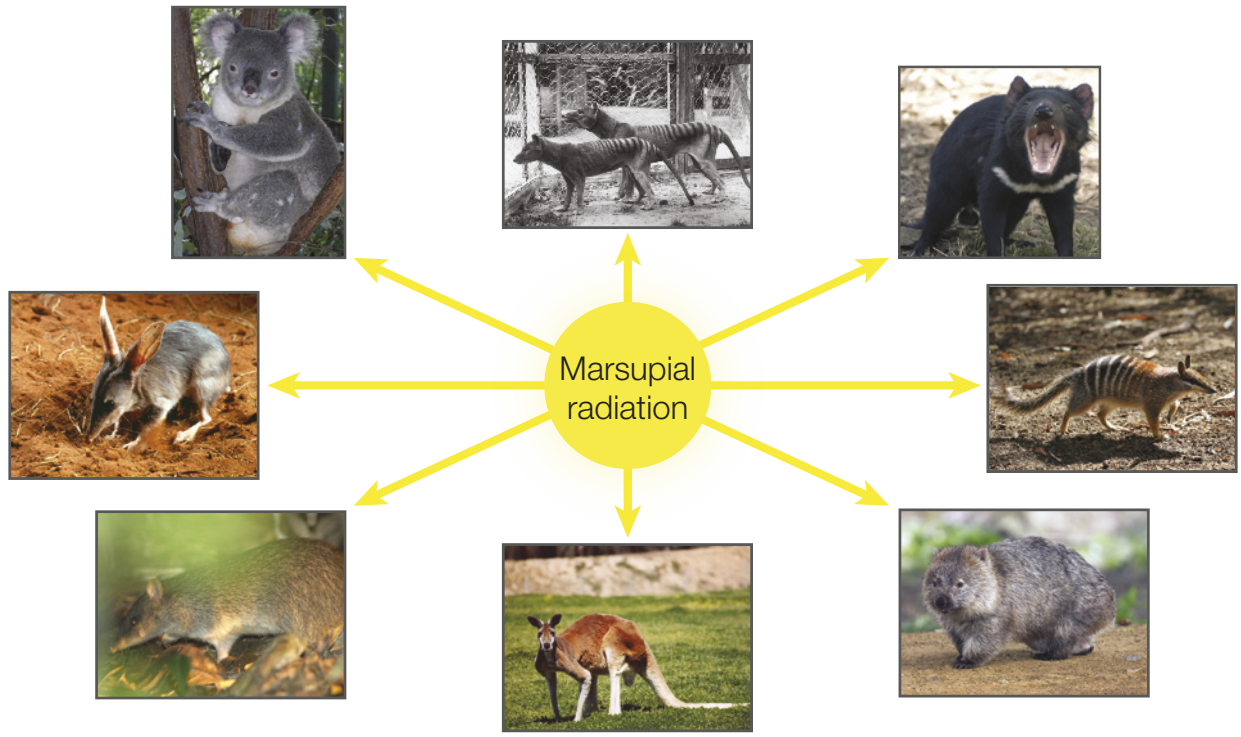


Figure 466 The evolution of marsupials in Australia

Refer to the table below showing a summary comparison of divergent and convergent evolution.

Divergent evolution	Convergent evolution
Species evolved from a relatively recent common ancestor	Species have relatively different common ancestors
Gives rise to homologous structures; species diverge	Gives rise to analogous structures; species converge
Species become more different over time	Species appear to become more similar over time
Species are relatively closely related, as they share a recent common ancestor	Species are less closely related, do not have a recent common ancestor

Helpful online resources

2 Minute Classroom: Convergent Evolution vs Divergent Evolution | Shared Traits Explained
<https://www.youtube.com/watch?v=X-XtZyHcck4>

Succession

The location and composition of ecosystems are influenced by the abiotic and biotic factors that are found in the habitat. Any **change** to these components of the ecosystem can make the conditions **more suitable for other species**, resulting in a change in the make-up of the community and the range (distribution) over which it is found.

Long term change to ecosystems as a result of such changes brought about by the colonisation of new species to the area or natural disasters, may lead to such significant change that the whole ecosystem changes to favour a new mix of species. This type of change is called succession.

Succession is therefore the gradual process by which the species composition of a community changes and is often brought about by the modification of the habitat caused by the organisms that live there.

Below is a list of some ways that **organisms modify the ecosystem** in which they live:

- Providing food or shelter for others e.g. producers absorb and change light energy into chemical energy for use by consumers and and provide food and shelter for animals like birds, spiders and insects.
- Changing the soil structure causing the breakdown of rock or increasing the organic matter in soil.
- Decomposing dead organic material, making nutrients available for other organisms.

Refer to *Figure 467* of lichen. These organisms are often the first species to be established on barren rock after which they secrete acids which start the weathering of rock and thus the gradual formation of soil.

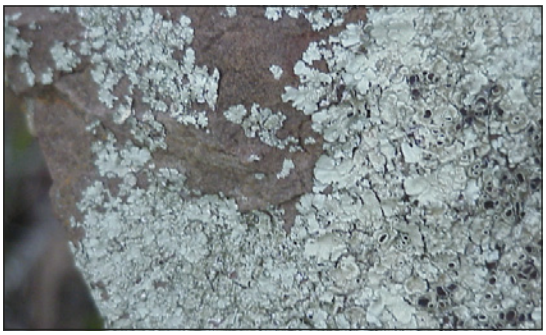


Figure 467 Lichen on bare rock

Figure 468 A glacier and its moraine

Helpful online resources

Oxford Mastering Biology: Animation 19.1 Ecological succession
<https://www.youtube.com/watch?v=IrlvMt6HWIA>

Primary succession

Primary succession usually **starts in a lifeless area**, one that lacks soil, such as bare igneous rock from a volcano or on the rocks left behind (moraine) by the retreat of a glacier or as a result of a decrease in sea level. Refer to *Figure 468* showing a glacier and moraine.

Colonisation effectively begins from an environment that consists of virtually zero living things and provides new habitats and opportunities for organisms to evolve. Species need to be very hardy and possess a variety of adaptations to enable them to survive harsh environments.

A consideration of the typical changes in the community from the coastal sand dunes back to the woodlands enables the study of typical examples of succession in an Australian ecosystem. Refer to *Figure 469* and the following table for more information.

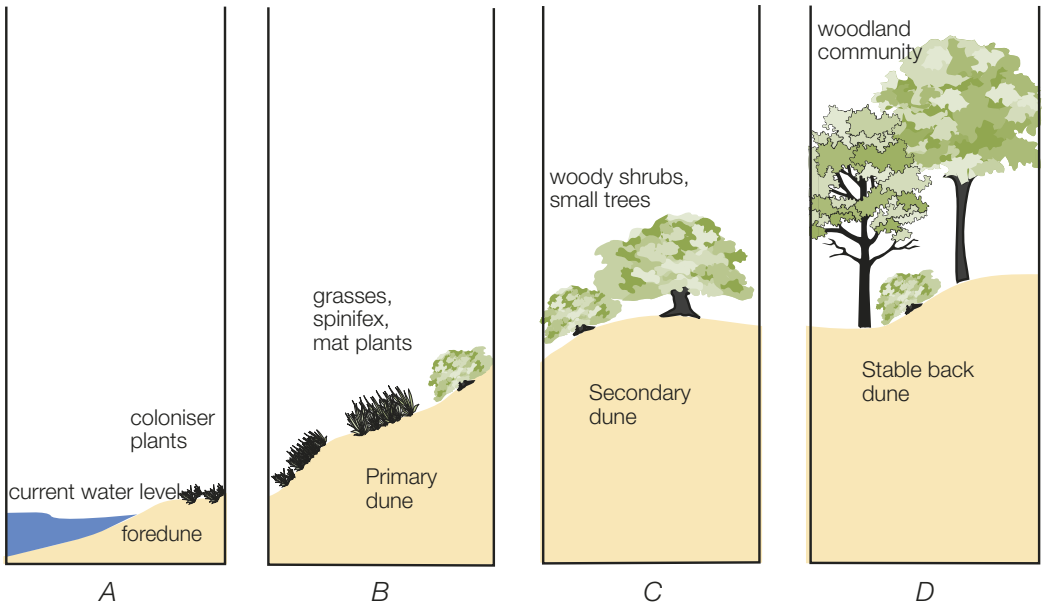


Figure 469 An example of coastal succession

Zone	Abiotic factors	Colonising organisms	Changes occurring to the ecosystem
a	High temperature, low water, low nutrients, high salinity	Spinifex	Spinifex runners trap windblown sand and thus help stabilise dunes
b	As above but beginnings of new micro-habitats with less extremes	Grasses, pig face, small herbaceous plants	Further stabilise dunes, beginning of micro-habitats with more moisture etc
c	Layer of organic material, higher levels of moisture	Insects and other invertebrates; vertebrates like lizards and snakes	Waste material provides nutrients, soil begins to develop
d	Greater soil depth, higher nutrient and good soil structure, organic material, temperatures moderated	Birds, mammals, establishment of a woodland community	Shelter, protection, food sources much more varied

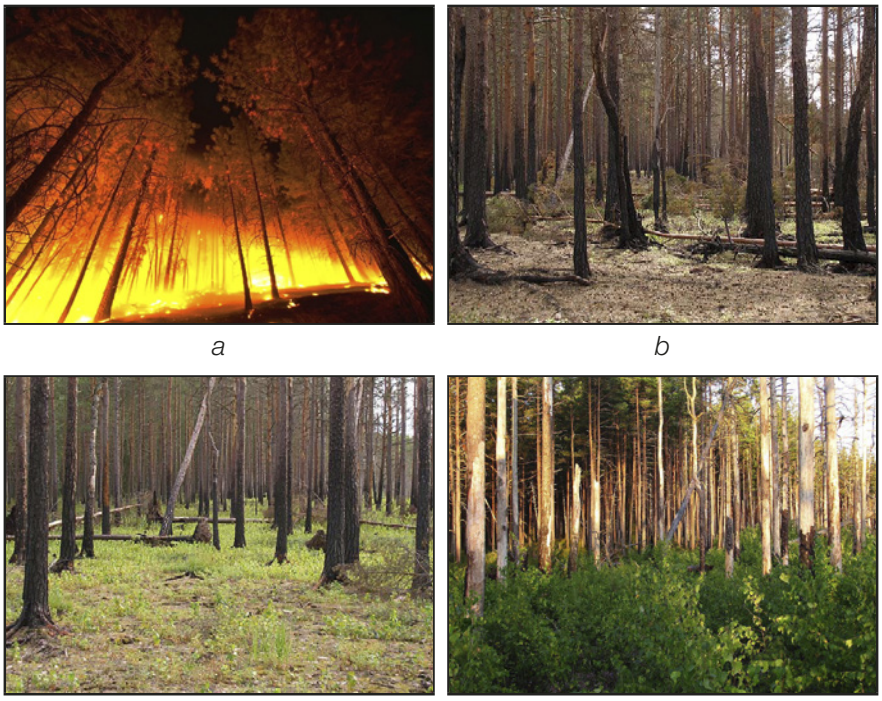
Many ecologists view succession as the result of competition between organisms. As previously discussed, new habitats or niche, provide the opportunity for new populations to evolve; the new areas often present new selective pressures and thus the forces of natural selection begin to operate.

Secondary succession

Succession may also occur in a mature ecosystem if there is a **natural disaster or major human impact,** such as forest clearing. This type of succession is called **secondary succession**.

A good example can be observed in a Eucalypt woodland after a bushfire. The fire stimulates the germination of seeds and growth is usually more rapid than with primary succession owing to the warmth of soils, its high nutrient content and its ability to retain water. As a result, a new mixture of populations of plant and animal species is quickly established. Competition between populations of colonising species and between returning and new species of animals influences the new community and how it compares with the original.

Refer to *Figure 4610 (a), (b), (c) and (d)* showing the images of a forest fire and the recovery of the ecosystem in the years following.



a *b*

c *d*

Figure 4610 (a) A forest fire (a) and recovery after (b) 1 year (b), 2 years (c) and 9 years (d)

Some characteristics of mature or late succession communities and ecosystems are:

- there are usually more species
- the number of heterotrophs tends to increase more than the number of autotrophs
- the recycling of nutrients is more efficient
- the organisms tend to be more specialised

Following succession or environmental change, the **different selective pressures** may lead to divergent evolution or adaptive radiation as species exploit new niches.

Helpful online resources

Amoeba Sisters: Ecological Succession: Nature's Great Grit

<https://www.youtube.com/watch?v=uqEUzgVAF6g>

Species diversity

In Chapter 4.4 the concept of genetic diversity within a species was introduced with particular reference to the health or robustness of the group. The Mallee-Emu wren was presented as an example of a species with **low genetic diversity in the gene pool,** probably as a consequence of genetic drift caused by bushfires.

Information regarding 'devil facial tumour disease' (DFTD) in Tasmanian devils was also presented in Chapter 4.4. The susceptibility of these animals to the disease is thought to be linked to reduced genetic diversity of a group of genes associated with the immune system.

The issue of reduced genetic biodiversity relates to the **ability of the population to survive** and evolve in the face of **changing environmental selective pressures;** with a large gene pool it is more likely that at least some members of the population will survive and pass on the favoured genes to the next generation.

Another organism, the koala (see *Figure 4611*), is also faced with reduced genetic diversity in its gene pool. Originally scientists believed that Aboriginal hunting and later European settlement and hunting reduced population numbers significantly and that this was the main causative factor in low genetic diversity. When examining museum specimens and comparing them with modern day koala, however, it appears that the event which reduced genetic diversity of the koala must have happened a long time ago. It is likely that the low diversity may be responsible for the high susceptibility of the koala to diseases such as chlamydia and the koala retrovirus (KoRV).

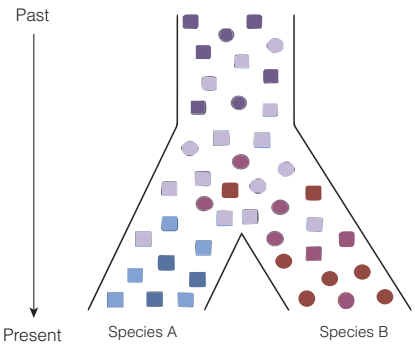
Figure 4611 Koalas have low diversity

4.6 Review questions

Multiple choice questions

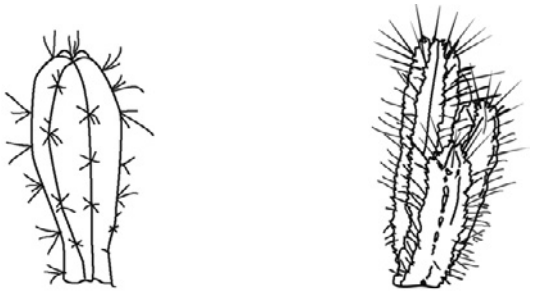
1. Conservation biologists are most concerned about small populations because of:
   - J high predation rates.
   - K high competition for food.
   - L natural selection.
   - M low genetic diversity.
2. Which of the following best explains why biological communities change over time?
   - J Organisms modify the environment leading to the conditions being more suitable for alternative species
   - K Depletion of resources means that new species must move in and can adapt to these conditions.
   - L Species evolve over time.
   - M Old species move on, and others move in.

3. Convergent evolution tends to occur when two different species:
   J converge to become the same species.
   K develop different traits from common structures.
   L evolve similar traits from different structures.
   M develop homologous features from different structures.
4. *Refer to the diagram to the right to answer the question that follows.*
   Species A and B would likely:
   J have analogous structures.
   K be distantly related.
   L have homologous structures.
   M encounter similar selection pressures.



5. There have been five mass extinctions on Earth. Following each mass extinction, the diversity of life increased beyond pre-extinction levels.
   Identify the main source of genetic variation supporting the increase in biodiversity, following each mass extinction.
   J Adaptive radiation.
   K Mutation.
   L Allopatric speciation
   M Succession.
6. Identify the correct analogy for secondary succession.
   J Two parents welcome their only child into the world.
   K Designer's blueprints are used to build a concept car.
   L A new road is built on land where no road previously existed.
   M A house is subdivided, and two houses are rebuilt in its place.
7. It is important to preserve genetic diversity within a species because:
   J high genetic diversity is always associated with high economic profits from ecosystems.
   K high genetic diversity helps species adapt to the changing environment.
   L populations require high genetic diversity to grow large in number.
   M populations with high genetic diversity are all naturally resistant to viruses and bacteria.
8. Which of the following options would be the easiest to find examples of adaptive radiation of species at?
   J A humid tropical rainforest.
   K An isolated region with multiple diverse habitats.
   L In the environment close to nuclear power plants.
   M At the top of a mountain.
9. In which of the following situations would you least expect to see succession of biological communities?
   J In an area recently destroyed by a bushfire.
   K In a wetland area exposed to flood conditions.
   L In a creek bed where water flows after 2 dry seasons.
   M A mature rainforest.

10. *Trichocereus macrogonus* is an American plant that is distantly related to the South African *Euphorbia pentagona.* The two plants belong to different families, but they both live in dry areas. Both plants have spines for protection and stems that store water.



Trichocereus macrogonus *Euphorbia pentagona*

not to scale

T. macrogonus and *E. pentagona* have similar form and function. This is evidence of:

J a common ancestor.

K gene flow between the *T. macrogonus* and *E. pentagona.*

L exposure to similar selection pressures.

M a shorter period of isolation than previously thought.

11. The Serengeti in Africa contains a population of lions and cheetahs. Research has identified that the population of lion's genetic diversity is high, but the cheetahs is low. Both the cheetah and lion populations are susceptible to a pathogenic infection that can be fatal for both.

If both lions and cheetahs becoming infected, the most likely outcome is:

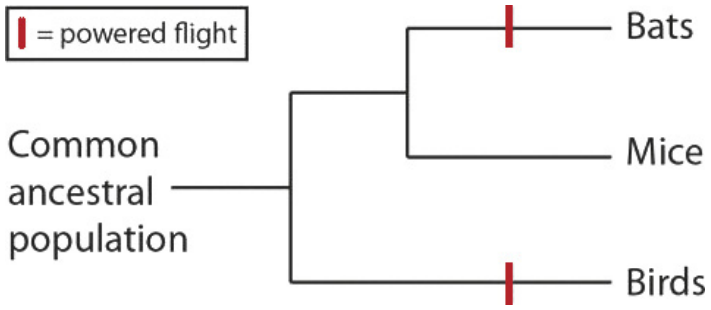
J Large populations are immune to pathogens, so the lion population would survive.

K Small populations are more likely to survive because there are less individuals to infect, so the cheetah population is more likely to survive.

L High genetic diversity increases the likeliness of individuals with favourable traits to combat the pathogen, so the lion population is more likely to survive.

M Low genetic diversity increases immunity to pathogens, so the cheetah population is more likely to survive.

12. *Refer to the species tree below to answer the question that follows.*



Which of the following statements is true regarding the species tree above?

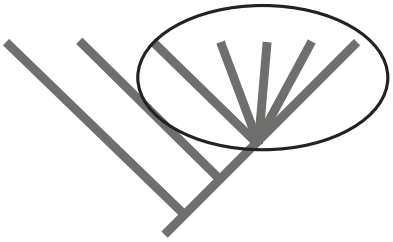
J Bats and birds have a more common recent ancestor than bats and mice.

K Bats and birds are an example of convergent evolution.

L Bats and birds have greater genetic diversity than mice.

M Bats and birds have become structurally more different over time.

13. *Refer to the diagram to the right to answer the following question.*



The circled part of this phylogenetic tree represents:

J Genetic drift.

K Convergent evolution.

L Sympatric speciation.

M Adaptive radiation.

14. Which of the following is likely to cause genetic drift and precede secondary succession?

J Mass extinction

K Hunters kill a large amount of animals

L Habitat destruction

M Selective pressures.

15. The genetic diversity and population of several populations of peppered moths were measured. The results showed that all the populations had high genetic diversity and large population numbers, except for one. This population came from a forest ecosystem and was similar in number to the other populations, but much lower in genetic diversity.

The most likely reason for the forest population having lower genetic diversity than the other populations is:

J At some point, the forest population went through a population bottleneck.

K Less niches are found in the forest for different species of moths.

L There is a higher mutation rate in the forest population than the other populations.

M The forest population has grown more slowly because of low genetic diversity.

Free response questions

1. Describe how the development of sclerophyll plants in Australian ecosystems is an example of convergent evolution.

2. Explain the links between convergent evolution and analogous structures compared to divergent evolution and homologous structures.

3. Many marsupials are endemic to Australia.

a) Suggest possible reasons for this.

b) Outline how this is a good example of adaptive radiation.

4. Cheetahs suffer from low genetic biodiversity and there are a number of significant genetic conditions that are common. It appears that approximately 12,000 years ago, there was a mass extinction of the cheetahs in Africa and very few survived. It is very likely a population 'bottleneck' occurred.

a) Explain why this reduced genetic diversity places the cheetah population at risk of extinction.

b) In one case study, 50% of the population of cheetahs died as a result of exposure to one virus. Describe how the 'bottleneck effect' can contribute to such a disaster.

5. Complete the following table comparing primary and secondary succession:

Area of comparison	Primary succession	Secondary succession
Examples of habitat where it occurs		
Examples of likely first colonisers		
Possible events leading to the succession		
Speed or rate of succession		
Number of species		

6. The mix of species in communities may change over time. Describe possible ways that each of the following might modify the environment for other species:

a) lichen

b) spinifex

c) Eucalypt or Acacia (wattle) trees

d) insects

7. The evolution of the eye is a very good example of convergent evolution. One of the master genes (Pax6) involved in regulating the development of the eye is thought to have evolved in a common ancestor of all animals some 500 million years ago.

a) Suggest how the development of a complex eye in squid (invertebrate) and mammals like humans (vertebrate) is an example of convergent evolution.

b) Using your understanding regarding transcription and translation from Chapter 1.2 suggest a possible role for RNA splicing of the Pax6 gene thus providing variation in the development of the eye in different evolutionary pathways.

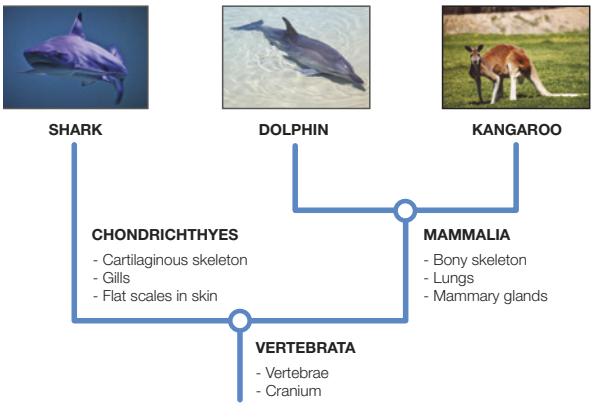
8. Compare the effects of convergent and diverging devolution on populations of different species.

9. *Refer to the phylogenetic tree indicating the branching or speciation of some species from earlier existing vertebrates.*

a) Identify examples in the tree that represent:

- divergent evolution
- convergent evolution

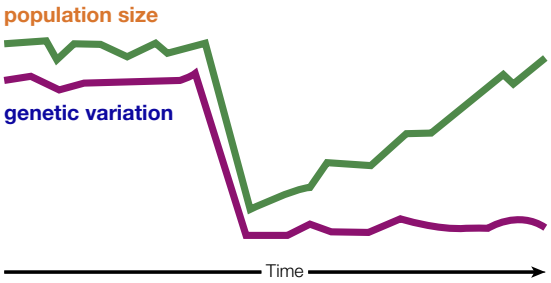
b) Identify an example from the tree of an analogous feature that has evolved in separate species in response to a similar selective pressure.



c) Similarly, from the tree, identify an example of a homologous feature.

10. *Refer to the graph to the right, to answer the questions that follow*.

a) Describe the pattern of results as indicated in the graph.



b) Provide a possible explanation for the rapid drop observed in both population size and genetic variation about half way through the timescale.

c) Explain potential implications for the population as a result of the diverging lines for population size versus genetic variation.

11. It is widely accepted that the extinction of the dinosaurs took place around 65 million years ago. Referring back to *Figure 465* on page 412 it can be seen that around this time, the number of marsupial and placental species dramatically increased. This was a product of divergent evolution and, subsequently, adaptive radiation.

a) Describe how this is a good example of adaptive radiation.

b) Explain a possible link between the extinction of the dinosaurs and the divergent evolution of mammals.

Chapter 4.7 Human impact

Science Understanding

Human activities can create new and significant selection pressures on a gene pool, leading to species extinction.

- Give examples of human activities that lead to climate or environmental change.
- Describe how these activities have caused or may threaten the extinction of species.

Maintaining biodiversity is an ethical issue with long-term biological and/or environmental consequences.

- Recognise that humans have an obligation to prevent species extinction.

Human practices

For most of human history there was essentially little significant increase in the numbers of the human species. In the last few hundred years, however, the size of the global human population has shown **exponential growth**. Refer to *Figure 471*.

This increase in human population size is not **sustainable** and is placing huge demands on resources needed by human populations across the planet for food, water, and raw materials for energy, all of which jeopardise biodiversity.

Human practices impact on other species in a number of ways and some of the more significant ones are illustrated in *Figure 472*.

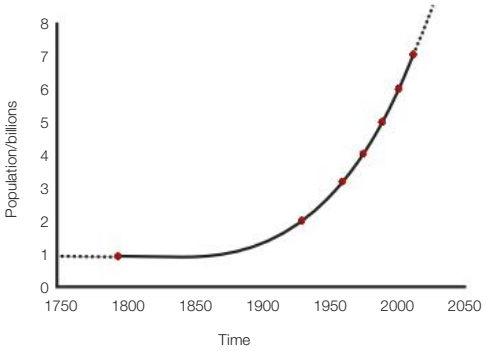


Figure 471 Human population growth

Figure 472 Some impacts of human practices (clockwise from top centre: Introduced species; Mining; Atmospheric change; Harvesting; Habitat clearance; Pollution)

Helpful online resources

FuseSchool - Global Education: Human Impact | Environment | Biology | FuseSchool
<https://www.youtube.com/watch?v=Um-bo2MWDsQ>

Kurzgesagt - In a Nutshell: Overpopulation – The Human Explosion Explained
<https://www.youtube.com/watch?v=QsBT5EQt348>

Introduced species

Foreign species brought to Australia from other countries are known as **invasive or exotic species.** Since European settlement many species have been introduced into Australian ecosystems, often with devastating consequences. They **compete with native species** for habitat or resources or directly feed on them. Terrestrial examples of such vertebrates include feral cats, dogs, foxes, rabbits, pigs and goats, cane toads, camels and rats.

Rabbits, for example, were introduced around 1859 and by the early 1900s covered much of Australia. Rabbits destroy native vegetation and compete with native animals for resources. They are also known to take over burrows from burrowing Australian species like bandicoots and the Bilby. Refer to the 'Information Box' titled '*Biological control of Australian rabbit populations*' which outlines some of the issues as well as control measures that have been attempted recently and over the preceding decades.

Cane toads are native to countries in Central and South America. They were introduced to Hawaii, from where they were subsequently brought to far north Queensland in 1935 to act as biological control agents of cane beetles that were damaging sugar cane crops. The biological control program designed to use them was unsuccessful mainly because the introduced toads ate more than just cane beetles. Having **virtually no natural predators** in the intervening decades to the present day has enabled them spread over huge areas of Australia.

The impact of the cane toads on **biodiversity** in Australia has been significant. Many of their predators die after ingesting a toad, due to the poisonous glands on their backs.

Helpful online resources

TED-Ed: The threat of invasive species - Jennifer Klos
<https://www.youtube.com/watch?v=spTWwqVP_2s>

MinuteEarth: Why Biodiversity Is Good For The Economy
<https://www.youtube.com/watch?v=c80oLYvr9ck>

Re-introduction of wolves in Yellowstone National Park

The introduction (or re-introduction) of a species to an ecosystem does not always have negative effects and can be used to restore balance in an ecosystem. Some species, known as **keystone species**, are important to the balance of an ecosystem. An example of this occurred when wolves were re-introduced into the Yellowstone National Park in 1995. It is well known that wolves are carnivorous predators at the higher end of food chains; however, they also shape behaviours of other animals, and this can result in giving life to other species. Before reintroduction, the wolves had been absent for 70 years due to hunting and clearing of land for agriculture (which removed the wolves' prey). The re-introduction caused a trophic cascade, which is an ecological process that starts at the top of the food chain (the re-introduction of the wolves), and the effects of this cascade (flow on) all the way to the bottom of the food chain. This resulted in a significant increase in biodiversity and amazingly, the behaviour of the rivers also changed. To find out how, watch the 'Helpful online resource' below:

Helpful online resources

Sustainable Human: How Wolves Change Rivers
<https://www.youtube.com/watch?v=ysa5OBhXz-Q>

Pollution

As a direct result of the modern day human lifestyle, pollution is a major problem for the planet's biodiversity. A few of the more serious threats are listed below:

- The use of chemical **pesticides** that can affect higher order consumers through **bio-magnification**; for example, insecticides like organophosphates and, in some countries, DDT (see related Helpful online resources).
- Oil spills from ships at sea.
- Accumulation of **plastic waste** in waterways and the oceans killing animals, and its degradation into **microplastics** that can enter our food chain through **bio-magnification** (see related Helpful online resources).
- **Acid Rain** and **photochemical smog** that is a product of the emission of sulphur dioxide and nitrogen oxides into the atmosphere from the combustion of fossil fuels (see the related Helpful online resource below).
- Ineffective or insufficient processes to treat and dispose of sewage.
- Production, transport and storage of radioactive waste.
- The impact of the chlorofluorocarbons (CFCs) used in aerosol cans and refrigerators, causing destruction of the ozone layer (now banned in most countries).

Helpful online resources

Kurzgesagt - In a Nutshell: Plastic Pollution: How Humans are Turning the World into Plastic
<https://www.youtube.com/watch?v=RS7IzU2VJIQ>

SciShow: 3 Unexpected Effects of Plastic Pollution
<https://www.youtube.com/watch?v=X4uefUtvLpc>

TED-Ed: The science of smog - Kim Preshoff
<https://www.youtube.com/watch?v=CdbBwIgq4rs>

Bio-accumulation is a process where particular chemicals are not broken down or excreted when an animal or plant ingests them.

This can lead to **bio-magnification**, where organisms at higher trophic (feeding) levels accumulate higher and higher levels as they feed on other organisms.

DDT is a toxic pesticide that is banned in most countries due to its toxicity. It is still used in some poor, developing countries however. DDT can bio-magnify through food chains (see *Figure 473*). **Methyl mercury** and **microplastics** are other examples that can undergo bio-magnification and enter the **human food chain**. For example, it is strongly recommended that pregnant women eat deep sea fish sparingly (i.e. battered flake can only be consumed once every 2 weeks, with no other fish in between). This is because the bio-magnification of methyl mercury is detrimental to the developing brain of the foetus. Refer to *Figure 473* illustrating the accumulation of DDT in a food chain, leading to bio-magnification.

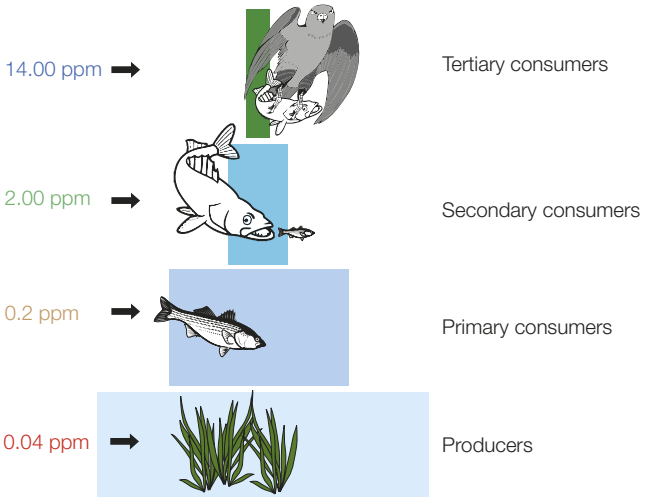


Figure 473 The process of bio-magnification

Helpful online resources

Amoeba Sisters: Biomagnification and the Trouble with Toxins
<https://www.youtube.com/watch?v=TZk6vcmLcKw>

Biological control of Australian rabbit populations

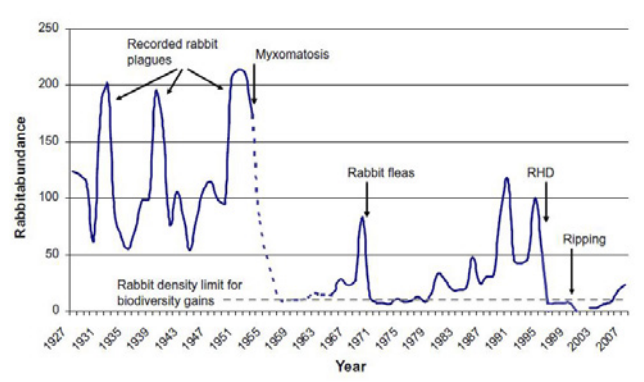
Introduced European rabbits (*Oryctolagus cuniculus*) are a major pest in Australia. They became widely established in the late 1800s, causing severe agriculture losses through crop damage and competition with livestock for pasture. Rabbits also caused severe ecological damage to native vegetation in pastoral areas, eliminating many of the highly palatable native grasses and herbs, which affected sheep and cattle production, contributed to soil erosion, and opened the way for invasion by unpalatable introduced weeds. Rabbits also prevent the regeneration of many large native trees and shrubs, including sheoaks and acacias, due to their extraordinary capacity to find and eat their palatable seedlings. They also affect native marsupial herbivores, by selectively eating the most nutritious parts of native pastures on which the marsupials, like wombats, depend.

The impact of Myxomatosis

That situation changed with the introduction of biological control agents, including the virulent myxoma virus in 1950, and the virulent calicivirus called rabbit haemorrhagic disease virus (RHDV) in 1995. Together, these agents have greatly reduced rabbit numbers and provided an estimated economic benefit of approximately $70 billion as a result of reduced agricultural damage.

The graph shows an example of how rabbit abundance in semi-arid South Australia has varied through time in response to the release of biological control agents and warren ripping. Rabbit fleas were introduced to help spread myxomatosis in areas where mosquitoes were scarce. Ripping involves mechanical destruction of rabbit warrens, an expensive but highly effective control method.

Myxomatosis is a natural, mild skin infection of South American cottontail rabbits but a lethal disease in European rabbits caused by the myxoma virus. When first introduced to Australia, it reduced most rabbit populations by a staggering 99% although it was less effective in arid inland areas where there weren't enough mosquitoes to spread it effectively. Within 15 years, however, weaker strains of myxoma emerged and rabbits began to develop genetic resistance to the virus. Rabbit numbers began to recover; although never reaching pre-myxomatosis levels, they remain a major problem.



The impact of Rabbit Hemorrhagic Disease (RHD)

In 1988, RHD was first recognised on rabbit farms in China, and rapidly spread through many parts of the world. It was introduced to Australia in 1995 and took less than 12 months to reach most rabbit populations. Unlike myxomatosis, this virus was spread by flies and was most effective in arid areas, where it reduced rabbit numbers by more than 90%, allowing widespread recruitment of many threatened native plant communities. The size of rabbit populations however, began to recover again after about 10 years.

A research program, called RHD Boost, was begun to see if overseas strains of RHDV that were not present in Australia might improve its effectiveness here. One RHDV from a Korean rabbit farm (K5) was chosen because it was more effective in rabbits that had been partially immunised against RHD by exposure to another benign (not fatal) calicivirus that is common in rabbits from high rainfall areas of south-eastern Australia. It was released at 600 Australian sites in autumn 2017.

Another new calicivirus, RHDV2, emerged in Europe in 2010 where it rapidly spread. It was discovered in Canberra in May 2015. How it arrived in the country is unknown, but within two years it spread to most rabbit populations in southern Australia.

RHDV2 can kill immune wild rabbits that have survived disease outbreaks caused by the older RHDV strains. It has greatly reduced many rabbit populations and it is hoped that, along with K5, it might keep them very low for some years. In France, Spain and Portugal where RHDV has also been established for 20-30 years, rabbit populations have been severely depleted by RHDV2, during the past six years. RHDV2 is a severe problem there because rabbits are important native animals in many ecosystems in southern Europe.

Written in collaboration with Greg Mutze, a South Australian researcher who has studied rabbits, rabbit diseases and rabbit damage in natural environments in South Australia for about 40 years.

Mining/agriculture/urbanisation

These practices lead to **habitat destruction** and, in many cases, are the main contributing factors that cause species to become threatened, endangered, or extinct.

Helpful online resources

Kurzgesagt - In a Nutshell: Unlimited Resources From Space – Asteroid Mining
<https://www.youtube.com/watch?v=y8XvQNt26KI>

Harvesting

In this category are included practices generally referred to as causing **over-exploitation** of resources; this means the unsustainable harvesting of species from the wild, made possible by the expansion and intensification of agriculture, hunting and gathering abilities. It is believed that harvesting by humans today is putting more species in danger of extinction than any other threat. For example, the unsustainable logging is driving the decline of the Australian Leadbeater's possum. See *Figure 474*.

Figure 474 Leadbeater's possum

Helpful online resources

The Green Revolution: Natural Resources Depletion: Consumption in a World of 32:1
<https://www.youtube.com/watch?v=TPrXUTXikJs>

Climate change

This very important and growing threat will be discussed in more detail later in this chapter.

The extinction crisis

In Chapters 4.4 and 4.6, the concept of biodiversity in the gene pool of populations was presented. It was noted that populations that lack genetic diversity are at a greater risk of extinction. This is because the ability of such populations to survive a changing environment (selection pressure) is limited, thus jeopardising the long-term survival of them. This was observed with the examples of the Mallee Emu Wren and also the Tasmanian Devil.

Human activities presented earlier in this chapter **create new selection pressures** on communities of organisms, often, over time, being so severe that no organisms can survive, leading to species extinction.

In much the same way, species diversity in an ecosystem provides ecological communities with the genetic variability they need to withstand environmental stress. This is noticed first in ecosystems that have fewer species, such as grasslands, deserts and the polar oceans where any loss of species can have drastic impacts on the community.

Many scientists state that planet Earth is now experiencing the most significant period of species' extinctions since the loss of the dinosaurs about 65 million years ago. Although extinction is a natural product of selection, scientists estimate that the Earth is currently losing species at 1,000-10,000 times the normal expected or 'background' rate (see *Figure 475*).

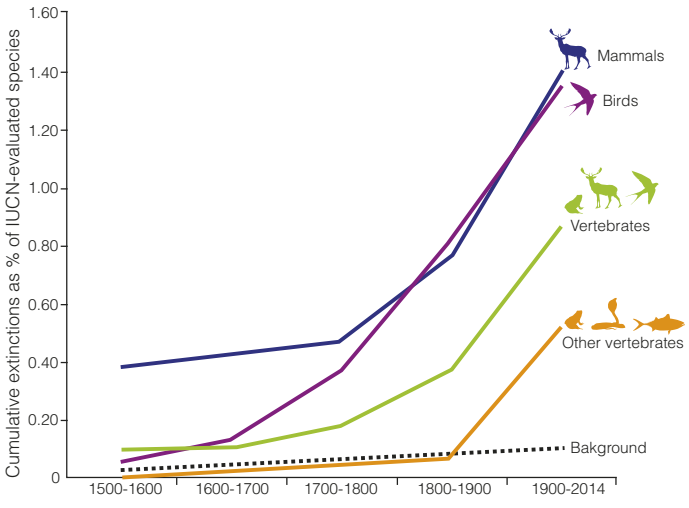


Figure 475 The 'very conservative estimate' of cumulative vertebrate extinctions using International Union of Conservation of Nature (IUCN) data

Australia has around 500-600,000 different species. More than 50% of the plant and animal species in the country are **endemic**, meaning they are found only in Australia. No other nation has as many endemic flowering plants or marsupials as are found in Australia. As such, Australia is regarded as a mega-diverse country, meaning it possesses a high level of diversity of species and ecosystems.

Since European settlement, hundreds of species have become extinct in Australia. According to the Australian Wildlife Conservancy, this includes 30 species of mammals which is more than any other country. Many other species are considered to be vulnerable or threatened or are listed as endangered under Australian Government legislation. It has been estimated that, in Australia today, more than 310 species of native animals and over 1180 species of native plants are at risk of extinction.

Refer to *Figures 476(a) and (b)* illustrating two Australian animals that are now extinct; the Tasmanian Tiger (*Thylacine*) and the Toolache Wallaby (*Grey's Wallaby*). Both probably became extinct due to human practices including hunting, habitat loss and the impact of introduced species, such as the fox.

Figures 476 (a) The Tasmanian Tiger and 475 (b) The Toolache Wallaby

Helpful online resources

TED-Ed: When will the next mass extinction occur? - Borths, D'Emic, and Pritchard
<https://www.youtube.com/watch?v=RAdNCIlYXvo>

TED-Ed: Will the ocean ever run out of fish? - Ayana Elizabeth Johnson and Jennifer Jacquet
<https://www.youtube.com/watch?v=WNdR808jMSA>

4.7

Global warming and climate change

The overwhelming majority of scientists agree that **global warming** is leading to **climate change** and, as a consequence, significant and irreversible changes in physical and biological systems.

Atmospheric concentrations of carbon dioxide (CO_2), methane and nitrous oxides began to rise around 200 years ago, after having changed little since the end of the last ice age. The concentration of CO_2 has increased from 280 parts per million (ppm) prior to 1800 to more than 400 ppm today, which is an increase of greater than 40%.

Human-induced CO_2 emissions from fossil fuel combustion, cement manufacture and deforestation have significantly disrupted the global cycling of carbon (carbon cycle), adding CO_2 to the atmosphere faster than it is removed.

The sun radiates ultraviolet (UV) radiation towards earth. About half of the UV is absorbed by the Earth and re-emitted as infra-red (IR), or heat radiation. Some of the IR radiation will leave the atmosphere, but some is absorbed by **greenhouse gases**, such as carbon dioxide. The IR is re-emitted by greenhouse gases. Some of the IR is directed back towards Earth, warming the planet. The warming of the Earth by IR emitted by greenhouse gases is called the **greenhouse effect**. Without the greenhouse effect, the average temperature of the Earth's surface would be too low to support living things. As the concentration of greenhouse gases increases in the atmosphere, so too does the warming of the Earth. This is called the **enhanced greenhouse effect**, which leads to **global warming**. Refer to *Figure 477* and the Helpful online resource for more information on the greenhouse effect process. Also, *Figure 478* illustrates the strong correlation between global surface temperatures and carbon dioxide concentration in the atmosphere.

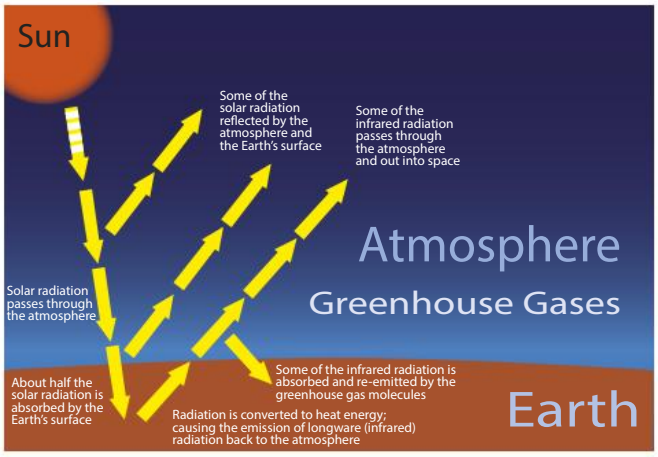


Figure 477 The greenhouse effect

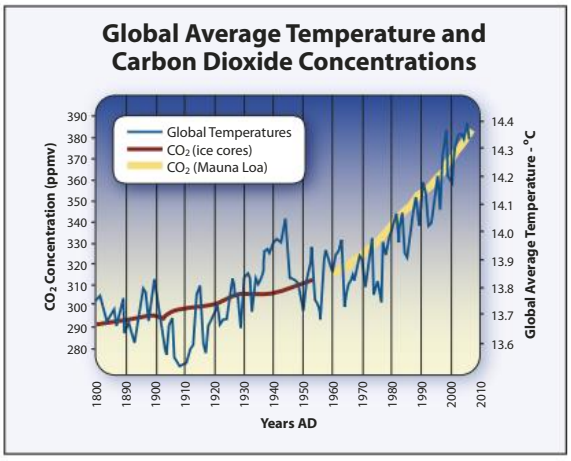


Figure 478 Global temperatures and CO_2

Global warming and climate change are not the same process. Global warming refers to the increasing average temperature on Earth; however, **climate change** is much broader. Climate change refers to the changing weather and climate patterns and includes the side effects of global warming, such as melting polar ice caps/glaciers and drought. The side effects of global warming contribute to the changing weather and climates; for example, the cold freshwater released into the ocean's saltwater from **melting polar ice caps** can contribute to **changing ocean currents**. Ocean currents play a significant role in **global weather patterns**.

Climate change can be seen as perhaps the single greatest threat to global biodiversity which, left unchecked, almost certainly will cause the extinction of thousands of species over the next couple of hundred years or so and may even threaten the long-term survival of the human species.

Helpful online resources

MinuteEarth: How Do Greenhouse Gases Actually Work?

<https://www.youtube.com/watch?v=sTvqlijqvTg>

Factors leading to extinction due to climate change

- Increasing air and ocean temperature - rising temperatures that exceed the physiological tolerance limits of the species
- Starvation - increased temperatures may decrease the activity and thus foraging for food time of organisms hence more die from starvation
- Lack of oxygen - more aquatic organisms may die from lack of oxygen as warming of the rivers, lakes and oceans reduces their oxygen content
- More frequent extreme weather events -large fluctuations in air temperature, as in a heat wave, can kill large numbers of organisms.

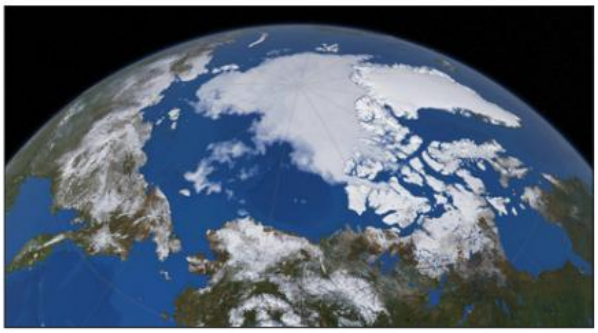


Figure 479 The Arctic ice

- Altered patterns of rainfall -decreasing precipitation may lead directly to increased water stress and loss of habitat for freshwater species
- Increasing frequency and intensity of fires-leading to death of huge numbers of organisms and/or habitat destruction.
- Greater thermal expansion of seawater and more melting of ice caps and glaciers causing rising sea levels, the impacts of which include elimination of coastal habitats and increased salinity of freshwater habitats and coastal soils.
- Changed biotic factors -by causing extinction of one species in an ecosystem the 'flow-on' effect on feeding relationships could impact on many species, especially if there is extinction of keystone species.

Refer to *Figure 479* showing the Arctic to the north of North America based on satellite data. The minimal ice area occurs during September at the end of the Arctic summer and this has been steadily decreasing since satellite observations in 1979 at a rate of about 10% per decade (or 1% per year!) This decrease is attributed to global warming and climatic change.

Flying foxes are an important species for seed dispersal and pollination and are protected in Australia. Climate change has the potential to affect food availability and cause heat -related mortality in the flying foxes. Once temperatures rise above approximately 43°C, mortality events rise significantly. In 2014, due to an extreme temperature event in northern Queensland, it was estimated that around 45,000 flying fox deaths occurred. Note there were also other species of flying fox included in this number. Refer also to the information box about the '*Grey- headed flying foxes in SA*' later in this chapter.

The profile of an environmental scientist - *Dr Wendy Telfer*

What do you love about the landscapes you live in? How do our landscapes work? What do we want them to look like in the future? These are some of the questions that we have been asking the community as part of developing a new Regional NRM Plan for the South East region of South Australia.

'NRM' stands for Natural Resources Management; how we use and look after the water, soil, biodiversity, and environments that support us. My job is to facilitate the planning process that determines where we most need NRM action in the region. I love bringing strong science together with local community knowledge to plan for the management and conservation of our ecosystems, biodiversity and natural resources. I regularly consult with community stakeholders, including school students (pic).

Scientific evidence is crucial for good decision making. A great part of my job is working with a team of ecologists and hydro-geologists to make sure our planning and the policies that regulate the use of natural resources are based on up-to-date and robust science. We also work together to plan the best methods of monitoring the condition of natural resources and the trends in the health of our landscapes. For example, how do we measure the impacts that rabbit control are having on the recruitment of threatened native plant species?

For some natural resources and values in the landscape, it will always be difficult to balance their use by humans and their protection for the future. Water planning is complex in the South East as it needs to balance the use of water by agriculture and forestry with water being available for the unique wetlands that characterise the region. Planning must balance these competing needs and determine where the sustainable limits are for use of water.

Another challenge for planning is the changing climate. Recently, scientists have developed detailed models of future climates for different regions in South Australia. The modelling suggests that in the next 50 years in the South East we can expect more frequent heat waves, less rainfall (especially in spring), higher storm surges, increased bushfire risk and less recharge (i.e. rainfall) to groundwater. The reduced rainfall and recharge of groundwater (subterranean) aquifers will place increased pressure on water resources, which will potentially exacerbate the conflicts over water security in the region. The changing climate is likely to have significant impacts on natural ecosystems and biodiversity. Some species will be able to move to inhabit their preferred climate, others may be able to adapt to the new climate, but some will be unable to persist in the new climate and the changed environments they face.

For me, it is a privilege to work with fantastic scientists and our knowledgeable community to try to shape the best NRM Plan we can so that natural resources and our landscapes can be sustainably used, enjoyed, and appreciated for their own intrinsic values, into the future.

Education and Career

Bachelor of Science (B.Sc.) (Honours in Botany) at The University of Adelaide, 1997

Doctor of Philosophy (Ph.D.) in Ecology at Charles Darwin University, 2006

Kindly contributed by Dr Telfer who has worked with local, State and the Australian Government on conservation, biodiversity and land management programs, she works currently with DEWNR in the South East of South Australia.

Helpful online resources

Kurzgesagt - In a Nutshell: Is It Too Late To Stop Climate Change? Well, it's Complicated.
<https://www.youtube.com/watch?v=wbR-5mHI6bo>

Climate Science: Food Waste: The Hidden Cost of the Food We Throw Out I ClimateScience
<https://www.youtube.com/watch?v=ishA6kry8nc>

The 'Anthropocene' Era?

For many scientists, the present era of increasing human influence on Earth should be termed as the 'Anthropocene Era'. Human-dominated ecosystems now cover more of the Earth than do wild or natural ecosystems. It has already been established in this course that, as species are lost and thus as species biodiversity decreases, ecosystems become more fragile and prone to breakdown or collapse.

Natural species are the primary expressions of natural evolutionary processes that extend back billions of years. The ethical principles which inform human behaviour more generally should be applied in such a way as to promote the importance of preserving species both for the continued survival of present day species, and that of humans. To share the lands and waters of the Earth with other species and implement local, national and global strategies to ensure the long-term survival of them can be seen as an ethical obligation.

As British biologist and science writer *Colin Tudge* put in his book "The variety of life":

"The prime motive of science is not to control the universe but to appreciate it more fully. It is a huge privilege to live on Earth and share it with so many goodly and fantastical creatures".

Michael Soule, a US biologist and founder of the *Society for Conservation Biology*, who is often termed the 'grandfather of conservation biology', articulates an ethical vision whose central tenet is that human-caused extinction of other species is morally wrong.

The Australian Government works towards the goals of conservation and biodiversity maintenance in a variety of ways including through the 'Environmental Protection and Biodiversity Conservation Act 1999'.

The Act specifically provides for:

- Identification and listing of threatened species and ecological communities
- Development of recovery plans for listed species and ecological communities
- Recognition of major threats to the survival of species and listing of them
- Reduction of the impact of threats through threat-abatement plans.

A number of international conventions and agreements provide guidance for governments to assist them to protect species, ecosystems and the genetic resources associated with them. One of them, the International Union for Conservation of Nature (IUCN), publishes an annual Red List of Ecosystems to identify and describe the threats facing ecosystems across the world. Unfortunately, Australia to date has a relatively poor historical record of maintaining biodiversity.

Of the vertebrates, the amphibians are probably most vulnerable to extinction. This is mainly because of the very high permeability of an amphibian's skin, essential for efficient gas exchange but a characteristic that makes amphibians highly susceptible to death due to environmental change. As a result, various species of amphibians have been viewed as the "canary in the global coal mine" by being an indicator of changes that could claim many other species, even humanity itself. Refer to *Figure 4710*. The future of life on this planet is in the hands of humans.

Figure 4710 The future is in human hands

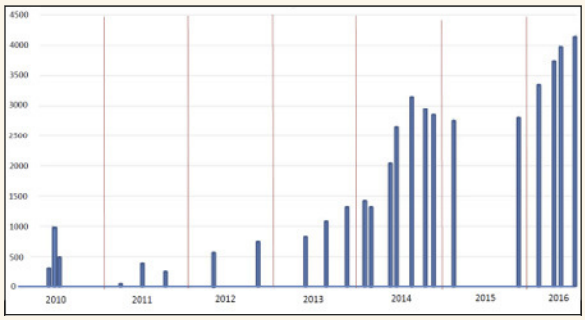
Grey Headed Flying Foxes in South Australia

Bats constitute about 25% of the world's terrestrial mammal species making them the second largest group behind the rodents. Australia is famous for its marsupials which comprise nearly 50% of all mammal species here, but bats too are numerous with 85 species. Bats are generally divided into two groups, the small insect-eating bats that use sonar for navigation and prey location, and the larger flying-foxes and their allies that use sight and smell for locating their fruit and nectar diet. These two groups play important ecological roles including insect regulation, and long-distance seed dispersal and pollination.

Grey-headed flying-foxes (GHFF) are native to the east coast of Australia from about Rockhampton (Qld) to Melbourne (Vic). They are nomadic throughout this distribution but do form regular camps that can hold as many as 50 000 individuals. Adults can weigh near 1kg and have a wingspan of approximately 1.5 m (see photo). They normally fly at night (nocturnal) and feed on fruit and nectar. However their natural feeding habitat has been under pressure because of housing development and agriculture, and in 2001 they were listed nationally as a threatened species.

Prior to 2010, occasional individual GHFFs were seen in Adelaide, but in 2010, several hundred GHFFs were discovered roosting in a single pencil pine in suburban Adelaide. These bats came probably because of a food shortage in eastern Australia, but they left within weeks presumably back to the east coast. In 2011, a camp of about 400 individuals formed in Botanic Gardens but this camp was quickly relocated to Botanic Park near the entrance to the Zoo. In 2017 the colony size had grown through birth (in October) and immigration to around 10,000 (see graph and QR code below). GHHFs do not cope with temperatures above 43°C, and several hundred individuals (mainly young) died on days when this temperature is exceeded.

This colony is being monitored by staff at the Department of Environment, Water, and Natural Resources, and study into the growth of the population, feeding habits and future impacts on humans, including aviation and agriculture is being undertaken by researchers at the University of Adelaide and the South Australian Museum. To do this, they regularly observe the colony and use GPS collars on some of the bats to track their flight patterns and habits. Studies so far indicate that the bat may fly up to 160 km in a night to feed e.g. to Aldinga and back.



Also of interest to public health authorities is the potential of the GHFF for disease transmission. This species carries bat *Lyssavirus* as well as the *Hendra* virus. Although transmission of both to humans is said to be rare, a person must be bitten or scratched, the *Hendra* virus can infect horses, and horse-to-human transmission is a possibility. They are also being monitored for the possibility of carrying and transmitting rabies.

It is well known that the GHFF are vital for the maintenance of a variety of woodland ecosystems in the Eastern states; the role they may or may not play in South Australia in this regard, is also being investigated. As part of ongoing monitoring and research by the Museum and Universities, such issues as whether they are out-competing local species of flower-eating animals and devastating fruit crops, are being considered, both of which might trigger calls for population control measures.

Written in collaboration with Mr Terry Reardon from the South Australian Museum.

4.7 Review questions

Multiple choice questions

1. Humans are having the most significant negative impact on the environment than any other species. A likely reason for this is that humans have a greater:
   J ability to change.
   K requirement for food and water.
   L desire to do so.
   M ability to alter environments.
2. Deforestation is least likely to result in an increase in:
   J soil erosion.
   K enhanced greenhouse effect.
   L biodiversity.
   M soil salinity.
3. Humans should be aware of their impact on environments because:
   J humans cannot reverse the depletion of finite resources.
   K severely impacted ecosystems can never recover.
   L the demand for naturally occurring substances is decreasing.
   M with every action there is always a negative reaction.
4. Identify the human impact that would have the least negative effect on the environment from the options below.
   J Livestock farming close to rivers resulting in runoff of animal waste.
   K Killing insects using pheromone-based traps.
   L The deforestation of rainforests for expanding populations.
   M Groundwater contamination from leaking storage tanks.
5. The Queensland cane toad (*Bufo marinus*) was introduced to prey upon a beetle that ate sugar cane. It has since spread to other parts of Australia and is a major threat to the environment. The most likely reason for the spread of this species is
   J habitat destruction.
   K environmental change.
   L the lack of a natural predator.
   M global warming.
6. An exotic plant species was introduced to a forest.

   Identify the statement below that has the greatest chance of preventing the non-native plant species from becoming an invasive species.
   J There is low biodiversity in the forest it is introduced to.
   K The exotic plant has some competition for resources with others in the forest.
   L The forest does not contain any animals that consume the exotic plant.
   M The exotic plant can reproduce quickly in this forest ecosystem.
7. The name of the process involving the concentration of toxins, such as heavy metals, in cells of organisms through the food chain is:
   J Biotechnology.
   K Biochemistry.
   L Bioconcentration.
   M Biomagnification.

8. Krill contains an average concentration of 0.077 µg/g of the heavy metal mercury.

   Calculate the average amount of mercury consumed by a penguin that consumes 100g of krill per day for 30 days.

   J 231 g

   K 7.7 g

   L 3000 g

   M 0.231 g

9. We are currently experiencing an energy crisis. Approximately 80% of global energy consumption, still relies on the combustion of fossil fuels. There is an increasing demand for more energy due to increasing populations, but at the same time there are increasing campaigns for less reliance on the use of fossil fuels.

   Which of the following options would best help with the energy crisis and reduce impact on the environment in the long-term?

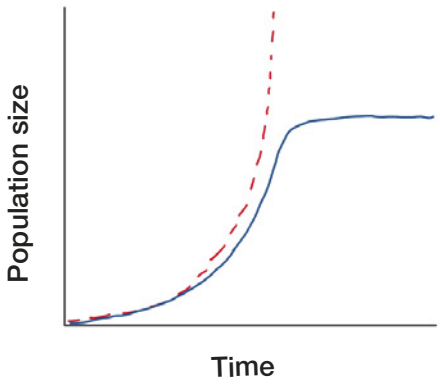
   J The construction of more power plants to meet the growing population's needs.

   K Limiting the number of people allowed to carpool.

   L Additional funding to develop renewable based fuel sources.

   M Doubling fossil fuel combustion to supply energy needs but offsetting a fifth of the carbon dioxide released.

10. *Refer to the graph below showing the potential and actual size of a population to answer the following question.*



Legend	
- - - - - -	Potential size of the population based on reproductive capacity
———	Actual size of the population

   The reason why the actual population size is less than the potential population size is most likely because:

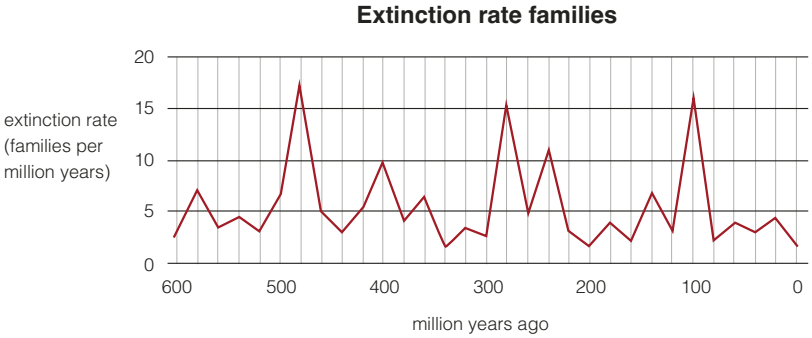
   J the species could not produce any more fertile offspring as represented by the plateau in the graph.

   K the death rate was lower than the birth rate.

   L there was greater immigration than emigration.

   M natural resources are limited.

11. *Refer to the graph below showing the extinction rate of families to answer the following question.*



   If a mass extinction is classified as the extinction of eight or more families per million years, how many mass extinctions have occurred?

   J 4

   K 5

   L 6

   M 7

Source: adapted from University of California Museum of Paleontology's Understanding Evolution, <http://evolution.berkeley.edu>

12. Mosquitoes are vectors for the transmission of diseases such as malaria, zika and Dengue fever. One way to reduce the spread of mosquito-borne diseases is to implement control methods to reduce the size of mosquito populations.

    Identify the control method that would cause the least disruption to ecosystems.

    J Increasing populations of native fish that consume mosquito larvae.

    K Spraying DDT insecticides over large swamps to kill mosquitoes and their larvae.

    L Spraying petroleum over large swamps resulting in mosquito larvae drowning.

    M Draining the known bodies of water where mosquitoes breed.

13. It is important to maintain biodiversity because:

    J less diverse species are more likely to survive major changes in the environment.

    K more diverse species are more likely to survive major changes in the environment.

    L species with large gene pools are less likely to survive major changes in the environment than species with small gene pools.

    M species with small gene pools are more likely to survive major changes in the environment than species with large gene pools.

14. Pablo Escobar is arguably Colombia's most notorious drug lord. Escobar organised his own zoo on his large estate and arranged for many exotic animals to be imported illegally. When he died in 1993, these animals were transported to nearby zoos except for one, the four hippopotamuses. These hippos were deemed too difficult/dangerous to transport and were left to try and survive the wet Amazonian rainforest. The hippos have thrived in the Amazonian wetlands where the population has grown to 70.

    Which of the following statements is likely to be true with regards to the hippos?

    J The introduction of hippos has had very little effect on the Amazonian wetlands.

    K This is an example of the bottleneck effect.

    L The Amazonian wetlands contains many predators of hippos.

    M In Africa, seasonal drought limited the hippo population size.

15. Albert Einstein once prophetically remarked, "mankind will not survive the honeybees' disappearance for more than five years." Bees are responsible for pollinating about one sixth of the flowering plant species worldwide and approximately 400 different agricultural types of plant. Bee colonies are collapsing across the world. One likely cause is the use of neonicotinoid fertilisers that have been shown to damage bees' brains. Bee colony collapse is therefore a pressing issue that needs to be addressed and provides opportunities for innovation.

    Scientists have been researching and developing the use of robotic bees to replace native bees if they are wiped out. Identify the statement that would require the least monitoring, assessment, and evaluation of risk for the use of robotic bees.

    J The robotic bees could malfunction whilst in action and not be retrieved, polluting the environment.

    K Microscopic cameras could be applied to the robotic bees and used to spy on other people.

    L GPS technology could be attached to the robotic bees to track their movements and locate them.

    M The robotic bees could be consumed by birds and other animals who confuse them with real bees.

Free response questions

1. The exponential growth of the size of the global human population is not sustainable. Name four human practices that negatively impact on ecosystems and give an example of each.

2. The following data was collected when scientists were measuring the mercury content in the tissues of various marine organisms. The figures are given in parts per million (ppm).

Phytoplankton	Zooplankton	Small fish	Shark
0.03	0.21	1.65	15.81

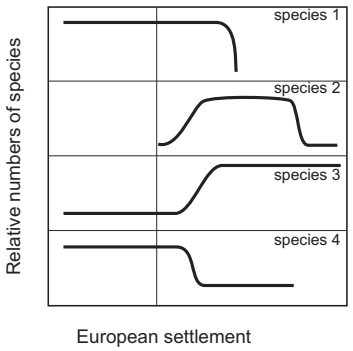
a) Suggest a biological reason for the higher levels in the shark.

b) Mercury is a cumulative poison. Explain what this means concerning its accumulation in the tissues of organisms.

3. Given that species extinctions are a normal component of ecosystems, explain why scientists are so concerned about the current extinction rate.

4. When individual species are threatened or destroyed, there are often serious implications for the whole community in the ecosystem. Explain the most likely reason for this observation.

5. Refer to the diagram to the right representing changes in the relative numbers of four species following European settlement of Australia to complete the table that follows. The four species, but not in correct order are Eucalyptus tree, Tasmanian tiger, Cane toad and the Rabbit.



	Species			
	1	2	3	4
Describe the pattern of results				
Name of the species from the above list				
Describe the likely reasons for the numbers since European settlement				

6. Today, climate change is accepted by most scientists to be a direct result of human practices, increasing surface temperatures across the planet. There are also impacts directly linked to climate change that impact negatively on species. Name and give a possible example of four such impacts.

7. List four ways in which the Australian government is working towards conserving the nation's biodiversity.
   a)
   b)
   c)
   d)
8. Refer to the information in this chapter on '*Biological control of Australian rabbit populations*', page 425, to answer questions 8 and 9.
   a) Suggest likely reasons why rabbit populations in Australia grow rapidly out of control but this has not happened in countries in Europe.

   b) Reduction in rabbit numbers would improve biodiversity in Australian ecosystems. Explain how this is possible.

9. Compare two methods used to control rabbit population numbers outlining the effectiveness of each.

10. It is well documented that the overwhelming majority of scientists accept that many human activities are contributing to an increase in atmospheric carbon dioxide levels. Some research, however, has indicated that some species of plants compete more effectively in raised CO_2 levels increasing the chance of their survival. It has also been shown though that many other species of plants (especially annuals) produce significantly lower quantities of seed under these conditions.
    a) Describe two activities of humans that may contribute to an increase in atmospheric CO_2 levels.

    b) Explain one possible impact of raised CO_2 levels on plant biodiversity.

11. Some species are more likely than others to be affected more severely and sooner than others by climate change. For each species below suggest a likely reason they would be at risk:
    a) a plant species e.g. eucalypt tree

    b) an animal species with limited ability to regulate its body temperature (thermoregulation)

    c) an animal species that feeds during daytime

    d) freshwater species that inhabit wetlands

12. Refer to the information in this chapter on the *Grey-Headed Flying Fox* (GHFF), page 431, to answer the questions that follow;

    a) State two reasons for the importance of the flying fox in ecosystems.

    b) Outline a possible reason for the sudden appearance of the population of flying foxes in Adelaide.

    c) Predict possible implications for nearby ecosystems if the numbers of GHFF continues to increase well beyond the 10,000 already present.

13. Conservation biologists often focus their efforts on species-rich ecosystems like rainforests and coral reefs. Explain why scientists must also develop strategies for those ecosystems with fewer species like grasslands and deserts.

14. This chapter presented information supporting an ethical approach to conservation strategies where it is seen as a fundamental principle that humans treat all species with respect and ensure that we share Earth's resources. Some scientists point out that this is 'very noble' but the reality is tens of millions of humans across the world wake up every day hungry and/or suffering from malnutrition and wondering how they will adequately feed themselves and their families. Write a short response outlining your thoughts and opinions on these different perspectives.

Science as a Human Endeavour 4.7 - Red crabs on Christmas Island

Christmas Island is a small Australian island located in the Indian Ocean 1500 km off the coast of Western Australia. Its National Park is of major evolutionary significance for a number of reasons, one of which is the high level of endemic (native) species it supports. Like the *Galapagos Islands*, it has also been critical to the development of modern understanding of evolution by natural selection, and speciation. Though it is highly regarded internationally as a place of scientific research, it is perhaps best known for its keystone species of red crab that inhabits the island rainforest but, during the autumn every year, marches to the sea in search of mates to breed.

The problem

A number of human practices have had an impact of the ecosystems of Christmas Island, most notably the introduction of rats and cats and two species of insect; scale insects and yellow 'crazy' ants. Over the last 20 years or so yellow crazy ants have killed tens of millions of red crabs and displaced a wide variety of other species from ecosystems on the island.

Scientific knowledge

Yellow crazy ants form 'super-colonies' that consist of huge numbers of ants. They are highly aggressive and kill other species, including red crabs, by spraying toxic formic acid on them. The ants also feed on sugars produced by scale insects. The relationship between yellow crazy ants and the scale insects is an example of mutualism – both species benefit.

The death and decomposition of red crabs has altered abiotic factors in the rainforest ecosystems. There are few natural predators of either yellow crazy ants or scale insects. Chemical control of the ants has been attempted but has proved to be a costly, short-term, and thus an unsustainable solution. A species of wasp in Malaysia is known to lay eggs inside the body of female scale insects in order to reproduce, an action that ultimately kills the insects.

A sustainable solution

After several years of work involving Parks Australia, *Latrobe* and *Monash Universities* and Malaysian authorities, a biological control program was launched on Christmas Island in late 2016 to deal with the size and impact of the yellow crazy ant population. Adult wasps have been released to trigger the death of female scale insects, thus depriving yellow crazy ants of a major food source. It is expected that, over time, the numbers of yellow crazy ants will decrease dramatically. The program is designed to be a long-term and sustainable solution to the yellow crazy ant problem because the agents of control (the wasps) produce, through natural breeding behaviour, enough wasps to maintain their population size.

1. Biological control of pests does not have a particularly good track record. Many attempts have not lived up to expectations. Discuss one other example of biological pest control and evaluate its level of success.

2. Discuss some possible unexpected consequences of introducing the wasp as a biological pest control.

Topic 4 Review Test

Allocate 90 minutes to complete this Test. These are all SACE exam-style questions. Indicate your choice for each of the multiple choice questions (each worth one mark) and answer all of the other questions in the spaces provided. The number of marks for each free response question is shown in brackets. It is recommended that you compare your answers to the suggested answers section as part of your revision. Please note that the suggested answers are not extensive or exclusive.

Section 1: Multiple choice questions (10 marks)

1. Which of the following options is not evidence for the theory of endosymbiosis?

   J Chloroplasts provide glucose to eukaryotic cells through the process of photosynthesis.

   K Mitochondria and chloroplasts have circular DNA.

   L Mitochondria and chloroplasts are similar in size to modern day bacteria.

   M Mitochondria and chloroplasts can synthesise their own proteins.

2. *Refer to the phylogenetic tree on the right to answer the question that follows:*

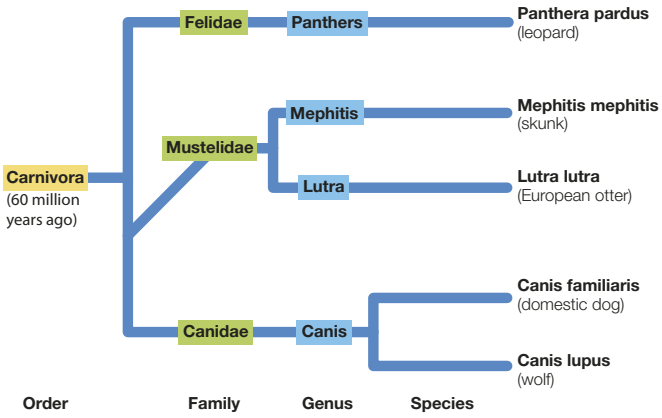
   Which of the following is **incorrect**?

   J The dog and the wolf probably share more in common with their DNA than other species.

   K All of the organisms have shared a common ancestor from the order Carnivora.

   L The leopard has not evolved over 60 million years.

   M The leopard and the otter have had separate gene pools for over 60 million years.



3. One theory for the origin of the last universal common ancestor (LUCA) for life is that this primitive life form evolved in a hydrothermal vent on the ocean floor. Which of the following would **not** be consistent with this hypothesis? The hydrothermal vent provided:

   J a warm environment with temperatures suited to the evolution of a simple cell.

   K easy access to DNA and RNA as self-replicating molecules.

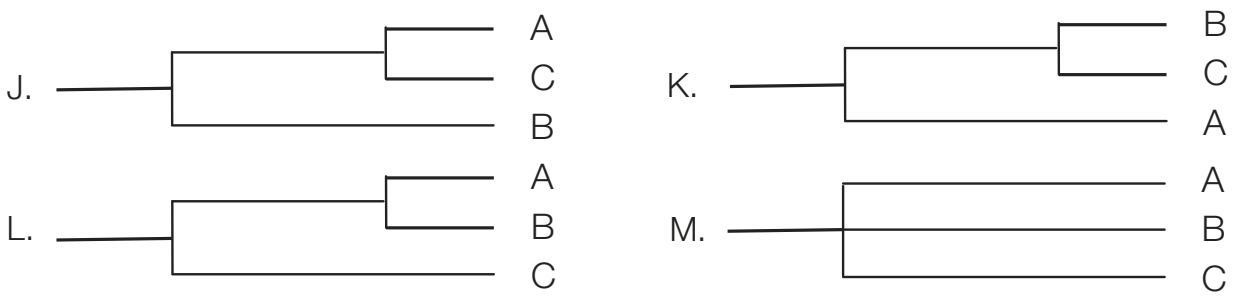
   L a rich supply of molecules from which a simple cell could be assembled.

   M a potential energy source to drive cell metabolism.

4. The process of DNA hybridisation was used to compare the DNA of three species A, B and C. The results of the melting points of the hybrid DNA formed are given in the table below:

DNA hybrid	Melting point °C
A-B	82
B-C	78
A-C	72

   Which of the following hypothetical models is supported by the above data?



5. Which one of the following is **least** likely to result in reproductive isolation between two populations of organisms which are members of the one species?

   The two populations:

   J mate in different seasons of the year.

   K have little genetic diversity.

   L live in a range of environments.

   M have different mating calls.

6. Antibiotics kill bacteria and act as:

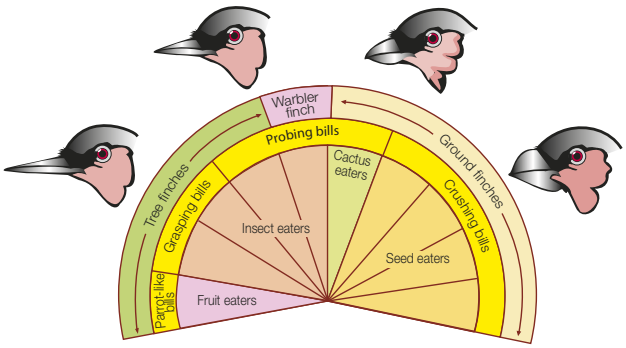
   J an abiotic selective advantage

   K a biotic selective advantage

   L an abiotic selection pressure

   M a biotic selection pressure

7. Refer to the diagram of four species of finches found in the Galapagos Islands. Each species was found on a separate island.



   Which one of the following would have had the **least** effect in explaining the differences in beak shapes of the finches?

   J Predation by lizards.

   K The wind direction in the vicinity of the islands.

   L The distance between each island.

   M The type of food on each island.

8. Which one of the following is **not** always essential for speciation to occur?

   J Geographic isolation of populations.

   K Reproductive isolation of populations.

   L Reduced gene flow between populations.

   M The inability for members of two different populations to produce fertile offspring after mating.

9. The limbs of many vertebrates have a similar structure (the pendactyl limb).

   Charles Darwin, the famous evolutionary scientist, wrote:

   "*What could be more curious than, that the hand of a man formed for grasping, that of a mole for digging, the leg of a horse, the paddle of a porpoise and the wing of a bat, should all be constructed on the same pattern and should include similar bones and in the same relative positions.*"

   Which of the following is most likely to be true concerning Charles Darwin's observations? This is an example of:

   J convergent evolution giving rise to analogous structures.

   K convergent evolution giving rise to homologous structures.

   L divergent evolution giving rise to analogous structures.

   M divergent evolution giving rise to homologous structures.

10. Which one of the following best represents the series of events that could lead to the formation of two separate species from one original common ancestor?

    J Variation, Geographic Isolation, Natural Selection, Speciation.

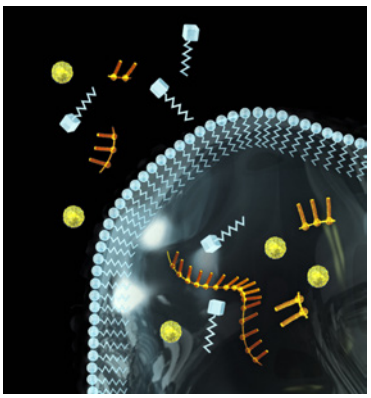
    K Natural Selection, Reproductive Isolation, Variation, Speciation.

    L Geographic Isolation, Speciation, Variation, Reproductive Isolation.

    M Variation, Reproductive Isolation, Speciation, Natural Selection.

Section 2: Free response questions (90 marks)

11. Refer to the following picture showing the proposed structure of one of the first simple cells on Earth.



It has been hypothesised that the first simple cells may not have had DNA as their genetic code.

a) List three characteristics of all living organisms on Earth.

(3 marks)

b) Explain why it is unlikely that DNA was the genetic material present in the first simple cells on Earth.

(3 marks)

c) Describe why some scientists believe that the first cells contain RNA instead of DNA as the genetic code.

(3 marks)

12. The flood plains and the wetlands associated with the River Murray have 100 times more species than the water in the main river channels. It is known that several environmental factors working together, determine the distribution of species.

    a) Suggest two likely reasons to explain the greater biodiversity on the flood plains compared to the main river.

(2 marks)

RT

b) Explain the importance of biodiversity for this ecosystem.

(3 marks)

13. Haemoglobin in mammals is made up of 4 polypeptide chains, 2 identical alpha (α) chains and 2 identical beta (β) chains.

The table below shows a sequence of 15 amino acids in an alpha chain from 4 different primate species.

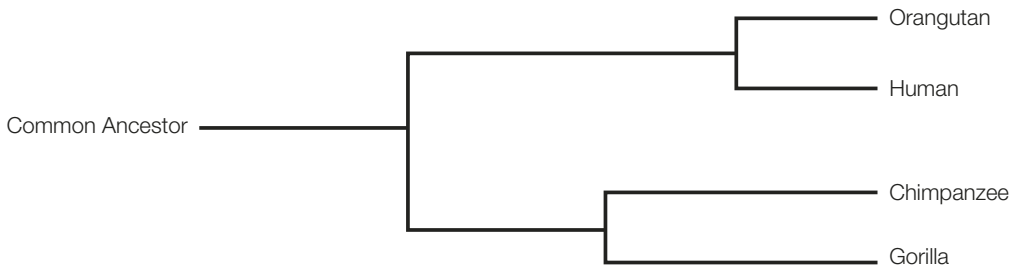
The amino acids which are different from humans are highlighted in bold.

Primate	Amino acid sequence in alpha chain
Human	Lysine-alanine-alanine-tryptophan-glycine-lysine-valine-glycine-alanine-histidine-alanine-glycine-glutamic acid-tyrosine-glycine
Gorilla	Lysine-alanine-alanine-tryptophan-glycine-lysine-valine -glycine-alanine-histidine-alanine-glycine-**asparagine**-tyrosine-glycine
Chimpanzee	Lysine-alanine-alanine-tryptophan-glycine-lysine-valine -glycine-alanine-histidine-alanine-glycine-glutamic acid-tyrosine-glycine
Orangutan	Lysine-**threonine**-alanine-tryptophan-glycine-lysine-valine -glycine-alanine-histidine-alanine-glycine- **asparagine** -tyrosine-glycine

a) Assuming that all of these primates arose from a single common ancestor, name the process which would have given rise to the changes in the amino acid sequences.

(1 mark)

b) A student drew a diagram to represent the evolutionary relationships between the four primates as it is shown below.



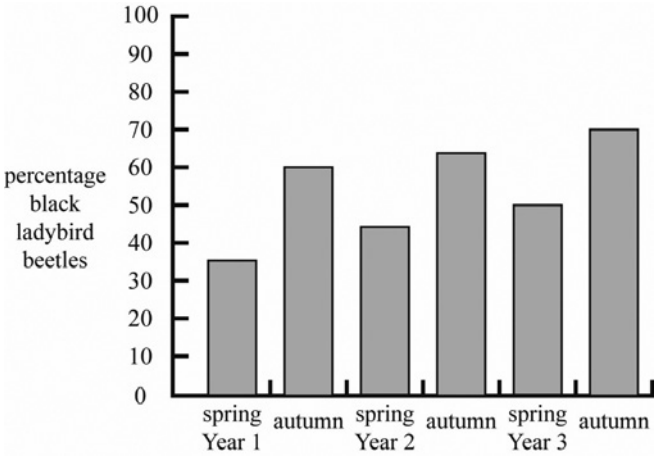
A scientist indicated that the diagram had a major flaw that would not be supported by the amino acid sequences as shown in the table above.

Identify the flaw and explain the likely reasons why the scientist believed this to be the case.

(3 marks)

14. Populations of ladybird beetles can be either red or black.

Refer to the graph below showing the percentage of black ladybird beetles over a three year cycle to answer the questions that follow.



a) What is the percentage of red ladybird beetles in the spring of Year 2?

(1 mark)

b) Name one natural selective pressure that may account for the changes in percentage of different coloured beetles during different seasons and explain how it might give rise to these changes.

(3 marks)

c) Outline the changes relating to colour in the gene pool in the ladybird population from spring to autumn.

\

(2 marks)

15. *Refer to the information below to answer the question that follows.*

The Mallee Emu Wren (*pic*.) is a small wren that lives in fire-prone semi-arid Mallee shrub lands of South East Australia. It has low to moderate genetic diversity in its gene pool.

a) State why low genetic biodiversity places the Mallee Emu Wren at risk.

(2 marks)

b) The low genetic biodiversity is suggested to have been brought about by genetic drift, in particular the bottleneck effect. State the likely cause of this.

(1 mark)

RT

c) Explain how genetic drift can act on the gene pool to reduce genetic diversity.

(2 marks)

16. There is a small craggy island (*Pedra Branca Rock*) located not far from the southeast coast of Tasmania. This island was once connected to Tasmania during the Ice Age, some 20,000 years ago but has since been isolated as a result of the higher sea levels. The *Pedra Branca* skink is a small lizard found only on this island. No evidence of this lizard has ever been found elsewhere.

a) It is thought the skink shares a common ancestor with a species of lizard on the Tasmanian mainland. Describe a technique that could be used to compare DNA from the *Pedra Branca* skink and the lizard on the mainland of Tasmania.

(3 marks)

b) Describe the importance of the geographical isolation on the evolution of the *Pedra Branca* skink.

(3 marks)

c) Explain how the existence of this *Pedra Branca* skink is a result of speciation.

(3 marks)

17. *Refer to the two photographs below of (a) an anteater and (b) a numbat.*

(a) An anteater (South America)

(b) A numbat (Australia)

The anteater lives predominantly in South-Central America and feeds on termites and ants, whereas the numbat is mainly found in Western Australia and feeds on termites. They are both characterised by pointed snouts and long tongues. They do not have a particularly recent common ancestor.

a) What name is given to features such as the long tongue that develops independently in species that are not closely related?

(1 mark)

b) This is an example of convergent evolution. Explain the reasoning for this statement.

(3 marks)

c) Birds and bats are another example of convergent evolution. Explain why.

(2 marks)

18. Refer to the diagram and information that follows of an introduced species of grass; Serrated Tussock (*Nassella trichotoma*).

This grass produces over 10,000 seeds annually and has been listed as a pest of national significance in Australia.

a) Such introduced grasses can impact on native species by competition. Name two abiotic factors that native grasses and Serrated Tussock would compete for and state why this competition may have a detrimental effect on the native species.

(3 marks)

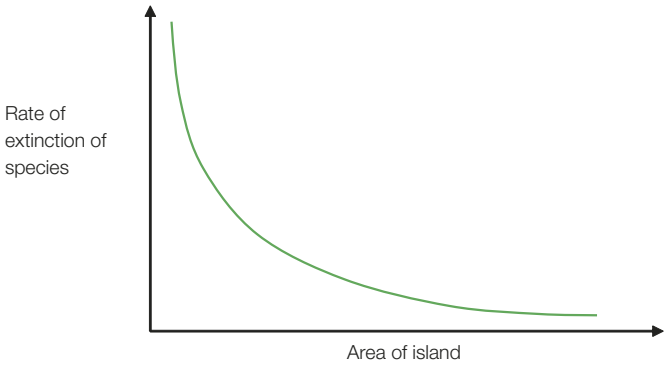
b) Fire is a regular occurrence in native bush ecosystems. Explain how fire presents an opportunity for secondary succession to occur.

(3 marks)

c) The introduced grass may alter the course of the secondary succession that may further impact on the ecosystem. Suggest how this might be possible.

(2 marks)

19. *Refer to the graph below which shows data collected by scientists regarding the relationship between extinction of species of birds and islands of different sizes.*



a) With reference to the graph and the role of natural selection, explain the likely reasons for the relationship between island sizes and the extinction of species.

(6 marks)

One of the most significant factors contributing to the extinction of species is habitat destruction. Wildlife reserves are sometimes formed in order to conserve some of the remaining habitat of threatened species.

Habitat fragmentation is a secondary effect of habitat destruction. It occurs when remaining populations become isolated when links between habitat patches have been destroyed. Over time, habitat fragmentation can lead to the loss of genetic diversity which can affect a population's ability to respond to environmental changes.

b) With reference to the information above, discuss the possible implications for the future management of parks and wildlife reserves as well as clearing land for logging or agriculture.

(2 marks)

20. Antibiotic resistance has developed in many different types of bacteria.

a) State the method of permanent variation responsible for antibiotic resistance.

(1 mark)

The misuse and overuse of antibiotics has led to multi-resistant strains of bacteria developing. Some strains are resistant to all common antibiotics available and are called superbugs. Two examples are:

1) the sexually transmitted "super gonorrhoea", and
2) the respiratory superbug "super pneumonia".

b) Explain how "super gonorrhoea" evolves multi-resistance to antibiotics.

(6 marks)

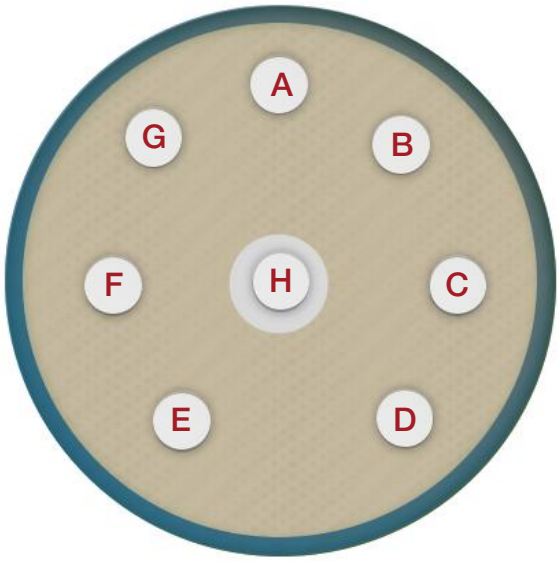
c) Explain how the exponential growth of bacteria plays a role in the development of superbugs.

(2 marks)

d) A patient has presented himself to an STI clinic with suspected gonorrhoea. The health professional needs to take a swab and send it for testing to determine if the strain is "super gonorrhoea" or if it is another strain that an antibiotic can be prescribed to treat.

To do this, the bacterial sample was cultured in a lab, and then eight paper discs coated in 5 µg of different common antibiotics were applied to an agar plate, prior to incubation for 48 hours. The zones of inhibition for each antibiotic were then observed. Refer to the picture below for the results.

Disc letter	Name of antibiotic
A	Azithromycin
B	Streptomycin
C	Ciprofloxacine
D	Ofloxacin
E	Penicillin
F	Doxycycline
G	Tetracycline
H	Ceftriaxone



RT

(i) State two conditions required to culture bacteria on an agar plate.

(2 marks)

(ii) With reference to the results shown above, state if the strain is likely to be "super gonorrhoea" and justify your answer.

(3 marks)

(iii) Describe one limitation of the results of this experiment when making a conclusion.

(2 marks)

(e) In 2022, the UK approved faecal microbiota transplants (FMT) for the treatment of patients that have had two *Clostridium difficile* (*C. diff*) infections and have not responded to antibiotics. *C. diff* causes diarrhoea and can lead to severe dehydration and even death. However, with the rise of antibiotic resistance in *C. diff*, the antibiotics are no longer always a viable solution. FMTs involve transplanting a healthy donor faecal (poo) sample into the intestines of the infected patient. This helps to reset the balance of microbes in the gut and is a solution to treating antibiotic resistant *C. diff*.

Discuss *one* positive impact and *one* limitation that the application of faecal microbiota transplants for the treatment of resistant *C. diff* infections could have for society.

(4 marks)

Total: /90

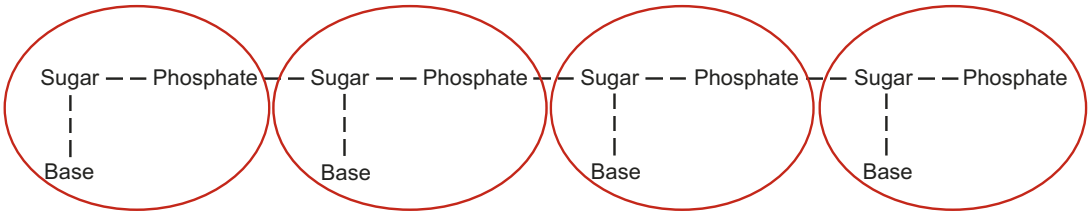
Chapter 1.1 Suggested answers

Multiple choice questions

1. K 2. J 3. L 4. M 5. L 6. K 7. K 8. M 9. L 10. K

Free response questions

1. Linear chromosomes are generally in pairs and are found in the nucleus of eukaryotic cells and they have distinct ends. Circular chromosomes are joined at the ends and prokaryotic organisms only have one which is located in the nucleoid region.
2. When cells are not dividing, chromatin is present, which is a very long stretched out (decondensed) version of chromosomes, that cannot be seen under a light microscope. Only condensed chromosomes during cell division can be seen.
3. The possible base pairings are: A-T, T-A, G-C, C-G.
4. a) Any phosphate, sugar and base combination. Some examples are below:



   b) There are four nucleotides shown here.
5. A are complementary bases, B is a deoxyribose sugar, C is a phosphate group, D is weak hydrogen bonds.
6. DNA replication is the process during which the DNA molecule on a chromosome makes an identical copy of itself. It is called semi-conservative because the original DNA is made up of 2 complementary strands and the 2 new DNA molecules will each have one original strand and one new strand.
7. a) Information is stored in DNA in the number, sequence and type of organic bases (A, T, G or C).
   b) DNA replication makes an identical copy of the original DNA molecule. When a cell divides, DNA is passed on to the new cells that are formed. If the division is mitosis or binary fission, each daughter cell has the same DNA as the parent.
8. Chloroplasts and mitochondria. It is theorised that the were both originally independent cells. Therefore, they both likely contain codes for molecules required by the organelle.
9. A chromosome refers to the structural unit, made up of DNA and protein, that contains the hereditary information. When DNA divides during replication, a chromosome makes another copy of its DNA molecule and, for a brief period, the chromosome is made up of 2 identical DNA molecules called sister chromatids.
10. The chromosomes are made up of genetic information. Different species have different features and characteristics and therefore have different numbers and types of chromosomes, each coding for the characteristics specific for that species.
11. Just as a cell could be described as a structural unit that builds a multicellular organism, a chromosome is often described similarly because it is a visible structure that contains information in the form of bases (A, T, C, G) that will provide a code for genetic information.
12. If guanine is 30%, then cytosine is also 30% which means together they are 60% of the bases. Therefore adenine and thymine make up 40% and, since A and T are always equal, thymine will be 20%.
13. The complementary strand would be: **3' T T C C G A A C G 5'**
14. a) As DNA is made up of 2 strands that are complementary to each other, Watson and Crick recognise that if the 2 strands were to separate this would expose the bases and new bases could pair on each exposed strand creating 2 identical DNA molecules.
   b) When cells reproduce, they usually produce daughter cells that are identical to the parent cell (sex cell production is an exception). If the cells are to be identical, they must have equal and identical copies of the chromosomes, hence DNA replication.

Chapter 1.2 Suggested answers

Multiple choice questions

1. L 2. M 3. J 4. K 5. M 6. M 7. J 8. L 9. M 10. J

Free response questions

1. Genes are unique sequences of DNA nucleotides that code for a polypeptide. Each gene is located in a particular position (locus) on a specific chromosome, hence the term 'linked'.
2. a) messenger RNA (mRNA) - carries gene message to ribosomes for translation

   transfer RNA (tRNA) - transports specific amino acids to codon

   ribosomal RNA (rRNA) - important constituent of ribosomes which are the site of protein synthesis

   microRNA (miRNA) - regulatesgene expression after transcription by binding to mRNA and deactivating it

   b) Genes are sections of DNA that are inherited from previous generations hence the term 'unit of heredity'.
3. a) About 98% are introns and 2% are exons in humans.

   b) It is now known that introns can code for rRNA, tRNA and miRNA. These molecules have essential roles in protein synthesis and gene expression.
4. The appropriate nucleic acids are:

   a) DNA
   b) tRNA
   c) DNA
   d) DNA
   e) RNA
   f) DNA
   g) tRNA
   h) mRNA and DNA (coding strand)
   i) mRNA and miRNA
   j) tRNA and DNA (template strand)
5. The completed table is:

DNA	→	mRNA	→	tRNA
A	→	U	→	A
T	→	A	→	U
G	→	C	→	G
C	→	G	→	C

6. For a protein with 12,300 amino acids, there will be:

   a) 12,300 codons

   b) 36,900 nucleotides
7. The completed table is:

DNA anticodons (template strand)	**AGA**	GCC	CTG
mRNA codons	UCU	**CGG**	GAC
tRNA anticodons	AGA	GCC	**CUG**

8. A DNA-template for transcription
   B mRNA-carry message to the ribosomes for translation
   C RNA polymerase-enzyme necessary for transcription
   D RNA nucleotides-needed to assemble mRNA
   E nuclear membrane-defines and contains the nucleus
   F a pore in the nuclear membrane; allows mRNA to move to ribosomes
   G ribosome - site of translation
   H mRNA codon-binds to anti-codon and codes for one amino acid
   I amino acid-building blocks for polypeptides
   J tRNA-carries a specific amino acid to the ribosome
   K mRNA-translated into polypeptide
   L anticodon-binds to codon in complementary fashion
   M growing polypeptide chain-once complete it can bond with other polypeptides to form a protein
9. miRNA binds to the mature mRNA in a complementary fashion. This deactivates the mature mRNA by either promoting its destruction or by blocking the translation of it. As a result, the synthesis of the respective polypeptide is stopped preventing the expression of the gene.
10. a) The mRNA molecules are made during transcription when mRNA nucleotides that are complementary to the DNA template nucleotides bind to these exposed bases. The double helix also consists of complementary binding of nucleotides i.e. of the template to the coding strand.
    b) mRNA has uracil (U) instead of thymine (T). mRNA has a ribose sugar compared to DNA's deoxyribose sugar.
11. Transcription occurs so that cells can produce the protein molecules are required for a range of needs. This is in comparison to DNA replication which makes an exact copy of the DNA that is necessary for cell division. Transcription involves making a mRNA molecule for a gene, whereas DNA replication involves copying 2 full strands' the template and the coding strand.
12. a) Intron sections do not contain code for polypeptides and therefore need to be removed to ensure only exons are transcribed.
    b) The exons are the coding sections of DNA transcribed into polypeptides. The alternative splicing of exons means that it is possible to produce a range of different polypeptides/proteins from the one gene.
13. tRNA molecules have 2 critical binding sites. One is the anticodon which binds to a specific mRNA codon ensuring it can bring the correct amino acid into position. The other binding site is where an amino acid binds to it, each tRNA can carry only one specific amino acid.
14. The specificity of tRNA molecules, only carrying one specific amino acid, ensures that when the tRNA molecule binds to the codon on the mRNA, this specific amino acid will be placed in its correct position on the polypeptide chain. The fact that many amino acids can be carried by up to several tRNA molecules does not change or alter the accuracy of the translation process.
15. Note: Switch frame of reading to 5' to 3' first (or read from right to left).

    Note: The amino acid sequence should be determined from the mRNA codons, not the tRNA anticodons when referring to the table of mRNA codons.

	Nucleotide sequences and corresponding amino acid codes
DNA coding strand	5' A T G G A A T G G G A G C C T G A A G G A 3'
DNA template strand	3' T A C C T T A C C C T C G G A C T T C C T 5'
Messenger RNA	5' A U G G A A U G G G A G C C U G A A G G A 3'
Transfer RNA	3' U A C C U U A C C C U C G G A C U U C C U 5'
Amino acid code	met – glu -trp – glu – pro – glu - gly

Chapter 1.3 Suggested answers

Multiple choice questions

1. M 2. K 3. M 4. K 5. L

Free response questions

1. Each protein molecule has its own 3-D structure, the structure is intrinsically linked to the function of that protein. An example would be the protein insulin that has a 3-D shape complementary to a membrane receptor on several cells e.g. liver cells. When it binds to these receptors it initiates a response by the cell.
2. The original determining factor is the number, sequence and type of amino acids in the primary structure. As a result of this original make up, hydrogen bonds form between amino acids forming alpha helices and/or beta pleated sheets; this is the secondary structure. The tertiary structure forms spontaneously due to multiple forces of reactions between amino acids giving the protein its unique 3-D structure. Not all proteins have a quaternary structure. This level of protein structure arises when a protein is made up of more than one polypeptide chain.
3. Not all proteins have a quaternary structure, as they may consist of only one polypeptide chain.
4. a) Two genes code for haemoglobin, one for the alpha chain and one for the beta chain.
   b) Two alpha and two beta chains have to be synthesised at the ribosome and the four polypeptide chains are arranged together to form one protein molecule of haemoglobin.
5. The primary structure is determined by the number, type and sequence of amino acids. Each protein differs in regard to each of these 3 factors.
6. As proteins differ in their number, type and sequence of amino acids, there is an infinite number of possible proteins that can be made by changing these 3 variables.
7. Four examples (there are many more) include:
   - structural proteins e.g. keratin in skin
   - enzymes e.g. pepsin
   - hormones e.g. insulin
   - antibodies e.g. against HIV virus
8. This variation is due to the fact that it is an oversimplification to say that one gene is transcribed and translated into one polypeptide or protein. Processes, such as alternative splicing introduces variation through exons being spliced out of pre-mRNA in various ways, resulting in many possible mature mRNA's from one gene. Therefore, many possible proteins can be produced from one gene.
9. The specific shape of a particular hormone is complementary to one specific surface cell receptor embedded into a particular type of a cell's plasma membrane. When this binding occurs, it initiates a specific response inside the cell, such as gene expression of enzymes involved in the control of metabolic pathways.
10. Only cells that possess the specific cell membrane receptor that can bind in a complementary fashion to adrenaline will respond, such as liver cells.
11. Invaders such as bacteria and viruses are characterised by specific antigens or antigenic markers on their membranes. The antibodies made by the body are complementary to the antigens and bind to the bacteria and viruses. This action can assist in a number of ways in the destruction of these invaders.
12. a) It is the binding between the specific amino acids in the primary structure that leads to the secondary structure e.g. a pleated sheet.
    b) The secondary structure of a protein forms localised 3D structures called beta pleated sheets (and alpha helices). Lysozymes will have specific numbers and types of alpha helices and beta sheets based in its unique primary structure. Ultimately, the secondary structure will help determine the final 3D shape of the protein. A lysozyme will have a specific active site that enables it to break down cell walls in bacteria.
13. a) Different cells have different genes that are switched on and switched off. Not all genes are active in all cells.
    b) Gene activity is carefully controlled. There are a range of triggers that determine what proteins are made at a specific time e.g. high sugar levels in the blood trigger insulin production.
14. a) D will have a specific 3-D shape. If D was to bind to a promoter region near a gene involved in the production of A, it may stop transcription of that gene.
    b) This would mean that when ample amounts of D are available, the cell can slow or stop the production of A. This will conserve energy and reduce overproduction of D.

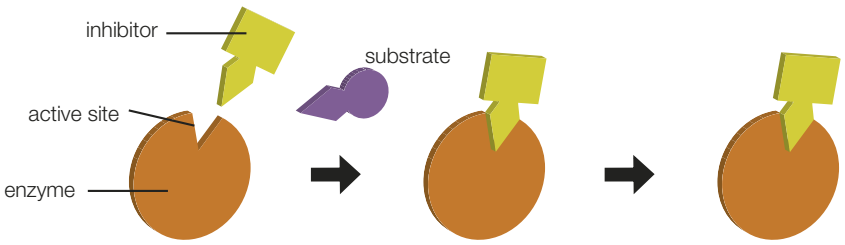
Chapter 1.4 Suggested answers

Multiple choice questions

1. L 2. L 3. M 4. J 5. L 6. M 7. K 8. M 9. L 10. J

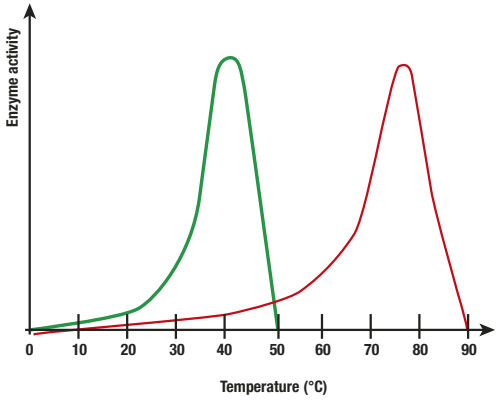
Free response questions

1. Four properties of enzymes include:
   a) biological catalysts
   b) not used up in the reaction
   c) bind to the substrate at the active site
   d) lowers the activation and energy for a reaction to proceed
2. Specificity exists between one enzyme and one substrate due to the complementary binding between an area on the substrate and the active site on the enzyme. This interaction is possible due to the special 3-D grooves and clefts on both molecules.
3. Refer to *Figure 141* or 144 for example diagram.
4. a) Lock and key model and induced fit model.
   b) The original lock and key model was simplistic in its nature and proposed that the substrate and enzyme's active site had perfect complementary shapes that fit together like a lock and a key. The induced-fit model builds on this model, highlighting that they substrate and active site of enzyme are complementary in nature but upon binding, they induce a slight moderation in each other's structure, increasing their complementary fit and increasing stress on the bonds of the substrate.
5. Enzymes are biological catalysts because they speed up chemical reactions inside cells and living organisms.
6. Some possible answers include:
   a) Physical factor (temperature): at optimum temperature the substrate and enzymes have kinetic energy enabling them to collide more frequently and bind together; however, temperatures above the enzymes optimum, progressively denature the enzymes decreasing reaction rate.
   b) Chemical factor (pH): a pH either side of its optimum may alter/denature the enzyme's binding site and thus reduce enzyme-substrate binding.
   c) Chemical factor (products): some products cause what is termed 'end-product inhibition'. The product may inhibit the action of the enzyme and prevent enzyme-substrate binding.
7. The diagram should look something like this with labels:



   With the binding of the competitive inhibitor penicillin, the active site of the enzyme is not available to the substrate and this may prevent cell wall synthesis by stopping an important reaction in this process.
8. a) A = hydrogen peroxide, B = the enzyme catalase
   b) Substrate (reactant) = hydrogen peroxide, product = water and oxygen, enzyme = catalase.
   c) This region of the enzyme catalase, where complementary binding occurs between the substrate, hydrogen peroxide and the enzyme.
   d) Catalase is specific to its substrate. Other substrates will not be complementary to its active site and therefore catalase cannot catalyse other reactions.
   e) pH, temperature, inhibitor
9. Activation energy is the energy that chemical reactions require before they can proceed i.e. they require an initial input of energy. Enzymes lower this energy and make it easier for the reaction to start i.e. they catalyse the reaction. They do this by bringing substrates into correct orientation and applying stress on bonds of substrate through induced fit model.

10. a) From A → B the initial increase in enzyme activity is very slow until a rapid rise occurs from about 35°C-37°C. The optimum temperature has not been reached yet.
    b) The optimum temperature = 40°C
    c) The optimum would be much higher ~70°-80°C. Virtually no activity would occur at low temperatures.

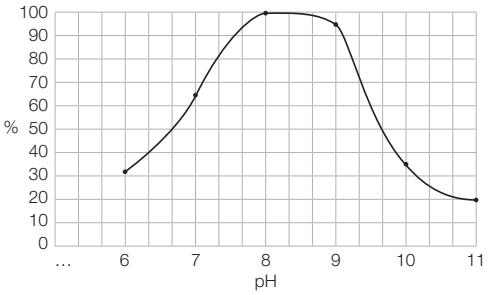


Estimated effect of temperature on enzymes of thermophilic bacteria in hot springs

11. a) They are different structures and this accounts for their specificity. Enzyme 1 and enzyme 5 would have different shaped active sites and only bind with substrates A and C respectively.
    b) No E would be produced.
    c) F would be produced in higher quantities as no C is converted to D or E.

12. a) Enzyme 2. Phenylalanine is in higher concentrations as it is only being broken down by enzyme 4.
    b) Because there will higher concentrations of phenylalanine due to the malfunctioning enzyme 2. Therefore, more phenylalanine will be converted to phenylpyruvic acid by enzyme 4.
    c) Melanin would not be produced as no tyrosine is made.

13. a) As shown in the graph to the right.
    b) The optimum pH for trypsin is approximately pH = 8.
    c) The independent variable is the pH. Dependent variable is the percent breakdown of polypeptide.
    d) Factors that should be kept constant include temperature, enzyme concentration and substrate concentration.
    e) In a controlled experiment there must only be one variable factor which is called the independent variable. If there are additional variables that are not kept constant the validity of the data obtained is reduced, which also limits the validity of conclusions to be made.

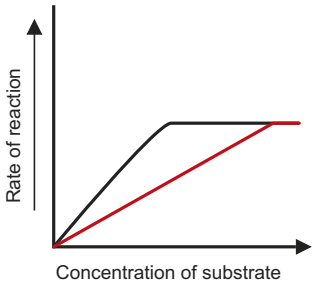


    f) The optimum pH = 8 which is where there is a maximum % breakdown of the peptide.

14. a) At cold temperatures i.e. around 5°C there are less molecular collisions. As a result, the activity of the enzyme phenoloxidase is slowed and hence there is less browning.
    b) Boiling the apples denatures or destroys the enzyme and this stops enzyme-substrate binding and consequently reduces browning.

15. a) Molecule B is a competitive inhibitor that mimics the shape of the normal substrate/reactant and thus competes with it for binding at the active site, hence reduced enzyme-substrate binding.
    b) Molecule A is a non-competitive inhibitor. By binding to another site on the enzyme called the allosteric site (i.e. not the active site), it changes the shape of the active site. This prevents or at least reduces binding by the substrate to the site.

16. a) All of the enzymes active sites are occupied by substrate molecules.
    b) As shown in the graph to the right.



17. a) Both reactions increase rapidly as enzyme concentration increases until a maximum rate of reaction is reached; this is represented by the 'plateau' region of the graph. Reaction B occurs more quickly than A and plateaus at a higher rate of reaction.
    b) The substrate concentration is likely to be a limiting factor. There is ample enzyme concentration but insufficient substrate for the reaction to go faster.
    c) A likely reason is that more substrate was added in reaction B.

Chapter 1.5 Suggested answers

Multiple choice questions

1. J 2. J 3. K 4. M 5. M 6. L 7. J 8. L 9. K 10. M 11. M 12. L

Free response questions

1. In the DNA that can be expressed, the DNA is more exposed and not wound up tightly by histone proteins. By contrast genes or DNA that are switched off tend to be wound up tightly and are inaccessible to RNA polymerase and are therefore unavailable for transcription.
2. a) They are active genes and are frequently being transcribed to produce polypeptides and protein molecules.
   b) Such genes are often termed 'housekeeping genes' and may be involved in energy supply for the cell.
3. This is the process of cell differentiation where cells become specialised for particular roles in the organism. The cells end up with these special structures and functions as the same genes are not expressed in each cell. Gene expression is regulated differently in different cells.
4. a) The epigenetic tags that define a cells specialisation are passed on to daughter cells. This results in all cells arising from that cell having the same specialisation and starts the formation of a tissue. The methylation of cytosines and deacetylation of histones can permanently cause chromatin to pack tightly and RNA polymerase cannot access certain genes, switching them off.
   b) This is because these stem cells do not have gene sequences or genes that are permanently switched off. As such, they retain their genetic potential and can theoretically transcribe into any of the approximate 21,000 genes (in humans).
5. Baldness is more common in men and not generally found in women. Males have higher levels of hormones like testosterone and this is involved in regulating or influencing the genes linked to baldness.
6. a) Cells may interact with others in the near vicinity as they possess surface cell receptors that are complementary.
   b) Cells may release hormones that bind to other cells with complementary receptors. In both instances they may stimulate genes and direct cell specialisation.
7. a) It would appear likely that temperature has influenced the activity of the gene that produces the black coloured protein in the fur.
   b) A change in environmental conditions (external temperature) has affected which gene i.e. white or black colour is expressed.
8. a) Cancer cells tend to have abnormal methylation i.e. too little or too much depending on the gene. Genes involved in cancer include suppressor genes and oncogenes.
   b) An example could be a gene involved in DNA repair. If this gene was suppressed (over-methylated) then DNA repair would be slowed and some abnormal DNA may lead to cancerous cells.
9. a) An activator will often bind in a promoter region (or another region) prior to the gene and trigger transcription, possibly by triggering RNA polymerase to release from the promotor region and start transcription.
   b) The repressor is likely to bind to the DNA and prevent the action of RNA polymerase from transcribing a specific gene.
10. This can be seen as a brief summary of the process involved in differentiation. All human cells have the same 21,000 genes but a liver cell; e.g. has different genes that are expressed compared to a nerve cell.
11. a) This is indicative of the effect of environmental factors e.g. temperature, diet and lifestyle on DNA methylation and other epigenetic changes. As the twins age. they are exposed to more different environmental factors and their epigenomes become increasingly different. These differences are then expressed physically and behaviourally.
    b) An individual may develop disease associated with changes to DNA expression OR offspring may inherit epigenetic changes that may predispose them to particular a disease.
12. a) Such genes include oncogenes that are genes that cause abnormal cell division and DNA repair genes that repair DNA before cells divide.
    b) If hyper-methylation could be detected in genes known to be associated with the disease, prior to the onset of the disease, this could alert the patient and health professionals and more screening tests could be undertaken. This would provide a greater prognosis for individuals. Additionally, a genetic test of intestinal cells could be made routine for over 50 year olds who are at higher risk of developing this disease.

13. a) Translation factors

b) i) miRNA is a short segment of RNA that is complementary to a section of a specific mRNA molecule. When present, it can bind to the mRNA to prevent any further transcription as it blocks the ribosome from accessing the full code of the mRNA strand.

ii) Specific lncRNAs can bind to specific miRNAs in a complementary fashion. Therefore, the miRNA cannot bind to the mRNA strand to stop its translation. As a result, gene expression will continue or be promoted.

c) i) Over expression

ii) Some cancers are caused by the overexpression of genes that stimulate cell division, for example proto-oncogenes. Researchers could synthesise siRNA that is complementary to a section of the mRNA transcribed from proto-onco genes being overexpressed. This could result in the mRNA of proto-oncogenes being degraded and not being expressed slowing down cell division and the spread of cancer.

d) Many members in society have lost someone close to them from cancer. It is a horrible disease, and it is hard for people to watch their loved one's battle through the treatments, which can often fail. As such, it is a very emotive topic in society, and this influences many people to fundraise for cures, donate to cancer research and put pressure on governments to increase funding, to hopefully find a cure.

e) i) If multiple variables are changed, the results collected from an experiment would be invalid. A fair experiment only changes one variable called the independent variable. If other factors are not controlled, the cause of the change in the dependent variable cannot be determined.

ii) Some possible answers include:

- If successful in developing a drug that works, increasing numbers in society could turn to this medication to control their weight instead of exercising. This could have the unexpected consequence of decreased gym memberships, putting gym owners under financial stress and personal trainers lose their jobs due to less demand.
- If an increased reliance on medication to control weight loss increased in society because of this discovery, it could see the unexpected consequence of increased diet related disorders. This is because people could feel more comfortable indulging in unhealthy energy dense foods, rather than healthy nutrient dense foods. This could result in increased numbers of disorders such as anaemia, scurvy and even certain types of cancer putting extra stress on the health system.

iii) The researchers will have to determine if the drug they have created causes any additional changes to the epigenome and the physiological effect of any resultant changes. They will also have to determine if the desired change only occurs in the target white fat cells and not other specialised cell types before applying for approval.

14. a) Some possible answers include*:*

- There are a range of factors involved in regulating gene expression such as transcription factors, translation factors and epigenetic factors.
- RNA splicing can regulate what sections of mRNA are translated.
- Promoters are regions of the DNA that can be either activated or repressed by factors binding to them, again either switching genes on or off.
- miRNA, siRNA and lncRNA can all influence gene expression post-transcription.

b) Some possible answers include:

- The environment can influence gene activity. Diet and lifestyle, temperature and a range of chemicals are a few examples that can influence change in epigenetic markers.
- Histone proteins are packed with the DNA and in regions where they are tightly packed, genes are usually switched off; therefore, RNA polymerase cannot access the DNA.
- Acetylation of histone proteins can switch genes on as DNA becomes more loosely packed. Deacetylation of histones results in more tightly packed histones, switching genes off.
- Methylation to cytosine bases is also a factor. Highly methylated regions of DNA are generally switched off. These factors can be passed on from parents to their children.
- It would appear that exposure to PAHs is causing epigenetic changes in prospective parents in the ACSL3 gene (e.g. increased or decreased methylation and acetylation) and this is contributing to an increase in asthma.

Chapter 1.6 Suggested answers

Multiple choice questions

1. M 2. J 3. M 4. K 5. L 6. M 7. L 8. J 9. M 10. L

Free response questions

1. Examples of such mutagens include:

   Chemical: cigarette smoke, benzene, asbestos

   Physical: UV radiation, gamma radiation, X-rays

   Biological: viruses

2. The four main types of chromosome mutations are: deletion, duplication, translocation and aneuploidy.

3. a) During DNA replication where bases are exposed and single base substitutions, insertions and deletions can occur.

   b) Often occurs during meiosis where chromosomes pair together providing the opportunity to occur. The homologous pairs then separate to form gametes with these new large scale mutations.

4. Interfering with normal base pairing and creating bonds that would not normally occur or breaking DNA links or bonds.

5. The chemical mutagens may mimic the shape (or be similar to the shape) of a normal base, and hence bond with its complementary base instead of a nucleotide base. The chemicals may alter or damage normal bases interfering with their normal base pairing.

6. a) The missing items are shown in bold:

Original DNA	CGA	CAC	GGT	ATA
Altered DNA	CGA	GAC	GGT	ATA
mRNA codon	**GCU**	**CUG**	**CCA**	**UAU**
Amino acid code	**ala**	**leu**	**pro**	**tyr**

   c) Guanine has been substituted for cytosine.

   d) A missense mutation has occurred where a valine has been replaced with a leucine.

   e) The missing items are shown in bold:

Original DNA	CGA	CAC	GGT	ATA
Altered DNA	CGA	ACG	GTA	TAT
mRNA	**GCU**	**UGC**	**CAU**	**AUA**
Amino acid code	**ala**	**cys**	**his**	**ile**

   g) A single base deletion has occurred. A cytosine (C) base was deleted.

   h) As a single base was deleted, the codes are all different after the deletion and the 'reading frame' has been moved. The frameshift mutation has resulted in a different amino acid where valine, proline and tyrosine have been replaced by cysteine, histidine and isoleucine. This will have a significant effect on the structure and function of the protein and could also result in a stop codon being introduced earlier and result in a shorter polypeptide.

7. Both mutations and epigenetic changes can alter gene expression and both can be inherited if the changes appear in gametes. Mutations, though, are permanent changes to the base sequence and can give rise to altered or faulty proteins. Epigenetic changes are usually expressed by methylation and can be changed as an organism's environment and experiences change. This means gene expression is dynamic and can range from being switched on to being completely switched off.

8. a) The third codon has a T instead of an A.

   b) Single base substitution.

   c) This is a missense mutation because it has resulted in the change in one amino acid (glutamic acid is changed to valine).

d) Protein structure is a determining factor for its function. Changing one amino acid in a critical position may alter the 3-D structure and hence affect the function of haemoglobin. This will affect its role of transporting oxygen to the body's cells as it may not be able to bind to oxygen as efficiently.

9. a) If benzopyrene causes a mutation that alters a particular gene's function, that controls cell division involved in controlling cell division, this may alter the normal function of the associated protein and lead to uncontrolled cell division.

   b) The mutation is in a somatic or tissue cell. Only mutations in germ-line cells giving rise to gametes can be passed on to the next generation.

10. If all life evolved from a common ancestor, then as mutations are the only source of new genes, it is the mutations in DNA which made new species possible as new characteristics rose from changes to the DNA.

11. Somatic or tissue mutations could give rise to cancer, but it would only affect the individual. Germ-line mutations could be passed on to the next generation and affect the descendants but not the individual (e.g. cystic fibrosis).

12. Several mRNA codons code for the same amino acid e.g. UUU and UUC both code for phenylalanine. Therefore some mutations may change the codon but not the amino acid. This is called a silent mutation.

13. a) The disorder is an extra X chromosome, this is an example of aneuploidy.

    b) This is likely to have occurred in meiosis. The chromosomes did not separate correctly when a gamete was formed.

    c) The individual has an extra chromosome i.e. XXY. To have so many extra genes interferes with normal gene expression in the phenotype.

14. Cancerous cells are undergoing uncontrolled cell division as some genes in their cells are abnormal. The drug etoposide can cause chromosomal breakages, which may destroy these abnormal cancerous cells.

Chapter 1.7 Suggested answers

Multiple choice questions

1. J 2. K 3. M 4. M 5. L 6. J 7. M 8. M 9. L 10. L 11. K 12. L 13. J 14. L 15. M

Free response questions

1. There are many possible answers. Three examples are:

   a) It may be used inappropriately e.g. by an insurance company.

   b) The economic costs involved to collect and hold vast quantities of data.

   c) Regulation of who has access to this data.

2. Some possible answers are:

   - They need to have a complementary base sequence to the gene of interest.
   - They need to be radioactive or fluorescent to identify their position.
   - They can be RNA or DNA.
   - They are short sequences (about 22 bases) manmade in a laboratory.

3. a) To separate the double helix (break hydrogen bonds) and expose the DNA bases on the strands.

   b) Human DNA polymerase would denature, changing shape of its active site and therefore be unable to bind to the substrate.

4. Restriction enzymes cut DNA at specific sites and expose a particular group of DNA bases as a result of the cut. When all the suspects DNA are cut with the same restriction enzyme, the DNA samples are all cut at the same restriction sites allowing a fair comparison of DNA profiles.

5. The segments of DNA moved towards the positive end of the gel as they are negatively charged (repelling from negatively charged loading well end of plate). Larger segments tend to move more slowly, and shorter segments move more quickly through the gel due to less restriction with the gel.

6. The number of copies will be $2 \times 2 \times 2 \times 2 \times 2 \times 2 \times 2 \times 2 \times 2 \times 2 = 2^{10} = 1024$ copies

7. a) Sources A and C have the same profile as the contaminated beef , therefore two.
   b) Since 2 out of the 4 sources were contaminated, this is 2/4 = 50%.
8. a) PCR which can multiply DNA in the laboratory to make multiple copies for analysis.
   b) DNA sequencing. When scientists need to actually identify differences in base sequences between two species.
   c) Gel electrophoresis, which can look for banding patterns that are associated with the abnormality.
9. a) 5' - TCAAGCGCACT - 3'
   b) 5' - AGTTCGCGTGA - 3'
10. a) Repeat offenders may have got away with their crime in the past but may leave genetic evidence at the scene of the next crime as well and convicted using DNA profiling. If they also left genetic evidence at the scene of previous crimes, this can also be checked and they can be charged for those crimes too, now that the police has their DNA profile on the database.
    b) There is international co-operation and communication between law enforcement agencies (e.g. Interpol) to share such stored data on suspected criminals. Recently, the USA updated their number of STR profiles tested to align with some loci tested internationally, making international collaboration easier.
11. Single-stranded ('sticky') ends enable host and donor DNA to bind in a perfectly complementary manner and hence can form recombinant DNA between the two species.
12. a) The suspect's DNA could be run in the manner described above in the gel electrophoresis. The DNA samples are cut using the same restriction enzyme, resulting in DNA fragments of different lengths based on unique repeating patterns. These bands are separated by size and charge using this process. DNA banding patterns are unique for individuals and as such, if DNA found at the scene of a crime matches that of a suspect, this provides very good evidence.
    b) The hybridising enables the radioactive RNA probe to bind to the single-stranded DNA. Using the radioactivity, scientists can now readily identify the position of the segment.
13. If these sections have low mutation rates, it suggests the DNA sequences are stable over time which is good for profiling. This is also good for tracing ancestral links for humans and other species.
14. DNA sequencing actually identifies DNA base sequences and can be used for gene analysis e.g. looking for gene defects. DNA profiling is looking at segments of DNA and can be used in forensic science.
15. a) On the left, redraw showing segment 2 moved to the left until it overlaps the DNA of segment 1.
    b) The cutting points will be between the fourth and fifth base (G-A) from the left on the upper strand and between the eighth and ninth base (A-G) on the lower strand.
16. a) Other than fragment size, factors include charge, temperature, gel consistency.
    b) i) The 5th nucleotide from the left is C in sequence 1 but G in sequence 2.
       ii) A codon has been altered and when it is translated it may lead to a different amino acid being inserted at this position in the polypeptide.
17. a) STR (short tandem repeats) are a short sequence of bases in an individual's DNA sequence that is repeated. It is known that the number of repeats vary significantly between people and therefore can be used to identify them.
    b) One allele comes from each parent.
    c) In marker D21S11: The evidence contained the alleles 28 and 29, so also did the victims DNA. The suspect did not contribute a new marker at this site.
    d) In markers D8S1179 and D7S820: In each case the suspects DNA STRs were the alleles 14 and 9 respectively, this was also present at the evidence at the crime scene but not present in the victims DNA. This suggests that the suspect was at the crime scene.
18. a) AATACAGACGAGTTCCGAAAATACCACGTTAAACGAAAGAATT
    b) UUAUGUCUGCUCAAGGCUUUUAUGGUGCAAUUUGCUUUCUUAA
    c) AAUACAGACGAGUUCCGAAAAU

d) Some example answers are:

(i) The mandated nationwide collection of genetic information is a violation of Kuwaiti citizens' right to personal privacy and international human rights law. Additionally, it is unclear how the genetic information will be used, and it is possible that the information could be used to discriminate against particular groups within society.

(ii) Tourists would also have to give their DNA to Kuwait authorities. This could have resulted in a decrease in tourists to Kuwait as individuals not wanting to hand their DNA over would choose another destination. Therefore, the application of this mandate would result in reduced economic input to their tourism industry.

(iii) Groups in society, such as Kuwaiti citizens, human rights activists, and lawyers specialising on human rights law, collectively put public pressure on Kuwait and got the attention of the media. This public pressure influenced Kuwaiti lawyers to bring a legal challenge against the mandate, and the court overturning the mandate.

19. a)

STR Locus	Evidence Sample
D8S1179	13, 16
D21S11	28, 29
D7S820	9
CSF1PO	11, 12

b) The individual is homozygous for the D7S820 STR. This means that the individual has inherited both alleles for this STR with 9 repeats for his/her parents.

c) (i)

STR Locus	Charlie	Becky	Tommy	Bailey
TPOX	15	13	10	13
D8S1179	16	13, 15	16	13, 15
D18S51	13, 18	13, 16	13, 18	13, 16

(ii) Becky and Bailey because they both have the exact same number of repeats for the three STR loci provided.

(iii) The conclusion is limited because only three STR loci have been analysed. A DNA profile generally requires about 13 STR loci to be analysed so that the chance of having the same set of alleles is very low. With only three STR loci analysed, there is not enough data to indisputably illustrate identical twins.

20. a) Suspect 2. The crime scene sample is likely to be a blend of the victim and suspect 2. This is because at every STR locus, both alleles for the victim and suspect 2 were present. Not all of suspect 1's alleles were present at all of the gene loci. For example, at TPOX the STR allele 20, was not present. There are also 13 STR loci investigated.

b) The crime scene sample is likely to be a mixture of the victim and criminal. Given that it seems to be a mixture, each person can carry a maximum of two alleles for a particular STR (one from mum and one from dad).

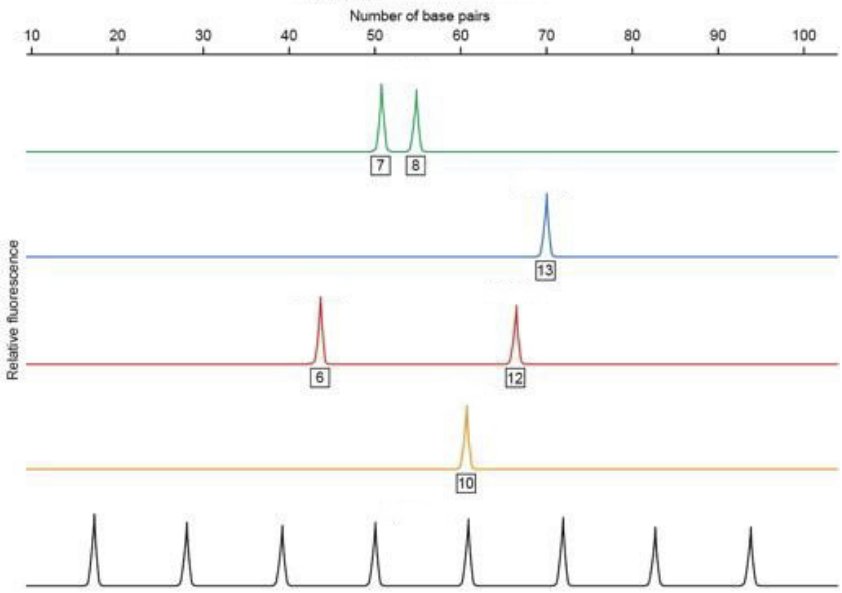
c) Confidence in the results of the DNA profile is high because there are 13 STR loci being compared. This means the chance of another individual having the same set of alleles for all 13 STR loci is very low (about 1 in 10 trillion).

21. a) Refer to the answers in the table below:

STR locus	Number of base pairs for allele 1	Number of base pairs for allele 2	STR repeat	Number of repeats for allele 1	Number of repeats for allele 2	Heterozygous or homozygous
STR D5S818 on Chromosome 5	51	55	AGAT	7	8	Heterozygous
STR CSF1PO on Chromosome 5	74	78	AGAT	14	13	Heterozygous
STR D7S820 on Chromosome 7	55	79	GATA	9	15	Heterozygous
STR D8S1179 on Chromosome 8	53	69	TATC	7	7	Homozygous

b) Allele 2 of D7S820 will travel the least distance because it is the longest DNA fragment of the 8 being tested; therefore, it will experience the most resistance as it travels through the agarose gel.

c) Draw spikes at the corresponding number of base pairs for each STR locus:



Chapter 1.8 Suggested answers

Multiple choice questions

1. J 2. M 3. J 4. L 5. L 6. K 7. M 8. L 9. M 10. K 11. L 12. J 13. K 14. M 15. L

Free response questions

1. a) A donor species with a gene resistant to the herbicide needs to be identified. The gene is removed, placed in a donor and transmitted to the cotton plant which can then be cloned as a GMO.

   b) It would enable farmers to spray the chemical directly on the cotton crop to kill weeds without impacting on the cotton plant itself, increasing yield and profits.

2. Some possible answers include:
   - Hormones–insulin is used to treat people suffering from diabetes.
   - Enzymes–Cas9 is a restriction enzyme used in cutting genes from DNA
   - Antigens–used in vaccinations to confer immunity to specific diseases.
   - Antibodies – used to provide passive immunity to specific pathogens.

3. Some possible answers include:

a) Individuals or groups may have religious beliefs that centre around not altering organisms in any way and that we are all 'made in the image of God' as we are naturally.

b) They may not have an understanding of the DNA and genetic engineering and therefore be hesitant not to consume something they don't understand.

c) They could have heard misinformation from friends or social media resulting in unwarranted concern.

d) They may have concerns about possible unknown side-effects of such food.

4. Some possible answers include:
   - Genes that have been transferred to a 'target species' may also accidentally be transferred to unintended species through cross-contamination and have unintended results.
   - Such crops may disrupt the food webs by changing balance and interactions between species currently in equilibrium.
   - Weeds may become resistant to herbicides used and more toxic ones may be required, which could contaminate waterways and higher order species through biomagnification.
5. Tomatoes can ripen early due to the action of specific proteins associated with ripening. If the production or availability of one of these ripening proteins was disrupted, early ripening would be prevented. A possible method of disrupting ripening could be inserting genes that code for proteins that degrade ripening proteins.
6. a) This is similar to restriction (endonuclease) enzymes, Cas9 cuts DNA at particular sites.

   b) Guide mRNA would bind in a complementary manner to the DNA adjacent to the cutting site.

   c) It may bind to a complementary section but not adjacent the specific gene that was needed because there could be multiple repeats of the code in the species' genome.
7. Some possible answers include:
   - It is a matter of personal choice, particularly if it involves the mistreatment of animals.
   - There are issues surrounding accessibility to the technology, particularly if it is for commercial gain by individuals or businesses.
   - Three is the possibility that we cannot safeguard against exploitation for commercial gain and unethical use.
8. Some possible answers include:

   a) Medical reasons: some genetic diseases are linked to gender.

   Family reasons: some may have several children of one gender and desire the other gender.

   b) This would set a dangerous precedent and could have a snowball effect to the production of 'designer babies'.

   The possible destruction of embryos of the 'undesired' gender.
9. Microinjection results in donor DNA being injected into the nucleus of a cell. For this to alter the host DNA the donor DNA must be incorporated into the genome. One possible reason that it may be unsuccessful is that it may be destroyed as foreign DNA.
10. Some possible answers include:
    - CRISPR has the ability to edit live organisms, whereas traditional genetic engineering cannot, and genes must be inserted into 'first cell' so it is expressed in all the organism's cells.
    - This technique is quick, easy and more cost-effective to use.
    - This technique is much more accurate and efficient than previous techniques.
11. a) A deletion of a DNA codon would result in a missing amino acid in the resulting ion channel protein produced during translation. This is because one codon codes for one amino acid. As a whole codon is deleted, only one amino acid is deleted from the sequence and a frameshift mutation is avoided. The deletion of one amino acid has changed the ion channel proteins structure and it cannot perform its function efficiently resulting in cystic fibrosis.

    b) Through DNA cloning. The 'normal' human gene that codes for the normal protein (preventing cystic fibrosis from occurring) is isolated using restriction enzymes and annealed to a bacterial plasmid (using DNA ligase) that has been removed from a bacterium. The plasmid, with the 'normal' human gene, is then re-inserted and the bacterium can divide by binary fission making multiple copies of the gene that can be extracted and used for gene therapy.

12. a) Scientists can also insert a gene that codes for antibiotic resistance with the gene of interest. Therefore, any transformed bacteria that have to recombinant plasmid will grow in the presence of the antibiotic in the agar. Those bacteria that don't take up the plasmids die because they won't be resistant to the antibiotic.

    b) Some examples include human growth hormone, blood clotting factors, some antibiotics, some bacteria derived toxins, etc.

    c) Some **possible advantages** include

    - Yeast are generally safe, inexpensive and easy to observe.
    - The genomes of the commonly used yeast have been sequenced and genes have been mapped making it a useful tool for biopharmaceutical industry.
    - Yeast can synthesise more complex eukaryotic proteins.
    - The yeast can make the required modifications to the proteins after being translated.
    - They grow and reproduce quickly, therefore produce large quantities of the protein quickly too.

    Some **possible disadvantages** include:

    - Yeast can produce methanol which is flammable.
    - Glycosylation (addition of carbohydrates) of proteins is different in yeasts compared to in human cells, which can lead to less effective vaccines

    d) Herbicide resistant soybean is resistant to a herbicide, therefore the herbicide can be applied to the crop fields, killing the weeds but not the GM soybean. This reduces competition for nutrients and increases soybean yield and profits for farmers. However, GM pest resistant corn can produce its own pesticide, which means farmers do not have to spray these crops with the pesticide, saving money. As the GM corn can produce its own pesticide, crops are not destroyed by insects, maintaining a high yield too.

13. a) Some example answers are:

    - This technology could result in the production of an omega-3 DHA supplement that has not caused harm to animals and is suitable for vegans concerned with the ethical treatment of animals to consume. This could result in better health outcomes for vegans, especially pregnant or lactating mothers (and their infants), who previously may not have been able to consume adequate omega-3 DHA.
    - The ability to produce omega-3 through GM crops instead of sourcing from deep sea fish could be more sustainable and have a positive impact on ocean ecosystems. There is currently unsustainable pressure being placed on our ocean ecosystems including sourcing omega-3 feed for salmon farmers from the oceans. If omega-3 harvested from canola can be fed to salmon instead, this would reduce pressure on the ocean ecosystems. Furthermore, fish would no longer be required to make omega-3 supplements further reducing the environmental impacts of farming the fish to make these supplements.

    b) An example answer is:

    - If Nuseed Pty Ltd is able to develop the DHA into a supplement, this could shift consumer spending to purchase their supplement rather than other companies DHA supplements. If there was a large shift towards the more ethically produced supplement, this could unexpectedly reduce existing supplement company profits, resulting in job losses and possible company bankruptcy.

    c) Some example answers are:

    - Currently, the Office of Gene Technology Regulator (OGTR) has only approved the Omega-3 canola for a field trial, and it hasn't been approved to be grown commercially. This obviously limits its potential use for society. Even if the OGTR does approve Omega-3 canola for commercial use, some states and territories such as South Australia and Tasmania have legislation banning farming of GM canola due to marketing concerns.
    - If commercial use is approved by the OGTR, it will still take Nuseed time to organise the crops growth and processing to release its human nutrition product, Nutriterra. This product still needs further testing for approval by the Food Standards Australia and New Zealand to be used in formula products.
    - The growing and harvesting of Omega-3 Canola requires land use, which is a valuable resource. The crops will also likely require water, fertilizer and pesticide use. The land and resources could be used for other purposes such as growing crops or livestock for the growing population.

14. a) The primary structure of a protein determines its shape but there are almost limitless possible folds a protein can take based on the interactions between amino acids in the chain. Scientists have been researching this 'protein folding problem' for 50 years but it has been hard to design a new protein because computers have not been powerful enough to process the required information.

    b) Some possible proteins to combat disease include:

    - Antibiotics – could be used to cure bacterial infections.
    - Antivirals – used against viruses such as HIV.
    - Immunotherapy proteins – used to treat cancer.

    c) (i) Scientists have had a great idea to collaborate with the general public and effectively, increase their research team. The creation of Foldit, and its ease of accessibility to citizens, can allow gamers and other people who are keen puzzle solvers to have fun and be challenged, but at the same time contribute to important research that they would otherwise not be able to. The collaboration with 'citizen scientists' increases the chance of finding a solution to problems regarding protein folding that scientists have been working on for years. It also increases the scope of possibilities of new protein design. This is because people think in different ways. In addition, most gamers love to 'win' and by making a game out of the protein folding problem, scientists have increased the chance of making new proteins for particular diseases.

    (ii) Some possible answers include:

    - The field of ecology could use citizen scientists to help them collect and record data such as studying population trends. This could involve citizens entering data on species they find, such as the bird watching community recording the number of bird species they see in a particular area.
    - Citizen scientists could report the sightings of animals to collect data on their population size and geographical range.
    - Counting numbers and types of insects to help scientists collect data to determine if numbers are in decline and their geographical distribution.

15. a) CRISPR is a new technology that enables very precise incisions to be made in DNA and the ability to manipulate and alter DNA in a much more efficient manner. The 'guide RNA' can be synthetically made to guide the enzyme to exact locations on the DNA. The CAS9 enzyme cuts at the position indicated.

    b) A possible mode of action could involve altering the DNA in the immune cells so that they possess molecules on their surface that can bind to cancer cells. This would enhance the ability of the immune cells to target the cancer cells and destroy them.

    c) Some possible answers include:

    - This technique is largely untested and therefore it cannot be used in humans right now to treat conditions such as HIV/AIDS and cystic fibrosis.
    - There may be unexpected outcomes, such as the potential for the CRISPR/Cas9 to cut in the wrong location if the guide RNA sequence is also located in other areas of the genetic code.

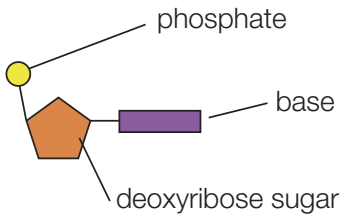
Topic 1 Review test suggested answers

Section 1: Multiple choice questions

1. K 2. J 3. K 4. K 5. J 6. J 7. M 8. M 9. L 10. M

Section 2: Free response questions

11. a)



b) Either C and B or D and A.

c) DNA replication produces two DNA molecules from the original. In each molecule formed in the double helix, one strand is an original strand (conserved), the other is a newly synthesised strand.

12. a) 3150 (3 bases code for one amino acid).

b) i) Translation.

ii) **Some similarities include**: that each molecule consists of a sugar phosphate backbone, nitrogenous bases and that the message/information is read in groups of three bases.

Some differences include: that DNA is normally found as a double helix (two strands) whereas molecule D (mRNA) is a single strand, and that the base thymine (DNA) is replaced by the base uracil (mRNA) in molecule D.

iii) tRNA contain a complementary anticodon to a specific codon on a mRNA molecule. At the opposite end of the molecule, tRNA have a specific amino acid attached that it carries to the mRNA chain at ribosome. Once released from ribosome, tRNA molecules bind to the same specific amino acid for future involvement in translation.

c) i) A protein's structure is determined by the genetic code. Each type of collagen is coded for by a specific genetic code and therefore specific sequences of amino acids. A protein's structure determines is function. The 24 types of collagens will have slightly varying structures and therefore different functions that suit the needs of different tissues.

ii) The quaternary structure is the arrangement of those protein molecules that have more than one polypeptide chain.

d) Because collagen is a protein which can denature in a morning coffee due to the high temperature. Denaturation changes the structure and function of proteins, and the consumed collagen would therefore not produce its desired effect of improved skin quality.

e) An example of a possible answer is:

i) The wellness corporations have a vested interest because they want their products to sell to consumers to increase profit margins. Independent studies are required to ensure that valid experiments are performed so that valid conclusions can be made (and validate or invalidate claims of companies with a vested interest). Without valid and independent data to compare to, consumers could believe the conclusions derived from wellness corporation funded experiments and this could influence their choice to purchase the product. This could result in consumers wasting their money as the product may not produce the desired effect.

ii) Some possible answers include:

- The collagen supplement could be contaminated. This could result in food poisoning and additional associated health consequences.
- An individual could have an allergy or intolerance to the collagen powder. This could cause serious health consequences such as anaphylaxis, and other symptoms associated with allergies/intolerances.
- The individual could gain weight. This is due to likely increased energy intake as collagen is made up of amino acids, which provide the body with energy.

f) Some possible answers include wearing a hat, applying sunscreen, staying in the shade, etc.

g) Some examples include cigarette smoke, asbestos, mustard gas, etc.

h) Normal DNA codon: GCA

Mutated DNA codon: ACA

i) Altering one amino acid will change the primary structure of the polypeptide. This may alter the forces of attractions between amino acids, and therefore the secondary, tertiary, and possibly the quaternary structure of the Type 2 collagen protein. A change in structure will cause a change in function of the Type 2 collagen protein in cartilage and could result in osteoarthritis.

13. a) An understanding of a metabolic pathway and how mutations in genes alter the product, in this case individual enzymes.

b) Possible variables include: temperature, availability of sufficient precursors, enzymes, pH.

c) They were thinking that one gene coded for one protein. It is now known that one gene may code for a polypeptide or a protein.

d) The products being formed (or not) ornithine, citrulline or arginine and their concentrations.

e) Exons are regions of DNA that code for a protein or polypeptide. Introns are sections of the DNA that do not code for proteins or polypeptides.

f) Introns have been discovered to code for other important molecules involved in protein production including rRNA, tRNA and non-coding RNAs that control gene expression (miRNA, siRNA and lncRNA).

g) One gene codes for multiple polypeptides (not just one).

h) An example of a limitation is:

- Exon skipping/splicing to create a variety of polypeptides from one gene may not occur in all species and this revised definition may not be suitable to define all genes in all species (for example only 40 to 60% of human genes are known to exhibit alternative splicing). Further research is likely required.

14. a) To amplify or produce many copies of the DNA.

b) The “blood of a suspect” has the shortest DNA fragment. This is because DNA is negatively charged and repels away from the negative terminal of gel electrophoresis (located at loading wells) and is attracted towards the opposite positive terminal. Therefore, the smallest fragment travels the furthest distance, which is seen in the “blood of a suspect” profile (furthest from the top of the profile).

c) There is a perfect match between the victim’s DNA profile (fingerprint) and the one from the suspect’s shirt (all 5 bands have the same length and align). Therefore, it can reasonably be concluded that the suspect has the victim’s blood on their shirt.

15. a) i) Increased acetylation of histone proteins. Note: it is also possible for methylation of histone proteins to result in decondensing of chromatin, but it depends on the amino acid being methylated and number of methyl groups added as to whether the chromatin condenses or decondenses.

ii) The genes in the area of the condensed chromatin are ‘switched off’ because they are tightly wrapped around histone proteins and cannot be accessed by RNA Polymerase (for transcription). Therefore, there is decreased gene expression of genes in the localised area of “A” for the cell.

b) If the baby is born into a world experiencing famine, then it is as biologically prepared as can be to face the threat and this increases its chance of survival.

c) One possible answer is:

If the infant is biologically prepared for a famine, then this could have caused activation of genes associated with increased absorption of nutrients from food. This impact could last as the individual ages and because there is ample food, it is likely an excess will be consumed and stored within the body. This could contribute to obesity, type 2 diabetes, and other disorders/diseases.

d) The guide RNA could be programmed to recognise known methylated cytosine base(s) within a known DNA sequence and replace them with an unmethylated cytosine base to open chromatin and increase gene expression.

e) An example answer for society is:

- Pregnant women and their families would be able to make educated decisions about diet and lifestyle choices leading up to and during the pregnancy. This could reduce risks of their children developing the condition(s) and possibly reduce associated financial costs to families of diagnosing and treating/managing these conditions as costs of living increases.

An example answer for governments is:

- Governments could continue to communicate findings through multiple avenues such as making it mandatory for doctors to discuss with pregnant women. Increasing awareness and understanding of how environment impacts genetics and offspring could lead to a certain percentage of pregnant women making lifestyle changes that decrease risk of epigenetic linked disease in offspring. This could help to reduce the pressure on the health system and allow governments greater financial flexibility to address other needs/desires of society.

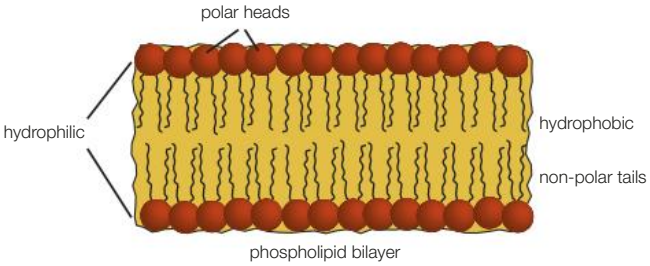
Chapter 2.1 Suggested answers

Multiple choice questions

1. J 2. K 3. M 4. K 5. L

Free response questions

1. Underlying principles are:
   a) Cells are the units of structure and function in all organisms.
   b) New cells arise from pre-existing cells.
   c) Cells require and use energy.
   d) Cells contain DNA as hereditary information.
2. Some examples include:
   a) Electron microscope; observing structural details of all cells.
   b) Computer technology; sequencing DNA of the human genome to improve understanding of genes.
3. Some examples include:
   a) The red blood cell: small and bi-concave shape to increase surface area for exchanging oxygen. Epithelial cells with microvilli: to increase surface area to allow increased movement of molecules (e.g. absorption of materials from the gut).
   b) Mesophyll cells; packed with chloroplasts to enable photosynthesis. Guard cells; controlling the opening and closing of stomates to allow gas exchange.
4. Phospholipids in the bi-layer, cholesterol (animal cells), proteins embedded, carbohydrates on the surface.
5. 'Fluid' explains the ability of molecules to constantly move about in the phospholipid bi-layer. 'Mosaic' refers to the variety of proteins on the surface, transmembrane proteins and proteins on the inner surface, and a variety of proteins with different structures.
6. Two example answers include:
   a) Carrier proteins: facilitate movement of specific molecules between internal and external environment.
   b) Receptor proteins: bind to specific complementary molecules to bring about a response.
7. Some possible answers include:
   a) It is semi-permeable. Only small molecules can move through. Its lipid nature tends to repel polar/charged substances.
   b) There may be specific carrier proteins that span the membrane to assist in the movement of specific substances (e.g. active transport of glucose into the cell, from low to high concentration).
8. Three possible answers are:
   - do not have normal cell structure and chemicals
   - they do not transform energy
   - they can only divide by using a host cell's replication mechanisms
9. Water is a polar (charged) molecule and the non-polar lipid tails of the phospholipid are repelled by this. As such a bi-layer with polar phosphate heads are outside and non-polar lipid tails face inwards.



10. The most likely properties are as follows:
    a) the lipid nature repels polar water molecules.
    b) mainly due to the non-polar lipids repelling the charged (polar) molecules.
    c) very flexible/dynamic bi-layer that can be added to and detracted from (e.g. endocytosis and exocytosis).
    d) protein receptor molecules that bind to complementary molecules from other cells.

11. The cell membrane allows some molecules to move through but not others. Structural characteristics of the membrane that assist in controlling the movement of molecules include the chemical nature of phospholipids, the presence of channel and carrier proteins, and its flexible nature (which enables it to enclose molecules in vesicles).
12. a) For the growth hormone to bind, it needs to bind to a receptor molecule that has a complementary shape. Not all cells in humans have molecules or receptors that are complementary to this specific growth hormone.

    b) The binding sets off a signal which can alter gene expression in the nucleus. This could involve a hormone which could alter calcium availability in the blood. Calcium is needed for bone formation.
13. Being soluble in lipids allows DDT to move easily through the lipid bi-layer thus accumulating inside cells and reaching toxic levels. Insects that feed on crops sprayed with DDT are consuming the DDT. Insects are generally lower trophic level organisms (bottom of the food chain), which can result in the toxic DDT being passed on to insect eating bird (and the rest of the food chain). As insect eating birds consume many insects, the DDT can accumulate inside cells to toxic levels and cause disease and possibly death.

Chapter 2.2 Suggested answers

Multiple choice questions

1. L 2. M 3. J 4. J 5. M 6. K 7. L 8. J 9. M 10. K 11. K 12. M 13. M 14. L 15. M

Free response questions

1. Some possible answers include:

Structure	Structural feature(s)	Special function(s)
Ribosome	Non-membrane-bound, made up of ribosomal RNA	Protein synthesis
Cell wall	Made up of a different carbohydrate to cell walls in eukaryotic cells (peptidoglycan)	Protection, support, shape
Cell membrane	Phospholipid bi-layer	Controls entry and exit of materials in and out of the cell
Chromosomes	Singular circular chromosome	Controls cellular activity and regulates protein synthesis

2. Some possible answers include:

Organelle	Present in fungal, animal and/or plant cells?	Structural features	Special functions
Nucleolus	All three	Consists of RNA and protein	Synthesises rRNA and assembles ribosomes
Lysosome	Animal cells only (plant and fungal cells have similar structures called acidic vesicles with similar function)	Is a membrane bound vesicle containing digestive enzymes	Digests foreign matter and recycles cellular components
Vacuole/ vesicle	Large central vacuoles only found in plant cells. Vesicles found in all three types of cells but more numerous in animal cells.	Consists of a single membrane bound sac. Contents depend on types of vesicle/vacuole (e.g. water, ions, proteins, etc.)	Structural support, storage of water and nutrients, waste storage/disposal, transport of substances within, into and out of cell
Chloroplast	Only plant cells	Contains a double membrane and chlorophyll	Site of photosynthesis
Mitochondrion	All three	Contains a double membrane and its own mtDNA	Site of latter stages of aerobic respiration
Smooth endoplasmic reticulum	All three	Network of interconnected flattened membrane sacs that does not contain ribosomes	Lipid synthesis and transport

3. Some possible answers include:
   - Membrane-bound organelles; none in prokaryotic cells, many in eukaryotic
   - DNA; circular in prokaryotic, linear in eukaryotic
   - Size; prokaryotic cells are smaller than eukaryotic
   - Ribosomes; small and free floating in cytoplasm in prokaryotic cells, larger and can be attached to RER or free floating in eukaryotic cells
4. They possess the molecules such as DNA and proteins (e.g. enzymes), to allow normal metabolic processes, pathways and synthesis reactions to occur. These processes just occur in the cytosol not in membrane-bound organelles.
5. Some possible answers include: the anchorage/movement of organelles, separation of sister chromatids during mitosis, movement of whole cell, movement of cell membrane during endocytosis/exoytosis.
6. Some possible answers include: cell wall, cell membrane, ribosomes, cytoskeleton.
7. a) Some possible answers include:
   - both cell types contain DNA in the form of chromosomes
   - both cell types contain ribosomes to make proteins
   - both cell types contain cell membranes to control the movement of substances into/out of cells
   - both cell types can contain cell walls (animal cells don't) to provide structural support to cells

   b) DNA is universal (in both prokaryotic and eukaryotic cells), which suggests that all living things evolved from a common ancestor. Additional similarities such as both containing ribosomes, cell membranes etc. adds evidence to suggest that the more complex eukaryotic cells evolved from prokaryotic cells.
8. Suggestions for the table include:

	Name of organelle	Present in fungal, animal and/or plant cells	Important structural features	Function
A	Mitochondrion	All three	Consists of a double membrane and mtDNA	Site for the latter stages of aerobic respiration
B	Chloroplast	Plants only	Consists of a double membrane, chlorophyll and cpDNA	Site of photosynthesis
C	Rough endoplasmic reticulum	All three	Interconnected network of membranous sacs that contains ribosomes	Internal transport of protein molecules
D	Golgi body	All three	A stack of flattened, membrane-bound sacs that are not connected to each other. Sacs are surrounded by vesicles.	Modifying, packaging, storage and secretion of molecules
E	Nucleus	All three	Surrounded by double nuclear membrane (with nuclear pores) and contains DNA and nucleolus	Controls all activity of the cell and regulates protein synthesis

9. Some possible answers include:
   a) ribosome, cell membrane, cell wall, cytoplasm
   b) cell C has circular DNA, whereas cells A and B have linear DNA
   c) prokaryotic cells are unicellular and therefore cannot make a tissue, which is composed of many cells
10. The most likely reasons are:
    a) many mitochondria to provide energy for movement
    b) many chloroplasts for the purpose of photosynthesis
    c) many Golgi bodies for packaging and secretion of proteins
    d) many lysosomes in order to breakdown foreign cells and material
    e) many ribosomes and RER in order to make antibodies

11. In no particular order:
    a) cell wall is a rigid outer structure that provides protection against mechanical and osmotic stress
    b) the large central vacuole stores water which helps to maintain osmotic potential and maintain cell shape
12. a) It's likely that there is abundant protein synthesis occurring and the nucleolus is producing increased rRNA and assembling ribosomes as a result.
    b) A cell containing numerous vesicles is likely storing a substance to be secreted when signalled to. Vesicles are often involved in secreting molecules such as hormones, enzymes, saliva or mucus.

Chapter 2.3 Suggested answers

Multiple choice questions

1. M 2. M 3. L 4. L 5. M 6. J 7. K 8. K 9. L 10. K 11. M 12. K 13. M 14. J 15. M

Free response questions

1. Some possible answers include:
    a) DNA replication, transcription, translation
    b) ribosomes and protein synthesis
    c) active transport across the membrane from low to high concentration
    d) the heart pumping blood around the body
    e) homeostasis of an organism e.g. keeping temperature around 37°C
2. a) Chloroplasts contain stacks of grana, which increases the surface area for reactions of photosynthesis. They also contain chlorophyll, which is a pigment that can trap light energy from the sun.
    b) Photosynthesis converts inorganic materials (CO_2 and H_2O) into organic molecules (glucose), which can be used by the photosynthetic organism to provide energy (ATP). The organism is therefore able to synthesise its own food in the form of glucose.
3. The main effects are:
    a) Light is the main source of energy and increasing light intensity will increase the rate of photosynthesis.
    b) Carbon dioxide is a reactant so increasing its concentration will increase the rate of photosynthesis until it is no longer a limiting factor.
    c) If temperature is too low or too high it will suppress photosynthesis. Optimum temperature is normally 20°C-30°C depending on the environment of the plant.
4. Aerobic respiration produces significantly more energy than anaerobic respiration, so organisms generally cannot rely on anaerobic respiration alone. However, when oxygen is in short supply, the cells switch from aerobic to anaerobic respiration, which can still release energy, and therefore a backup energy production pathway is required.
5. a) $C_6H_{12}O_6 \rightarrow 2C_2H_5OH + 2CO_2$
    b) $C_6H_{12}O_6 \rightarrow 2C_3H_6O_3$
6. Some possible answers include sprinting, weightlifting, boxing, cycling.
7. Much of the energy is lost as heat energy which is normally dissipated into the environment.
8. A heterotroph can make organic molecules, such as DNA and proteins, which are organic but they need simple inorganic molecules like nucleotides and amino acids to do so.
9. All reactions require an input or activation energy for a reaction to start; however, during aerobic respiration, a more complex molecule (glucose) is broken down to simple molecules (CO_2 and H_2O). This breakdown releases more energy than is required for the reaction to occur.
10. a) A, C, E
    b) A, B, D
    c) A, B, C
    d) D, E
    e) B

11. a) The light intensity is greatest at C. Light is required for photosynthesis and oxygen is a product. Therefore, the greatest light intensity would equate with the greatest release of oxygen, which occurs at C.

    b) Aerobic respiration: $C_6H_{12}O_6 + 6O_2 \rightarrow 6H_2O + 6CO_2$ and photosynthesis: $6H_2O + 6CO_2 \rightarrow C_6H_{12}O_6 + 6O_2$

    c) B and D

    d) Photosynthesis enables the plant to make glucose (but not ATP directly). When glucose is broken down during aerobic respiration this releases energy to make ATP, which can provide energy to be used at a cellular level.

12. It can be concluded that ATP is virtually used in all forms of life as the 'currency' of energy. N.B. the hooking and unhooking refers to the coupling and uncoupling of ATP/ADP.

13. Yeast will respire aerobically when oxygen is available and use fermentation when it is not. One molecule of glucose enables approximately 2 molecules of ATP in fermentation but approximately 36 ATP in aerobic respiration. Therefore fermentation would need about 18 times more glucose for the same energy output.

14. Only those cells in photo-autotrophs that possess chloroplasts can photosynthesise and as such are capable of autotrophic nutrition.

Chapter 2.4 Suggested answers

Multiple choice questions

1. K 2. J 3. M 4. J 5. L 6. L 7. M 8. J 9. L 10. J 11. L 12. K 13. K 14. K 15. L

Free response questions

1. a) Metabolic reactions and life itself can only function within tolerance limits, for example without adequate glucose for respiration, no energy can be transformed. Cells also need to excrete toxic and poisonous substances.

    b) Autotrophs carry out both photosynthesis and respiration; during photosynthesis they take in CO_2 and excrete oxygen, the opposite occurs in respiration in both autotrophs and heterotrophs. Humans secrete urea, a waste from proteins, whereas plants do not.

2. Some possible answers include:
    - Their composition i.e. a phospholipid bilayer which is semi-permeable
    - They are flexible, which means that they can break and re-form
    - They contain embedded proteins which are involved in active and passive transport of substances.

3. a) Being 'passive' implies that these processes do not require energy to operate.

    b) Diffusion of gases and solutes can occur in a container, the atmosphere or across a membrane. Osmosis is defined as the movement of water across a semi-permeable membrane which separates different solute concentrations.

4. The process of diffusion occurs until equilibrium is reached. If a difference is apparent, active transport occurs to move materials against the concentration gradient.

5. a) The two processes are facilitated diffusion and active transport.

    b) Facilitated diffusion can still occur without energy (along concentration gradient) whereas active transport needs a supply of energy in order to occur (against concentration gradient).

6. The larger cell has a smaller SA:V ratio. The greater the SA:V ratio, the more efficient the rate of exchange of materials.

7. a) B represents facilitated diffusion, C represents (simple) diffusion.

    b) B occurs through a carrier protein usually involved in recognition and binding. C is diffusion through the phospholipid bi-layer

    c) The breakdown of ATP → ADP + P releases free energy for cellular use. A represents active transport (i.e. from low concentration to high concentration) and this requires energy from ATP breakdown.

8. a) The movement occurs in this direction because there are relatively less (free) water molecules on the right-hand side of the membrane (inside the cell). This means that water molecules will move by osmosis from a high water/low solute concentration outside the cell (in the distilled water) to a lower water/higher solute concentration (inside the cell).

    b) If too much water moves into an animal cell it will usually swell and burst (lyse), whereas a plant cell has a cell wall and, although it will become turgid, will not usually burst.

9. The most likely methods of transport across cell membranes are:
   a) osmosis of water molecules
   b) active transport of the nitrate ions
   c) endocytosis
   d) this process occurs by endocytosis (phogocytosis)
   e) carbon dioxide molecules will move by diffusion
   f) this normally occurs by facilitated diffusion
10. a) Exocytosis/endocytosis moves large molecules that otherwise would not be able to move through the membrane by diffusion or active transport.
   b) They both involve breaking and re-forming of the cell membrane. This requires energy and is an active process.
   c) The flexible nature of the phospholipid bi-layer; it can break and reform.
   d) In endocytosis a vesicle pinches into the cell and the membrane therefore shortens. In exocytosis a vesicle from the cytoplasm fuses with the membrane which therefore lengthens.
11. a) The solute concentration is higher inside the cell than outside of the cell.
   b) The phospholipid bi-layer is hydrophobic on the internal lipid tails and these repel water.
12. Regarding the SA:V ratio:
   a) The completed table is as follows:

Edge length (cm)	Total area (cm^2)	Volume (cm^3)	SA:V
6	6 × 6 × 6 = 216	6 × 6 × 6 = 216	1:1
2	2 × 2 × 6 = 24	2 × 2 × 2 = 8	24:8 = 3:1
1	1 × 1 × 6 = 6	1 × 1 × 1 = 1	6:1

   b) The smaller the cube, the greater the SA:V ratio.
   c) Red blood cells have a very important function of exchanging oxygen (via diffusion) with cells. Small cells have an increased SA:V. Having a biconcave shape further increases the SA:V. This allows the red blood cells to exchange oxygen very efficiently with cells.
13. a) Simple diffusion is a straight, linear relationship; the greater the substrate concentration the greater the rate of diffusion. In facilitated diffusion, at higher concentration the rate of diffusion slows down or plateaus.
   b) Simple diffusion occurs across the semi-permeable membrane whereas facilitated diffusion occurs across carrier proteins in the membrane. When the carrier proteins binding is limited, facilitated diffusion slows down.

Chapter 2.5 Suggested answers

Multiple choice questions

1. K 2. M 3. M 4. K 5. L

Free response questions

1. a) Contains DNA, which codes for gene products like enzymes that control metabolism.
   b) The site of latter stages of aerobic respiration, which provides energy for cellular use and reactions.
   c) Enzymes catalyse reactions by lowering the activation energy required.
2. Some possible answers include:
   a) More controlled reactions means higher efficiency and less heat loss.
   b) Release of small 'parcels' of energy which can be easily trapped and transported.
   c) Useful intermediate products are formed; different inputs are possible.
3. Some possible answers include: antibiotics, chemotherapy drugs, antivirals, anti-fungals, etc.
4. Some possible answers include:
   a) Temperature: if it is too cold metabolism will slow down, but enzymes may progressively denture if it becomes too hot.

b) pH: enzymes work best at an optimal pH and may progressively denature if the pH deviates from the optimum (higher or lower pH).

c) Mutagens or toxic chemicals: can inhibit enzyme activity (either competitively or non-competitively).

5. a) Reactions that break down complex molecules into simpler ones release energy and not all of this energy is trapped for use in the cell.

b) It warms the blood of organisms that are 'warm-blooded' i.e. maintains steady temperature.

6. a) In mitochondria the membranes are the cristae and in chloroplasts, the grana.

b) The membranes greatly increase the surface area, providing more space for enzymes and therefore, enzyme controlled reactions to occur.

7. a) As the substrate concentration increases, the rate of reaction increases very rapidly until it levels off (plateaus) at higher substrate concentrations.

b) Competitive inhibitors mimic the shape of the substrate and compete with the substrate for binding at the active site thereby slowing down the reaction. However, as the substrate concentration continues to increase, the substrate "out-competes" the inhibitor and eventually, the reaction rate equals that of the normal enzyme. Non-competitive inhibitors bind elsewhere on an enzyme (allosteric site), changing the shape of the enzyme so that it can no longer bind to its substrate; therefore the reaction rate is severely slowed down and in this case, can only reach approximatively half the reaction rate of the enzyme reaction with no inhibitors.

8. a) Each enzyme catalyses a different substrate/intermediate compound based on its unique shape. As enzymes are proteins, they are made up of one or more polypeptide chains. Each polypeptide is coded for by a specific gene and therefore, different genes will code for the different enzymes within the metabolic pathway.

b) One possibility is end-product inhibition on enzyme 1, another possibility is end-product inhibition on gene 3 which, in turn, will act on enzyme 3.

c) It conserves useful resources which would be wasted if converted into tryptophan if there are already adequate levels of it.

9. a) CO_2 is a required substrate; the more CO_2, the faster the rate of photosynthesis until it is no longer a limiting factor. In this case some other factor will become limiting.

b) The optimal temperature is approximately 40°C; the reaction is very slow at low temperatures because there is little enzyme activity. Enzymes are denatured at higher temperatures.

10. a) A co-enzyme is an organic molecule that is not actually an enzyme but assists the enzyme in its function; for example, by binding to the enzymes active site to form a complex, which activates it allowing the substrate to bind to the active site. Vitamins are examples of co-enzymes.

b) It is likely that it binds to the actual enzyme at a site away from the active site (allosteric site) and influences the enzyme's actions to either increase or decrease the reaction rate.

11. a) The first stage of respiration occurs in the cytoplasm (not the mitochondria) where glucose is converted into pyruvate. This releases enough energy to synthesise 2 ATP molecules. Further breakdown in the mitochondria does not occur and there is no extra energy produced.

b) Irreversible suggests the cyanide bonds permanently and is not released from the active site of cytochrome C oxidase. Because aerobic respiration cannot occur, the organism cannot provide itself with enough energy to perform essential functions and death may occur.

Chapter 2.6 Suggested answers

Multiple choice questions

1. J 2. L 3. L 4. J 5. J 6. K 7. K 8. M 9. L 10. K

Free response questions

1. a) Condensation occurs so that chromosomes can be easily moved around the cell and the vital genetic code is protected.

b) Attachment to the membrane enables the separation of the two identical circular chromosomes to opposite ends of the bacterial cell as it elongates and prepares for division. It helps to ensure that each daughter cell receives a copy of the chromosome.

2. The main processes that occur are:

- Chromosomes migrate to the equator of the cell.
- They attach to the spindle apparatus.

- Each chromosome, consisting of two identical chromatids splits.
- Identical chromatids moved to the poles.

3. Some possible answers include:
   a) Yeast and protists
   b) From zygote to embryo to foetus
   c) Broken bone, torn muscle, scratch, etc.
4. Some possible answers include:
   a) spindle fibres moving the chromatids to the poles
   b) involved in cytokinesis when the cytoplasm of the cell 'pinches off'
5. The main processes that occur are:
   - DNA replication where the circular chromosomal DNA replicates.
   - The chromosome condenses and attaches to the cell membrane.
   - As the cell divides each cell has an identical chromosome.
6. The main differences are:
   - Chromatin is DNA and protein but in an un-condensed form.
   - A chromatid is one of two identical molecules of DNA making up a chromosome after replication.
   - A chromosome is the condensed form of chromatin consisting of a double-stranded DNA molecule.
7. Cell division is similar in that one cell divides to produce two identical cells which are clones of the parent. They differ in that only one circular chromosome in prokaryotic cells whereas there are many linear chromosomes in mitotic division. In eukaryotic cells there is a nucleus and spindle apparatus, this is not so in prokaryotic cells.
8. The replicated DNA in eukaryotic cells remains attached to its sister chromatid and only separates when the sister chromatids move into separate cell and become individual chromosomes.
9. a) They show eukaryotic cells because there are linear chromosomes rather than circular.
   b) A - sister chromatids are separating and moving towards the poles.
   B - chromosomes are unravelling as they form into two new nuclei.
   c) Sister chromatids are identical made by DNA during semi-conservative replication.
10. a) Cell a) is in anaphase, b) is in metaphase, c) is in prophase, d) is completing telophase and e) is in interphase.
    b) The correct order is: c), b), a), d)
11. a) The closer to the root, the greater the number of cells that have visible chromosomes and are undergoing cell division.
    b) Cells that are closer to the root are actively dividing and growing.
12. a) This represents the phase where growth, replication of organelles and DNA replication occur. These processes all take time.
    b) In prophase, the DNA is condensing and the nuclear membrane is breaking down. Once this has occurred the cell proceeds quite quickly through mitosis

Chapter 2.7 Suggested answers

Multiple choice questions

1. L 2. L 3. J 4. K 5. K 6. J 7. L 8. M 9. L 10. L 11. K 12. M 13. K 14. L 15. J

Free response questions

1. Homologous pairs consist of one chromosome that came from the sperm (paternal) and one chromosome that came from the egg (maternal) during fertilisation.
2. Each individual inherits one allele from its mother and father. Alleles are different forms of the same gene located at the same gene locus. For example, an individual could inherit genes coding for brown eyes from their mother but genes coding for blue eyes from their father.
3. Somatic cells are the result of mitotic division which maintains the diploid number of a cell (2n). In contrast, gametes are the result of meiosis, where the homologous chromosomes are separated into haploid cells (n).

4. a) During DNA replication when the bases are exposed and base pairing occurs.

   b) Both mitotic division and binary fission result in identical offspring (unless mutation(s) occur).

5. a) In the first division of meiosis the members of each homologous pair separate into different cells. Each new cell has only one member of each pair and therefore half the number of chromosomes (a reduction in number).

   b) Anaphase 1

6. a) Asexual. It shows a 'daughter' hydra budding from the 'parent' hydra. This does not involve meiosis/fertilisation and is therefore not reproducing sexually.

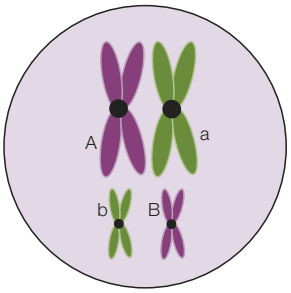
   b) Hydra consist of eukaryotic cells. As they reproduce asexually, the type of cell division is mitosis.

7. Fertilisation is the random union of a sperm cell with an egg cell. Egg and sperm cells are formed through meiosis which produces highly genetically variable haploid cells through independent assortment, crossing over and random mutations.

8. a) in the testes

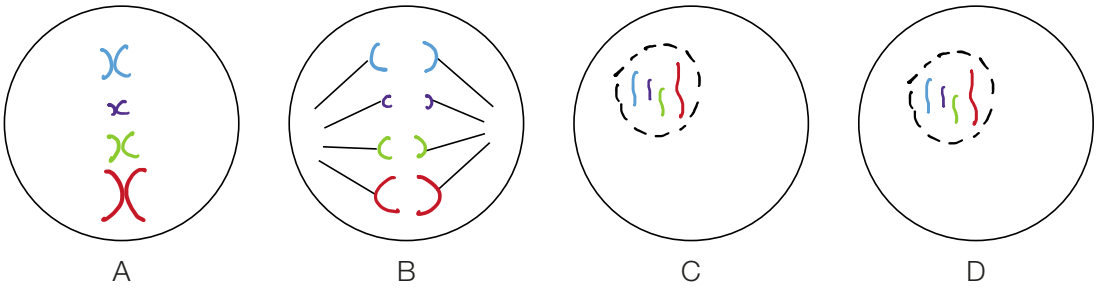
   b) the diploid number (2n) = 4, the haploid number (n) = 2

   c) as shown in diagram to the right



9. a) Meiosis. There are four chromosomes that are all different sizes and therefore, there are no homogous pairs present. This means that diagram B is showing a cell during anaphase 2.

   b)



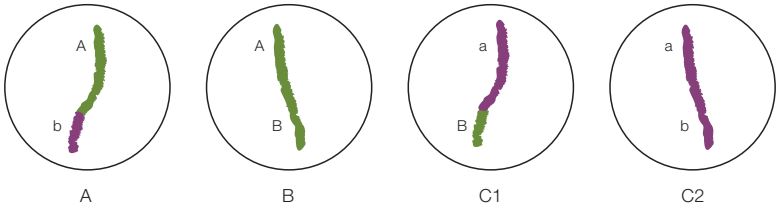
   a) 2n = 8, n = 4

10. a) 18 (i.e. half of the diploid 36).

    b) Male bees are haploid as they develop from unfertilised eggs. Meiosis cannot occur since there are no homologous pairs to separate.

11. a) Independent assortment involves the random pairing and separation of maternal and paternal chromosomes, hence producing a new combination of chromosomes. Crossing over swaps sections of sister chromatids between one homologous maternal and paternal chromosome pair; hence new combinations of genes are formed on homologous chromosomes. Both of these processes therefore increase genetic diversity of the resultant gametes.

    b)



12. Asexual reproduction produces clones of the parent whereas sexual reproduction produces variation in the offspring. In strawberry production a desired characteristic which is genetically inherited may be larger or sweeter strawberries. Gardeners wish to produce new plants all with this characteristic and therefore will use asexual reproduction and not take a chance of the variation introduced by sexual reproduction.

13. a) The processes are: A meiosis, B mitosis (growth), C mitosis, D fertilisation

    b) The sexual phases are A and D meiosis (gamete production) and fertilisation. The asexual phases are B and C which involve mitosis.

Chapter 2.8 Suggested answers

Multiple choice questions

1. M 2. J 3. K 4. K 5. J 6. L 7. M 8. M 9. M 10. K

Free response questions

1. a) Examples are:
   - Permanently; nerve cells that do not divide and multiply in number.
   - Temporarily; skin cells that suffer trauma and re-enter the cycle for repair of tissue.

   b) A trigger could be damage or some cell death which triggers surrounding cells to re-enter the cycle and divide.
2. a) End G1, end G2 and M metaphase of mitosis.

   b) To check the readiness of the cell to proceed further in the cell cycle e.g. at M phase the cell checks that the chromosomes are attached to the spindle apparatus and ready to separate.
3. a) A sharp increase of MPF signals the cell to proceed past checkpoint G2 and start mitosis.

   b) A sharp decrease in MPF (due to the breakdown of cyclin), allows the cell to move past checkpoint M and allows anaphase to begin.
4. Three types of genes are:

   a) Oncogenes; may over stimulate cell division

   b) Tumour suppression genes; may fail to stop uncontrolled cell division

   c) DNA repair genes; may not repair faulty DNA.
5. a) Such external factors include:
   - Ionising radiation may cause mutations and alter protein production, which can interfere with cell division.
   - Mutagenic chemicals may also cause mutation and interfere with cell division.
   - Viruses may change expression of DNA and alter normal controls of cell division.

   b) hGH acts on cells by binding to complementary receptors. Those cells that possess receptors respond to hGH and divide, others do not.
6. If cells with damaged or faulty DNA are destroyed, then these cells which may have divided uncontrollably, will no longer be able to develop into cancer cells.
7. Most likely reasons are:

   a) Sugars are substrates for aerobic respiration and energy provision.

   b) Growth factors; hormones are required to stimulate cell division.

   c) Suitable pH is necessary for enzymes to work, allowing optimal cell growth.
8. a) There are a range of possible applications, e.g. culturing human skin cells for skin grafts.

   b) Some possible limitations include; infection, destruction of tissue, failure of tissues to grow and integrate with other human tissues.
9. a) Contact inhibition; where cells come in contact and there is a message to the nucleus to stop dividing.

   b) There may be damage to the receptors involved in contact inhibition or mutations to genes involved in producing proteins involved in contact inhibition. In both cases, the cancer cell would fail to respond to contact inhibition.

   c) UV is a form of ionising radiation that can cause mutations to DNA and therefore DNA damage. The p53 gene is activated when DNA damage occurs to increase production of p53 protein, which activated pathways to repair DNA damage.
10. a) A hormone.

    b) The complementary nature of A and the receptor.

    c) Proteins called cyclins bind with kinase enzymes to form MPF, which then triggers the onset of mitosis.

11. The Sun emits UV radiation which is known to act as an agent that can induce mutations in the DNA. If the DNA genes that are mutated impact on cell division e.g. DNA repair genes, oncogenes or suppressor genes, a cancerous cell may arise and eventually develop into a malignant tumour such as a melanoma.
12. Some possible answers include:
    a) Growing stem cells that can differentiate into specialised cells that can then be used in research; for example, in repairing spinal tissue damage, replacing faulty insulin producing cells in the pancreas, combating neurodegenerative diseases such as Alzheimer's etc.
    b) A lot of research on stem cells uses embryonic stem cells. Embryonic stem cells are procured from an embryo, which contains the first cells of a developing organism. Therefore, many individuals, religions and cultures view research involving embryonic stem cells as unethical and unnatural. There are also possible unknown outcomes of transplanted tissue and long-term, unexpected consequences. This is an area that is controversial as scientists are manipulating or altering life and this involves research on animals, eventually including willing human trials.
13. Possible disruptions to the cell cycle, if microtubule production is affected, include:
    a) Chromosomes may not divide and separate during anaphase of mitosis. New cells are not formed which will stop cell growth.
    b) It may stop cytokinesis which occurs after mitosis and is the division of the cytoplasm of one cell into two.

Topic 2 Review test suggested answers

Section 1: Multiple choice questions

1. K 2. M 3. J 4. J 5. K 6. L 7. K 8. K 9. K 10. M 11. K 12. M 13. K 14. M 15. M

Section 2: Free response questions

16. a) Fluid-mosaic model

    b) Structure A is a glycoprotein (a protein with carbohydrate receptor) with a specific 3-D shape that will bind with a hormone in a complementary manner.

    c) B may act as a 'pump' with the ability to bind to specific molecules and then use energy from ATP breakdown to pump them from low concentrations to high concentrations.

17. While, in the dark, there is no photosynthesis but aerobic respiration is still occurring and this uses oxygen as a substrate. Once exposed to light (at about 15 minutes), the rate of photosynthesis is greater than the rate of respiration. Oxygen is a bi-product of photosynthesis.

18. a) In the cytoplasm/cytosol.

    b) In the earlier steps of the reaction, energy is required i.e. 2ATP breakdown to 2ADP. However, in the latter steps 4ADP molecules give rise to 4ATP. This implies an overall release of enough energy to manufacture a nett gain of 2 ATP molecules.

    c) $C_6H_{12}O_6 \rightarrow 2C_2H_5OH + 2CO_2$

    d) Some possible answers include:

    - It releases small 'parcels' of energy suitable for cells.
    - It releases the same amount of energy every time.
    - It is easily regenerated from ADP +Pi.
    - It is soluble which means that it can move wherever it is needed in cells.

19. a) The latter stages of aerobic respiration

    b) Cristae

    c) These membranes increase the surface area inside the organelle. This gives more area for the enzyme controlled reactions to occur.

20. a) Some possible answers include:

    - large steps would produce unfavourable conditions, such as high temperature
    - small steps release small amounts energy to be trapped by energy molecules like ATP
    - allows greater control and cells can direct alternative routes
    - provides intermediate compounds that be used as starting points for other reactions or are essential substances for the cell

    b) The end-product binds to the initial enzyme at an alternative (allosteric) site to the active site. This binding, however, changes the structure of the active site and prevents enzyme-substrate binding. It is a non-competitive inhibitor.

    c) When the cell has ample products, it makes sense not to produce any more, thereby conserving energy and resources.

21. a) the two photographs show:

    - Photograph A - identical sister chromatids are being drawn to the poles. The new cells produced will have identical DNA.
    - Photograph B - the chromatin is condensing and forming chromosomes so that DNA can more readily move throughout the cell and be divided.

    b) Mitosis produces clones or identical copies of the original organism. This preserves the features from the parent to the offspring. Additionally, only one parent is involved so energy is conserved.

22. a) From D → A the amount of DNA doubles (replication)

    b) The cell would check to ensure that the DNA has replicated and scan for errors that may have occurred in base pairing. If errors are detected, the cell cycle would be stopped until the problem has been rectified.

    c) When cyclin and cdK (gene products) combine to form MPF (mitosis promoting factor) this acts as a stimulus for the onset of cell division. Alternatively, the rapid breakdown of cyclin, and hence MPF, allows the the cell to progress from metaphase to anaphase.

23. a) Some possible answers include:
    - they have the same size, position of centromere and banding pattern when stained with particular dye.
    - at identical spots or loci, they may have different forms (alleles) of the same gene.

    b) This process is crossing-over and occurs during prophase. It gives rise to new combinations of genes of maternal and paternal chromosomes-and increases variation in the gametes.

    c) Independent assortment occurs at metaphase I where the homologous chromosomes randomly align either side of the metaphase plate. This results in varied combinations of maternal and paternal chromosomes occurring in the gametes. Alternatively, random mutations could occur during meiosis I and could give rise to variation. If a point mutation occurs that results in a different amino acid being introduced to the resultant polypeptide, this could increase variation.

24. Some possible answers include:

    a) Ensure there is correct temperature, pH, nutrients, sterile environment etc.

    b) The procedure is not always successful and may lead to multiple births (twins/triplets). In addition discarded embryos are sometimes destroyed showing disrespect for human life which is an ethical issue.

25. a) The impact of changing the external solute concentration on the rate of osmosis as measured by contractions of the vacuole.

    b) Variables include temperature, pH, energy availability to the Paramecium, differences in the internal solute concentration.

    c) As the external solute concentration increases, the rate of contraction of the vacuole decreases.

    d) The number of contractions of the vacuole.

    e) Size of the Paramicia, which therefore affects SA:V and could affect inital internal solute concentrations of the Paramecium, introducing scatter and imprecision to the data collected.

26. *Please note: The suggested responses are in dot point form, but best practice for students is to write extended answer responses in paragraph form, providing clear, concise and relevant information.*

    a) Some possible answers include
    - Transmembrane proteins span the cell membrane, embedded into the phospholipid bilayer. Spanning the membrane in this manner, they facilitate the movement of substances like ions between the internal and external environment of the cells.
    - Each transport protein has a unique shape that enables it to bind with and facilitate the movement of specific ions or molecules.
    - The transport proteins assist in movement by either facilitated diffusion or active transport.
    - Facilitated diffusion does not require energy but the ions may bind and be assisted through the channel.
    - Active transport proteins will bind with the ions and use energy to pump them against the concentration gradient.

    b) Some possible answers include
    - Deletion of the amino acid phenylalanine will change the 3-D structure of the membrane protein and as indicated above, this may prevent it reaching the membrane.
    - Ions, like chloride and sodium need to move through membrane proteins, they do not move readily through the phospholipid bilayer.
    - When ion transport is compromised this leads to the viscous secretions which will upset the normal solute concentrations and lead to cystic fibrosis. the viscous secretions which will upset the normal solute concentrations and lead to cystic fibrosis.

27. Some possible answers include:

    a) There are very long organ transplant waiting lists all around the world and many people end up dying waiting for a donor organ. The pressure of this situation on health systems and the push from society to find possible solutions to minimise transplant lists has influenced governments to increase funding into research such as bioprinting.

    b) Kidneys can be sold on the black market for a high price. If kidneys could be bioprinted, eventually there would be no need for kidneys to be sold on the black market and this would result in reduced illegal activity.

Chapter 3.1 Suggested answers

3.1 Multiple choice suggested answers

1. L 2. M 3. K 4. K 5. J.

3.1 Free response suggested answers

1. Life's processes can only occur within certain tolerance limits. Chemical reactions e.g. metabolism require optimum pH, temperature, osmotic balance etc. Homeostasis maintains these variables within the tolerance limits.
2. Temperature, pH, osmotic pressure, glucose concentrations etc.
3. Examples of responses include:
   a) Development of individual chemoreceptors to detect e.g. carbon dioxide levels.
   b) An animal seeking shade to avoid heat gain in hot weather.
   c) Increased levels of insulin in order to decrease blood glucose levels.
4. Certain variables need to be maintained between upper and lower limits; the tolerance range for efficient functioning e.g. human temperature between approximately 36 to 38°C.
5. Reasons include:
   a) CO_2 is the stimulus for increased rate/depth of breathing and providing oxygen to tissues.
   b) Changing the carbon dioxide concentration alters the pH of the blood.
6. The two mechanisms are:
   a) the nervous system
   b) the endocrine (hormone) system
7. Such factors include:
   a) high levels of exercise and fasting.
   b) high levels of exercise, poor circulation and low breathing rate.
   c) eating salty meals, high levels of perspiration and water loss, inadequate fluid uptake.
8. Impacts on metabolic reactions; high temperatures may denature enzymes and even destroy tissues. Low temperatures reduce energy output and lower metabolic rate.
9. Receptors are modified sensory neurons that respond to stimuli and can then initiate transmission of a message. An effector is a muscle or a gland that can bring about a response to a specific stimulus.
10. This maintenance between the tolerance levels occurs as result of homeostatic processes. The response 'feeds back' to the initial stimulus and reverses it e.g. high blood glucose leads (via insulin) to a fall in glucose.
11. a) An example is breast feeding.
    b) Positive feedback is not common because it leads to increasing levels which do not keep variables within tolerance limits.
12. a) Osmotic pressure; water/solid balance
    b) Problems with too high a cellular concentration impact on water balance in cells and tissues, critical for effective functioning. Osmo-regulatory factors may occur e.g. increased water reabsorption from tubules in the kidneys back into the bloodstream to reduce urine volume.

Chapter 3.2 Suggested answers

3.2 Multiple choice suggested answers

1. K 2. M 3. K 4. L 5. J 6. M 7. L 8. K 9. M 10. L

3.2 Free response suggested answers

1. a) CNS stands for the 'central nervous system' and refers to the brain and spinal cord. PNS stands for the 'peripheral nerve system' and refers to all other nerves in the body.
   b) CNS stores and manages information. PNS relays information to and from the CNS.

2. a) Somatic nerves are involved in voluntary action whereas autonomic nerves are involved in involuntary actions.

   b) Somatic nerves usually control skeletal muscles e.g. arms and legs whereas autonomic nerves usually regulate internal organs e.g. heart rate.

3. Sensory neurons have dendrites adapted to detect or sense information and long axons to transmit information. Interneurons have short axons as they only need to connect from one neuron to another.

4. a) The three components are dendrites, cell body and axon.

   b) Structures and functions include:

   - A dendrite is an extension that acts as a sensory receptor and will respond to stimuli.
   - A cell body contains organelles e.g. mitochondria for energy provision.
   - An axon is an extension of a nerve cell to conduct impulses over long distances.

5. a) This is a reflex response because it is not under voluntary control and managed by the nervous system.

   b) The stimulus is the light, the receptors are photoreceptors in the eye and the effector is a muscle that controls the constriction/dilation of the pupils.

   c) Constriction of the iris will restrict the amount of bright light falling on the receptor cells and may therefore prevent damage to these delicate receptors in the retina of the eye.

6. a) Mechanoreceptors respond to pressure or touch (e.g. skin, ear) and chemoreceptors respond to the presence of particular chemicals (e.g. nose, tongue).

   b) Dendrites are extensions from the dendron that branch out and can respond to stimuli, they act to receive information.

7. a) They allow the information to be transported from one neuron to another and in doing so transmit the nerve impulse.

   b) Exocytosis is the process involving large bulk transport of molecules, enclosed in vesicles as they are too large to diffuse out of the cell.

   c) Exocytosis is an active process that requires energy to move molecules through a membrane.

8. As the nervous impulse involves changing K^+ and Na^+ concentrations, it requires energy for active transport to move these ions against the concentration gradient.

9. a) By binding to the transporter, dopamine is not taken back into the cell and therefore increases in the synaptic cleft. This allows dopamine to repeatedly bind to the dendrites of the receiving neuron, amplifying the signal and therefore, affects mood, feelings and behaviour.

   b) Addiction refers to the alteration of biochemistry and dependence. Long-term damage to receptors resulting in failure to detect information may result.

10. a) Coughing is involuntary, stimulated by an irritant resulting in nervous transmission in a reflex arc to cause the response.

    b) As follows:

    - it is the irritant e.g. dust
    - chemoreceptors in the nose
    - the diaphragm/intercostal muscles
    - the cough; a rapid, forceful exploration of air

    c) Such medications may block a transmission of information, relax muscles, interfere with receptors.

11. a) Carbon dioxide reacts with water in the blood to form carbonic acid, increasing acidity and therefore decreases the pH of the blood. Exercise increases the production of carbon dioxide through aerobic respiration, lowering the pH of the blood. The excess carbon dioxide needs to be expelled from the body through increased breathing, to increase blood pH and to maintain within a suitable tolerance range.

    b) Increased carbon dioxide concentration, results in more carbonic acid in the blood and a decreased pH. The decreased pH is detected by chemoreceptors in the brain and blood vessels.

    c) If the original stimulus is an increase in carbon dioxide levels, the response causes a reversal of this and carbon dioxide levels decrease. The response feeds back to the original stimulus and results in decreased transmissions caused by initial stimulus or results in them being switched off entirely.

Chapter 3.3 Suggested answers

3.3 Multiple choice suggested answers

1. J 2. L 3. L 4. M 5. J 6. M 7. J 8. K 9. L 10. J 11. K 12. L

3.3 Free response suggested answers

1. a) It is like a master controller in that it releases hormones which control other endocrine glands e.g. TSH which then stimulates the thyroid gland.

   b) ADH - this is released from the pituitary gland and acts on kidney tubule cells to increase their permeability to water.

   c) One example is that the pituitary gland releases TSH which stimulates the thyroid gland to release thyroxine.

2. a) Type 1 diabetes is an autoimmune disease in which the immune cells malfunction and target the insulin producing beta cells of the pancreas. This results in the inability to produce insulin to control blood glucose levels, but the cells can still recognise glucose. Type 1 diabetics can therefore inject insulin to control their blood glucose levels.

   b) Type 2 diabetics can have some genetic predisposition but it is generally caused by poor diet and lifestyle. The overconsumption of sugar can result in the overworking of beta cells and result in their death. Over time this can result in less insulin production for an individual. Also, too much saturated fat in the diet can cause weight gain in the abdomen and result in inflammation that destroys the beta cells having the same effect. Additionally, a high saturated fat intake can result in fatty deposits building up in the insulin receptors, blocking insulin from binding.

   c) Type 2 diabetics can manage their blood glucose levels by eating a diet that consists of less sugar, low GI foods and low saturated fats. They can also increase their exercise to use up glucose and reduce any excess weight. If the individual is producing low levels of insulin, they can be prescribed insulin injections to increase concentration in the blood after a meal.

3. The completed table is as follows:

Example of homeostasis	Stimulus	Receptor	Hormone(s)	Effector	Response
Blood glucose concentration	**Low blood sugar level**	**Cells in pancreas**	Increase in glucagon	**Muscles, liver**	**Increase in blood glucose**
Metabolic rate	Increase in metabolic rate	**Hypothalamus, thyroid gland**	**Reduce thyroxine and adrenaline**	**Mitochondria, cells/tissues**	**Lowering metabolic rate**
Osmoregulation	**Increase solute concentration in the blood**	**Hypothalamus, heart, arteries**	**ADH**	**Tubules in the kidney**	increase in the absorption of water in tubules

4. Some possible answers are outlined below:

   a) It is important because most chemicals are dissolved in solution, water gives support to cells and is an important transport medium throughout the body e.g. blood.

   b) Drinking large amounts of water and having a diet which is low in salts and other solutes.

   c) Doing heavy exercise where perspiration causes the loss of water and eating a diet which is high in salt.

5. The nephron, in particular the tubules in the nephron, re-absorb water from the tubules back into the bloodstream. By increasing or decreasing the volume of water reabsorbed, this will change the blood water/solute balance.

6. When thyroxine levels fall, this is detected by hormone receptors and the thyroid gland reverses the stimulus and secretes more thyroxine. The stimulus is “fed back” and reverses the initial stimulus.

7. a) Peptide hormones are made up of amino acids usually with shorter chains. Proteins consist of polypeptide molecules. Steroids are lipid-based molecules.

   b) Protein and peptide hormones cannot penetrate the membrane and bring about their effects by binding to cell membrane receptors. Steroid hormones however are lipid-based and can move through the phospholipid bi-layer and bind to intracellular receptors.

8. Increased levels of thyroxine cause an increase in metabolic rate. It is likely that thyroxine binds to the mitochondrial receptors and this increases the rate of respiration in the mitochondria.
9. a) Papua New Guinea is a mountainous region with very high rainfall. Compounds of iodine are highly soluble and therefore these areas have low iodine concentrations in the soil and therefore also in the food that is eaten by the people.

   b) The thyroid gland is being stimulated to produce thyroxine but is unable to do so as there is no iodine present. Low levels of thyroxine are detected continually and thus the feedback is to continually over-stimulate the thyroid, causing its enlargement.

   c) Once iodine is present, thyroxine can be made and adequate levels of this will shut down over production of TRH and TSH and the gland will return to normal size.
10. a) These two hormones work in an opposing manner. The stimulus for ADH is low blood volume, the opposite of ANP. Consequently their actions will also be different: ADH will increase water in the blood and lower the solute concentration whereas ANP does the opposite.

    b) Decreasing sodium absorption will also mean less water being reabsorbed back into the blood. Less water reabsorption will lower the blood pressure which reverses the initial stimulus (negative feedback).
11. Osmoregulation is involved in regulating the water/solute concentration in the blood. High blood volume tends to be associated with higher water levels, this increase in volume/pressure is detected by receptors in the heart/arteries.
12. a) Any 3 of:
    - Poor title with only one variable,
    - Plotting errors (e.g. 10% salt line at 50 (should have been 82 at 120 mins) and 30% salt line at 85 (should have been 51 at 0 mins) or all three lines start at the same point for –30 mins (should vary slightly).
    - Vertical axis missing axis label/unit
    - No legend for the three lines on graph
    - –30 min plot in wrong position on X axis

    b) Testing on humans. Drinking salt solutions could dehydrate the volunteers, which can have serious consequences including death if not managed. This investigation needs to have mechanisms in place to ensure volunteer safety and safety procedures planned in case a volunteer becomes seriously dehydrated, such as nurses and doctors being on site to treat volunteers immediately.

    c) To use as a control to determine the amount of urine produced under normal conditions. Results can then be compared against the control to determine the effect of the treatment.

    d) Some possible answers include: temperature the participants were subjected to, the activity level of the subjects, the age of the subjects, gender of subjects, amount and type of food the subjects could eat, the amount and type of fluid intake prior to the investigation, whether or not subjects had any pre-existing medical conditions that affects water/solute balance such as kidney disease.

    e) Decrease of water concentration in blood, increased osmotic pressure in blood or increase in sodium concentration in the blood.

    f) At 60 minutes when the highest volume of urine was produced at 415mL (or between 30 – 60 minutes when the peak may have been reached). ADH increases reabsorption of water in the kidneys resulting in lower urine volume. As urine volume was the highest at 60 minutes, this is when the lowest volume of water was being reabsorbed by the kidneys and hence, ADH would have been at its lowest blood concentration.

Chapter 3.4 Suggested answers

3.4 Multiple choice suggested answers

1. J 2. M 3. L 4. K 5. J 6. M 7. L 8. J

3.4 Free response suggested answers

1. a) Similarities include:
   - both involve chemicals at some stage-neurotransmitters and hormones
   - both enable messages to be relayed from an area to target tissues

   b) Differences include:
   - hormones act more slowly than nerves
   - hormones are less specific in their action than nerves
2. a) The control of CO_2 levels in the blood only involves nerve transmission.

   b) The control of blood glucose only involves hormone transmission with the hormones insulin and glucagon.

   c) The nervous and endocrine systems work together in the control of blood temperature.
3. The roles include:

   a) Increased metabolism releases heat energy is a by-product. This warms the blood and the body.

   b) Increases blood flow to the surface of the skin thereby increasing heat loss.

   c) Causes evaporative cooling at the surface of the skin to lower body temperature.

   d) Thyroxine increases the activity of mitochondria and thereby the metabolic rate.
4. Suggestions for the table include:

Mechanism	Stimulus	Effector	Response
Shivering	**Temperature down**	**Skeletal muscles**	**Increase blood temperature**
Trap a layer of air close to the skin	**Temperature down**	Contraction of erector pili muscles	**Reduce heat loss**
Reduce heat production	**Temperature up**	**Muscles, liver**	Decreased metabolism
Vasocontriction	Temperature down	Small arterioles	**Reduced heat loss through the skin**

5. This mechanism maintains blood temperature around 37°C between narrow tolerance limits. The response reverses the stimulus.
6. The response is involuntary and very rapid with no conscious thought to activate glands, muscles etc., also wide ranging responses. This helps increase chance of responding to stimuli quickly and therefore, chance of survival.
7. This allows for a greater volume of air to move into and out of the lungs; speeding up gas exchange e.g. more O_2 into the blood.
8. a) During stress more blood is diverted to the muscles (87%) and less to all other areas compared to blood flow at rest, where blood flow is more evenly spread to bodily organs (e.g. 18% to the brain and only 20% to muscles).

   b) If blood is diverted away from the major organs during stress, more can flow to the muscles for the fight or flight response.

   c) With greater blood flow to the muscles, the body or organism is more able to fight or flee in response to the danger.

   d) With increased adrenaline there is an increase in heart rate, blood pressure, metabolic rate etc. and more energy is then available for muscle contraction.
9. The original threat is detected by sensory receptors and the brain activates nervous signals that respond instantaneously. Nervous signals are also sent to the adrenal glands to secrete adrenaline hormone into the blood, which complements the nervous system in responding to the stimulus by inhibiting insulin and mobilising energy stores for cells to use as the organism runs or fights.

10. The reflex action needs to occur very quickly and to specific tissues e.g. arm/hand and therefore nerves are better here. Changes to blood glucose do not need an immediate response and the actions activate a wider range of tissues e.g. muscles, liver which have receptors to the hormones involved; so hormones are better here.

11. a) They both reduced blood flow to the skin surface which reduces heat loss-primarily by radiation and conduction.

    b) Vasoconstriction in arteriole simply reduces the volume of blood that flows near the skin's surface. Constriction of pre-capillaries sphincters which surround vessels, diverts the blood away from the skin capillaries.

12. a) Cortisol increases blood glucose levels, which is required by cells to produced energy (ATP). Energy demands generally increase during stressful situations. An increased blood pressure also prepares an individual for a stressful event as this will increase blood flow providing more glucose and oxygen to cells for aerobic respiration.

    b) If stress raises cortisol levels, then the body may be exposed to a repressed immune system which exposes the body to increased risk to a range of diseases from infection to cancer. Increased blood pressure over long periods also has a range of very serious consequences to the cardiovascular system and other body organs and systems e.g. kidney.

13. a) (i) One of: touch receptors, pressure receptors or mechanoreceptors

    (ii) The skin changes temperature in response to environment and this change is detected by receptors. There are two types of thermoreceptors present in the skin (hot and cold receptors). Exposure of skin to low temperatures (below normal body temperature) activates the cold receptors and exposure to high temperatures (above normal body temperature) activates the hot receptors.

    b) Some possible answers include:

    - The e—dermis may not have the same touch threshold distance for fingertips as normal fingertips do. This could limit the ability to detect small stimuli such as Braille for the blind.
    - The e-dermis technology may not be reliable and last for a lifetime and may need ongoing maintenance/replacing to continue working. This could be inconvenient to members of society with prosthetic limbs accessing this technology and expensive.

Topic 3 Review test suggested answers

Section 1: Multiple choice questions

1. L 2. L 3. M 4. L 5. J 6. L 7. K 8. K 9. L 10. L

Section 2: Free response questions

11. The completed table should be similar to this:

Area of comparison	Hormonal (Endocrine)	Nervous
Speed of transmission	Slower	Quicker
Target site	Less specific - only those cells with complementary receptors	very specific effectors, usually muscles or glands

12. a) The oxygen levels would increase.
    b) This drop is due to an increase in lactic acid from fermentation (anaerobic respiration). It will be detected by chemoreceptors which detect the stimulus. Nerve impulses are sent to the diaphragm and intercostal muscles resulting in an increase in the rate and depth of breathing.
    c) The effectors are the diaphragm and intercostal muscles. An increase in the rate and depth of breathing will increase the diffusion of CO_2 out of the blood and lungs by maintaining the concentration gradient.
13. a) Heat is generated as a bi-product of metabolic reactions. The higher the metabolic rate, the greater the release of heat energy warming the blood.
    b) Homeostatic processes operate to reduce blood temperature. Negative feedback reverses the stimulus (i.e. an increase in temperature) to restore normal temperature.
14. a) TSH travels to the thyroid gland in the bloodstream.
    b) Elevated thyroxine levels stimulate mitochondria and cause an increase in the metabolic rate; hence more heat is released.
    c) A controlling hormone, TSH from the pituitary gland, travels in the bloodstream and stimulates the thyroid gland to release thyroxine. It does this by binding to receptors in the thyroid gland.
15. a) Smell receptor genes code for receptor proteins that are part of modified sensory receptors. These chemoreceptors bind with specific chemicals (i.e. smell molecules) and the brain interprets these stimuli as different smells.
    b) Those species where the sense of smell is more important for survival will have a higher percentage of functional smell genes compared to pseudogenes for smell.
    c) One example is pain which is detected by mechano-receptors which are located in the skin.
16. a) They are stimulated to be released at synapses-junctions between neurons and receptors/effectors. They act to activate ion channels and facilitate the transmission of impulses across nerve junctions.
    b) The toxic properties of botulinum include paralysis of muscles. This occurs because the impulse is not transmitted across the junctions to effectors such as muscles.
    c) The acceptance and understanding of neurotransmitters enables Botox to be used. Social and cultural pressures e.g. cosmetic alterations. Relevance to 'Scienced as a human endeavour' includes making reliable predictions, unexpected consequences and risk evaluation.
17. a) Gazelles are prey for cheetahs and it would be fleeing for its life. A range of physiological responses would occur to give the gazelle the best possible chance of survival.
    b) The presence of danger is detected by sensory receptors e.g. in eyes and ears. The brain sends nerve impulses to glands such as the adrenal glands which release hormones. Both nerve and hormone systems are working together in this situation.
    c) Changes would include an increase in heart rate, blood pressure, dilation of blood vessels to increase blood flow to muscles.
18. a) Amino acid derived hormones are made from only one amino acid whereas protein hormones consist of long chain(s) of amino acids. Some amino acid derived hormones can act similar to lipid hormones and be non-polar and pass through the cell membrane, whereas protein hormones are polar and cannot pass through the cell membrane.

b) Vasodilation results in the muscle arterioles expanding in width and in turn, increased blood flow to the muscles. As a result, there is an increased supply of oxygen and glucose to the muscles to increase aerobic respiration (energy production).

19. a) line graph

b) The reliability of this experiment is very low. This is because the experiment only has one set of data (no replication). Therefore, the reproducibility of results is unable to be determined.

c) Both forms of insulin were able to lower the BGLs, but the standard form of insulin was slightly more effective. The BGL reached a maximum of 135 mg/100mL for the subject treated with the new form of insulin compared with a maximum of 126 mg/100mL for the standard insulin.

d) Type 1 diabetics cannot produce any/sufficient levels of insulin due to the destruction of beta cells by the immune system. Therefore, injected insulin can still travel to the cells of the body and communicate efficiently with cells via complementary receptors.

e) (i) Some possible answers include:

- It is unclear if it is ok for women to take metformin when trying to conceive and during pregnancy/lactation. Therefore, further studies are required to determine this and provide updated advice to pregnant women to avoid preventable birth defects.
- Further information is required to determine if taking metformin or having uncontrolled type 2 diabetes is a higher risk for men when trying to conceive.
- Could alternative drugs for type 2 diabetes also increase the risk of birth defects? Further studies need to be conducted on these drugs to provide updated advice for potential fathers and mothers.
- Given that metformin is affecting the sperm, this highlights that a man's health prior to conception can affect the health of his child (epigenetically). Therefore, further research into how other common drugs such as antidepressants affect sperm.

(ii) Some possible answers include:

- A decent proportion of society are taking metformin for type 2 diabetes and off-label for conditions that are not officially approved such as weight loss (preventing type 2 diabetes), PCOS and gestational diabetes. As scripts for drugs such as metformin can have many refills, patients may not revisit their doctor often and may not know the effects taking metformin could have on their potential children. Furthermore, it is important for all women to have this knowledge to make educated decisions surrounding the risk and unknown potential consequences of taking metformin during pregnancy, especially since doctors could advise to continue taking the drug as the study focuses on men and not women.
- If the knowledge is not communicated effectively to the public, then the public cannot make educated decisions regarding this when deciding to conceive a child. As type 2 diabetes becomes more prevalent in out society, and metformin prescriptions increase, the amount of birth defects could also increase and this could add more pressure to an already under stress health system. It makes economical sense to notify the public.
- There is an ethical responsibility on the researchers and medical professionals who know about the greater risks to communicate this with the public/patients, so they can understand the possible risks of taking metformin prior to conceiving an the possibility of increased risk for women if diagnosed with gestational diabetes during pregnancy.

Chapter 4.1 Suggested answers

4.1 Multiple choice suggested answers

1. K 2. L 3. M 4. L 5. J 6. M 7. M 8. J 9. L 10. J

4.1 Free response suggested answers

1. Both geochemical and fossil evidence supports this hypothesis. Cells share common characteristics and features and the evolution can be traced through time as DNA is universal.
2. a) the formation of a lipid membrane around the 'cell'.
   b) the ability to transform energy
   c) the acquisition of a replicating molecule e.g. RNA or DNA.
3. In the oldest sedimentary layers, 3.5-3.7 billion years ago, simple prokaryotic cells can be found. Eukaryotic cells are not found until around 2 billion years ago.
4. a) For DNA to replicate, it requires protein enzymes which are synthesised by DNA. RNA, however, can use RNA ribozymes.
   b) RNA is still a complex molecule and the chance of it evolving from 'primordial soup' is considered to be very slight.
5. It is thought that larger cells engulfed smaller prokaryotic cells and that these became incorporated into the cell. Over time, these evolved as eukaryotic cells with membrane-bound organelles e.g. chloroplasts and mitochondria.
6. When photosynthesising, the cyanobacteria would produce sugars that could be used by the cell as a source of energy/organic molecules by the host cell.
7. It is noted that the internal membrane of the mitochondria is similar to prokaryotic cell membranes but the outer membrane is more like a eukaryotic cell membrane.
8. Independent existence would suggest displaying the characteristics associated with life. Two of these properties of life are to be able to reproduce and produce proteins associated with growth, metabolism or other cell processes.
9. a) They are small, unicellular and do not contain membrane-bound organelles.
   b) Both cells have DNA that can direct the synthesis of complex proteins. Both cells have the ability to carry out complex metabolic pathways to make energy available for cellular processes.
10. a) This experiment did show that simple organic molecules can be made from a 'soup' of inorganic chemicals and a source of energy i.e. lightning spark.
    b) No matter how many repetitions of this work are done, no molecule as complex as RNA or DNA has ever arisen. It would appear that further scientific research is still required.
11. a) They have separated from a common ancestor and over time have evolved different genes and enzyme systems to enable the release of energy by fermentation.
    b) All three Dom ains had a single common ancestor. Eukaryotes shared a more recent ancestor with Archaea but in the development of eukaryotic cells, they may have engulfed bacteria and incorporated them via endosymbiosis.

Chapter 4.2 Suggested answers

4.2 Multiple choice suggested answers

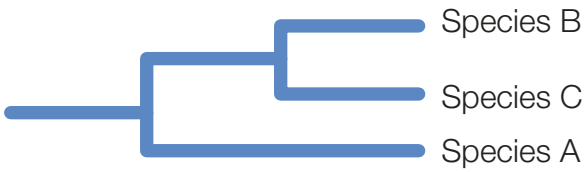
1. M 2. J 3. K 4. M 5. L 6. M 7. J 8. K 9. M 10. K 11. L 12. L 13. K 14. L 15. M

4.2 Free response suggested answers

1. a) Benefits include:
   - expand our knowledge of the evolution of life
   - expand our knowledge of the human genome and gene function
   - identifying genes that are essential for life
   - understand human evolution, migration and relatedness

a) Three techniques are:
- DNA sequencing
- DNA-DNA hybridisation
- comparing proteins e.g. amino acid sequences.

2. DNA from different species:
   a) is similar in the way it is arranged in chromosomes and its composition of bases A, T, G, C.
   b) Is different in the number, sequence and arrangement of bases and chromosomes which varies from one species to another.
3. DNA is the molecule that can self-replicate to produce copies of itself. The fact that DNA is the same molecule in all life forms, suggests that it has been passed down from a common ancestor.
4. Evolution is usually measured by changing gene frequencies in populations. These changes can be seen or measured by differences in DNA sequences and differences in proteins produced.
5. a) it is thought that larger cells engulfed simple prokaryotes and the symbiosis enabled the development of eukaryotic cells with membrane-bound organelles.
   b) Mutations are permanent changes to the DNA that are inheritable. As such, they cause permanent changes to successive generations.
   c) It is only the genetic information in sex cells that is used to form the zygote and thus provide information for the next generation.
6. If the amino acid sequence was very similar between two species, this would suggest they shared much DNA in common. Species that show much DNA in common are more likely to show a recent common ancestor.
7. Your phylogenetic tree should be something like this, B and C could be reversed:



8. If the DNA of two species is similar, it is likely that they have had a recent common ancestor because different species that are separated for longer periods are more likely to accumulate more changes in their DNA via mutations.
9. a) The point at which 50% of DNA is single-stranded and 50% is double-stranded.
   b) The higher the G-C content of DNA, is the lower the melting point.
   c) If the melting point is higher, it indicates a good match and therefore it is likely that the two species shared a recent common ancestor.
10. a) Cytochrome C is a protein which can be analysed to show its sequence of amino acids. These can then be compared directly to see how many amino acids are different between different species which in turn will indicate their relatedness.
    b) The degree of difference in the DNA, and proteins, of two different species will indicate approximately how long it is since they evolved from a common ancestor. The diagram indicates that these two moles did so a very long time ago!
11. a) The evolutionary rate (rate of mutation).
    b) Because a molecular clock uses the rate of mutation for the cytochrome c gene of two species to estimate the time in history that they diverged from a common ancestor. The point represents the estimated time of their closest common ancestor that they evolved from.
    c) Phylogenetic tree
    d) The line should be a linear line projecting from near the origin but between the line for cytochrome c (with species labelled on it) and the x-axis. A slower mutation rate would mean less bases substitutions, and would correlate with a line with a more gradual slope than that of cytochrome c.
    e) Because there is variation in the selective pressures that act on each gene. This results in different mutation rates for different genes, which therefore evolve at different rates (but at a constant rate for each gene). Therefore, each gene must have a calibration of its molecular clock completed separately.

f) (i) Because an error in its calibration would reduce the accuracy of the molecular clock by providing an incorrect rate of mutation and all estimations of times species diverged using this clock would be incorrect.

(ii) The effect could be reduced by increasing the sample size of independent fossil records and known samples used to calibrate the slope (evolutionary rate). This would reduce the effect of a calibration error and improve the divergence estimations.

12. a) The highly conserved regions are where few mutations occur. This allows researchers to easily synthesise primers that will bind to specific conserved sections of the gene allowing amplification of the gene by PCR.

The highly variable regions are where mutations occur more readily. This allows researchers to distinguish between different species.

b) i) Traditional DNA sequencing requires isolating the individual microbes first and it can be very hard to culture some species (in order to isolate them). rRNA sequencing can detect multiple species at once in comparison to sequencing the DNA of an individual species. rRNA sequencing can therefore test for multiple species at a time and use computer software to compare to a known library of species data to identify the species present.

ii) 16s rRNA sequencing will help to identify the types of prokaryotic species (bacteria and archaea) in the intestines but it will not be able to identify other microorganisms such as fungi because they are eukaryotes. To do this 18s rRNA sequencing would also have to be used.

iii) rRNA sequencing is a qualitative method of determining unknown species and different types of species in a sample, but it cannot provide researchers with the quantity of each species in the intestines.

Chapter 4.3 Suggested answers

4.3 Multiple choice suggested answers

1. M 2. K 3. M 4. J 5. K 6. L 7. J 8. L 9. L 10. J

4.3 Free response suggested answers

1. A population consists of members of the one species living in a particular place at a particular time. A species is a group of organisms that interbreed naturally to produce fertile offspring. A species may consist of many populations which may be partially or completely isolated.
2. a) Two examples are bacteria which reproduce asexually and fossils for which there is no evidence of interbreeding.

   b) They use either morphological (structural) or biochemical (DNA or protein) evidence to do so.
3. For a species to have a separate gene pool and maintain its own integrity there must be no interbreeding with other species i.e. they remain genetically isolated and have separate gene pools.
4. Examples include:

   a) flowering in different seasons of the year

   b) different mating calls

   c) incompatible chromosome numbers causing sterility in the offspring
5. Such mechanisms include:

   a) temporal - different mating seasons for frogs in different populations

   b) behavioural - different courtship rituals for different species

   c) mechanical (anatomical) - incompatible sex organs e.g. bats
6. Regarding this hybrid:

   a) The mechanism is post-zygotic (hybrid sterility)

   b) Gamete production involves the separation of homologous pairs of chromosomes; each gamete has an allele for each characteristic. When there are incompatible chromosome numbers this does not occur.
7. A species is a unique breeding group; members can interbreed and produce fertile offspring. For this to occur, the breeding group consists of a single gene pool.

8. a) Proteins are products of DNA synthesis and as such are indicative of the DNA of the bacteria. Different species of bacteria have significant differences in DNA and therefore the proteins produced.

   b) Amino acid sequencing of an essential protein such as cytochrome C. DNA sequencing of the gene coding for cytochrome C could also be compared.

9. Physical or morphological differences would be one piece of evidence, together with their inability to cross pollinate and interbreed. DNA evidence would also be used to establish significant differences.

10. The members of an individual species reproduce under natural conditions to produce fertile offspring. Therefore separate species must not reproduce i.e. reproductive isolation and separate gene pools must apply.

11. This could occur by temporal, behavioural or mechanical isolation. A possible hypothesis is that the two related species have different mating seasons and therefore remain as separate gene pools.

12. a) Temporal isolation

    b) Pollination is the transfer of pollen from one flower to another. If one species is pollinated by birds and the other by wind, it will act as a pre-zygotic isolating mechanism preventing pollination or fertilisation.

13. a) They have different morphology or appearance; their colour. They are found essentially in quite distinct zones, thereby reducing gene flow.

    b) If hybrids are found, then the groups are not reproductively isolated; they must occasionally interbreed. They are then perhaps on their way to becoming separate species but best termed sub-species at this stage.

Chapter 4.4 Suggested answers

4.4 Multiple choice suggested answers

1. L 2. K 3. M 4. M 5. L 6. L 7. J 8. K 9. L 10. M 11. L 12. J 13. K 14. L 15. M

4.4 Free response suggested answers

1. A mutation in a gamete can give rise to a new form of a gene i.e. a new allele. This could code for a new or altered protein thereby changing the appearance (phenotype) of the offspring.

2. The main sources of variation are:
   - Independent assortment - different combinations of chromosomes
   - Crossing over - different combinations of genes
   - Random fertilisation of gametes

3. Factors providing selective pressure include:

   a) Abiotic factors
      - temperature
      - rainfall
      - solute concentration

   b) Biotic factors
      - competition with other organisms
      - disease
      - predators

   c) Those individuals that are best adapted may have a survival advantage, e.g. finches with short, stout beaks will be more likely to survive on an island with seeds as a food source.

4. This keeps the population numbers in check from increasing too rapidly. It ensures the population evolves and individuals are better suited to changing environments.

5. Possible effects include:

   a) Could tend to favour particular genotypes-change the frequency of genes in these individuals that are mating and reduce the frequency of those not mating.

   b) The gene will, over time increase in frequency since it confers an advantage to the carrier.

c) This will tend to reduce differences between populations in different areas.

d) Reduce genetic biodiversity in the gene pool.

6. a) Nature selects those individuals best adapted. The more variation, the greater the diversity phenotypes that nature can select from.

b) Those that reproduce sexually have greater variation in their offspring. More variation provides opportunities for natural selection to act.

7. a) Factors include genetic drift such as the bottleneck effect. Perhaps hunting or loss of habitat has reduced the population size and therefore reduced genetic diversity.

b) Reduced diversity in the MHC genes may have meant that there were few individuals with an immune system capable of responding to the facial tumour and therefore the species is not able to evolve and change in response to the tumour.

8. For populations to evolve separately and accumulate differences gene flow needs to be reduced or stopped. Otherwise interbreeding occurs and the gene pools become more similar.

9. a) Bird predators

b) During the Industrial Revolution there was a decreased frequency of the allele for light colour and an increased frequency for dark colour.

10. a) Immediately after spraying the numbers fell dramatically. The number of insects remained low for several months before increasing rapidly again, although not quite to the same number as prior to the spraying.

b) At 5 months, there was a strong dip in numbers due the insects dying as they were susceptible to the DDT insecticide. However, at approximately 9.5 months, the insect numbers increased. This is likely due to an increased frequency of alleles for resistance to DDT.

c) The spray is only effective for a limited time period as natural selection acts on the insect population and the spray has reduced effectiveness.

11. a) This can accelerate the effects of natural selection as these occur from one generation to the next. With short generation times, natural selection can occur more quickly.

b) With some individual bacteria in a population having resistant genes to a particular antibiotic, they are more likely to survive and pass this on to the next generation.

c)
- The greater the use of antibiotics, the more likely it is that resulting strains will arise by natural selection.
- Same point as above, humans may be ingesting the antibiotics in their food.
- There is a scale of resistance from zero to highly resistant. Taking less than the full course, means some resistant bacteria survive and reproduce.

Chapter 4.5 Suggested answers

4.5 Multiple choice suggested answers

1. K 2. J 3. L 4. M 5. L 6. L 7. M 8. M 9. K 10. M 11. M 12. M 13. K 14. L 15. M

4.5 Free response suggested answers

1. a) Meiosis is fundamental for sexual reproduction which introduces variation into the offspring and potential for natural selection to act.

b) Mutations occur randomly in all cells and can introduce new forms of genes into the gene pool i.e. new genetic material.

c) Nature selects the best adapted individuals and can alter gene frequencies in the population, which is evidence of evolution.

2. a) They are similar in that they can both dramatically alter the frequency of alleles in a population.

b) The bottleneck effect happens due to a chance event e.g. a bushfire reducing the population size; the founder effect occurs when certain individuals start a new population.

c) The changes brought about may reduce the gene pool by eliminating certain alleles leading to less genetic biodiversity.

3. a) Appearances could be very similar, therefore, it is difficult to ascertain whether they breed together naturally and have fertile offspring. Genetic testing may also be inconclusive.

   b) The groups may be very close to reproductive isolation and any hybrids are very rare. Clear distinctions may be seen in physical appearance.

4. The main steps include:

   - Populations may be separated by physical barrier (geographic barrier) e.g. ocean
   - Different selective pressures may operate in each separate environment e.g. camouflage from predators, food sources
   - Over time genetic differences accumulate between the respective populations e.g. Darwin's finches with different beaks.
   - This may eventually lead to reproductive isolation and speciation.

5. For speciation to occur, the separate groups must not be able to reproduce naturally and have fertile offspring. This occurs when the gene pools are separate and distinct and there is no mixing (reproduction) between the two groups.

6. It appears from all the evidence that the land on planet Earth was once a single continent which has subsequently separated into separate continents. When Australia drifted apart there were no large placental mammals and the marsupials evolved in isolation. This is a very good example of allopatric speciation.

7. Genetic drift and natural selection both can give rise to evolution by changing gene frequencies in populations. One main difference is that genetic drift causes random changes, whereas natural selection is directional.

8. Regarding these tortoises:

   a) These tortoises had a selective or adaptive advantage in having longer necks e.g. they were better able to find and eat food than those with shorter necks.

   b) Genetic differences and the inability to reproduce under natural conditions and produce fertile offspring.

   c) The group with the longer necks would have an increased frequency of their gene (or genes) that code for longer necks.

9. This is the definition of evolution i.e. changes in gene frequencies in the alleles of the gene pool.

10. a) The two groups appear to be evolving into separate species even though they live in the same environment.

    b) There are clear differences in the gene pools of each type of fly.

    c) There is still a 4-6% hybridisation rate, indicating the gene pools are not totally distinct.

11. Geographic isolation sets up the chance for different selective pressures to act and bring about changes to the gene pool of separate populations. Reproductive isolation i.e. no mixing of genes and separate gene pools is an integral requirement for speciation to occur.

Chapter 4.6 Suggested answers

4.6 Multiple choice suggested answers

1. J 2. J 3. L 4. L 5. K 6. M 7. K 8. K 9. M 10. L 11. L 12. K 13. M 14. L 15. J

4.6 Free response suggested answers

1. Unrelated species like Eucalyptus and Banksias have evolved similar leaves due to similar selective pressures (hot, dry, very little water) for long periods, becoming more similar.
2. Convergent evolution gives rise to similar or analogous features due to similar selective pressures. Divergent evolution gives rise to differences in the features (homologous structures) due to different selective pressures (but a more recent common ancestor).
3. a) The ancestors of the marsupials were probably geographically isolated as a result of continental drift and evolved in isolation.
   b) From a recent common ancestor, divergent evolution has occurred and different species have evolved in different environments as they adapted to different selective pressures.
4. a) If there are significant selective pressures, such as disease, there may be insufficient diversity of immune systems for any of the cheetahs to possess the ability to combat the disease and survive. This could lead to extinction.
   b) The 'bottleneck' effect is a form of random genetic drift. If only a few survive then there is reduced genetic diversity in the gene pool and none may have resistance to the virus.
5. Comparing primary and secondary succession:

Area of comparison	Primary succession	Secondary succession
Examples of habitat where it occurs	**After glacial action or volcanic activity**	**In woodland after bushfire**
Examples of likely first colonisers	**Lichens, mosses**	**Grasses, small shrubs**
Possible events leading to the succession	**Totally new environment with no organisms**	**Bushfire, flooding**
Speed or rate of succession	**Generally slower**	**Generally quicker**
Number of species	**Relatively few**	**Relatively more**

6. Suggestions include:
   a) Secrete acids that break down rock and begin the formation of soil
   b) Bind sand/soil to reduce the effects of erosion and trap moisture, begin accumulation of decomposing matter
   c) Provide food and habitat for birds, insects etc. stabilising soil and increasing nutrient content
   d) Pollinators of flowers, food source for birds and other vertebrates
7. a) The original gene, over 500 million years, has been subject to natural selective pressures and the eyes have evolved closer to achieve the same goal of vision.
   b) RNA splicing influences the mRNA that is translated and hence the proteins produced in the eye leading to variation in eye structure/function.
8. Convergent evolution tends to occur with similar selective forces acting on different species to produce similar features in unrelated species. Divergent evolution is where populations from a recent common ancestor develop different features due to different selective pressures.
9. a) Examples are:
   - dolphin/kangaroo
   - shark/dolphin

   b) Streamlined body shape/fins with sharks and dolphins.
   c) Dolphin and kangaroo have pentadactyl limbs which have been modified for locomotion in each case.

10. a) The original population has good genetic variation with minor fluctuations. When the population size falls, so does genetic variation. In the recovery phase, the number of remaining individuals increase but now the genetic variation remains low.

    b) A bushfire or other natural event such as flooding (abiotic) or a new predator or disease (biotic).

    c) This is the 'bottleneck' effect, the genetic variation was severely reduced, the gene pool is now limited and is not recovering.

11. a) From a common ancestor many new species have evolved, each species becoming adapted to new environments.

    b) With the extinction of the dinosaurs, it is possible that a range of new environments or niches have become available for the mammals to inhabit (and became exposed to different selection pressures).

Chapter 4.7 Suggested answers

4.7 Multiple choice suggested answers

1. M 2. L 3. J 4. K 5. L 6. K 7. M 8. J 9. L 10. M 11. K 12. J 13. K 14. M 15. L

4.7 Free response suggested answers

1. Some possible answers include:

    a) Introduced species e.g. cane toad

    b) Pollution e.g. CFC gases

    c) Over exploitation e.g. overfishing

    d) Destruction of habitat e.g. for agriculture and forestry.

2. a) There is bio-accumulation of mercury because it is not being broken down. Higher order predators feed on organisms in lower levels leading to bio-magnification.

    b) It is accumulating to higher levels in tissues as it can not be broken down faster than it is accumulating. There is a safe level of consumption, but if it accumulates too high, it can have poisonous effects on the tissues/organism. Therefore, higher order consumers, such as sharks and humans, are at higher risk of its accumulative poisonous effects.

3. Scientists are very concerned because it is 1000-10,000 times the normal or expected rate of extinction. This indicates the massive and unprecedented impact of humans, which threatens every ecosystem on Earth.

4. In a community there are interacting populations: symbiotic relationships and feeding relationships. Anything impacting on one species will likely also impact many other species. If keystone species are removed from an ecosystem, it can have drastic effects and can result in major imbalances and further extinctions.

5. With reference to the diagram, suggestions include:

	Species			
	1	2	3	4
Describe the pattern of results	Steady then quickening to extinction	Rapid increase, sustained high level then a rapid fall	Increased rapidly, maintained high numbers	Levels reduced significantly
Name of the species from the above list	Tasmanian tiger	Rabbit	Cane toad	Eucalyptus tree
Describe the likely reasons for the numbers since European settlement	Destruction of habitat, hunting	Introduced species-control measures then introduced	No natural predators-rapid increase	Clearing for agriculture

6. Some possible answers include:
   a) Extreme heat events e.g. death of flying foxes
   b) Reduced oxygen levels leading to severe impact on aquatic species
   c) Increased intensity of fires leading to habitat destruction and loss of species
   d) Rising sea levels and destruction of coastal ecosystems.
7. Measures introduced by the government to conserve biodiversity include:
   a) Working to provide protection for threatened species.
   b) Recovery plan development for habitats and ecosystems.
   c) Working to reduce threats to endangered species e.g. reducing pollution
   d) Development of national parks for the purpose of species protection and research into reducing impact of introduced species.
8. With reference to the information about rabbits:
   a) There were few natural predators in Australia, ideal temperatures, food and environmental conditions. They evolved in Europe with predators and competitors in the ecosystem.
   b) Rabbits destroy habitat, reduce native plant numbers; if these could recover then native species and communities could again flourish.
9. Methods of rabbit control include: myxomatosis (and other viruses) which were very effective at first and are now less so because of the development of resistance. Also destroying borrows which is ongoing and labour-intensive, but an effective means to slow rabbit population growth.
10. Some possible answers include:
    a) Activities include the burning of fossil fuels, deforestation, production of cement, livestock farming, disposal of waste in landfill, processing of sewerage, etc.
    b) One impact is that it may favour particular species which may increase rapidly at the expense of others, hence reducing biodiversity.
11. Examples of possible impacts of climate change include:
    a) Unable to move, therefore whole populations may be destroyed e.g. flooding
    b) Unable to use homeostatic processes to keep temperature within tolerable levels
    c) Only able to feed in often extreme temperatures which would cause excessive water loss
    d) Often isolated and are susceptible to low oxygen levels in higher temperatures.
12. Referring to the Grey-Headed Flying Fox:
    a) They are pollinators, transferring pollen and assisting in the reproduction of plants. They also assist in seed dispersal (via faeces), important for many plant species.
    b) Reasons include: loss of natural habitat, changing climatic conditions, loss of food sources-further studies and data collection is required to be sure.
    c) It is likely that there will be a high impact. They may out-compete many other native species and lead to major influences on local communities, including human activities e.g. agriculture, aviation.
13. Ecosystems that have fewer species are naturally less diverse. With reduced species biodiversity, these ecosystems are more fragile and more likely to collapse with loss of species.
14. This is very much a personal response. If this was a Test or Exam question it would be essential that several points are clearly expressed and explained. Marks will be given for clear, logical arguments which are well discussed.

Topic 4 Review test suggested answers

Section 1: Multiple choice questions

1. J 2. L 3. K 4. L 5. K 6. L 7. J 8. J 9. M 10. J

Section 2: Free response questions

11. a) Characteristics include: the ability to use energy, to respond to stimuli, to reproduce/replicate.

    b) It is unlikely that DNA was the genetic code of the first simple cells because DNA requires transcribing and translating into proteins. It also requires enzymes to replicate itself. However, proteins are coded for by the genes on a DNA molecule. So it is a question of what came first - DNA or proteins? It is more likely to be another self-replicating molecule.

    c) Due to the discovery of ribozymes that are made of of RNA and can replicate itself and other RNA molecules. They can also act as enzymes, catalysing many reactions. Therefore, RNA had the advantage of being able to be replicated without proteins, unlike DNA that requires them.

12. a) A variety of biotic and abiotic factors. These could include specific niches, habitat protection, slower water flow, higher nutrient levels, accumulation of water plants and associated communities etc.

    b) This relates to the interdependence of populations in the community e.g. producers to trap energy, symbiotic relationships, decomposers to recycle matter.

13. a) Mutations

    b) The flaw is that the above diagram indicates that the human has more recent common ancestors with the orangutan compared to the chimpanzee and gorilla. The amino acid data however, indicates that in the section of the alpha chain there are no differences between the human and chimpanzee sequences, therefore they should share the more recent common ancestor.

14. a) 45%%

    b) This could be related to predation. Different seasons could have differently coloured fallen leaves e.g. the black beetles may be more visible and less well camouflaged in spring and therefore more vulnerable to predation.

    c) From spring to autumn an increase in the percentage of alleles that code for the black colour could be expected.

15. a) The species or population has less of a chance of responding to severe natural selective pressure e.g. a disease may wipe out all individuals because none can survive.

    b) The fires may simply destroy or kill numbers of wrens randomly.

    c) With only a few members surviving, the gene pool will be limited and as the individuals now represent the breeding population, the gene pool will be less diverse.

16. a) Techniques include:

    - DNA sequencing (comparing actual sequences of A, T, G, C)
    - DNA hybridisation - forming hybrid DNA and comparing melting points

    Note: Cannot have comparing amino acid sequences in proteins such as cytochrome C because the question asks for a comparison of DNA.

    Note: Explanation should link back to concept that more closely related species have fewer differences in their DNA sequences and have separated more recently from a common ancestor than distantly related species.

    b) Separates the populations and hence the gene pools. With different natural selective pressures, different individuals are better adapted and changes occur in gene pools. Eventually reproductive isolation may occur.

    c) Speciation occurs when there is no gene flow between populations, possibly due to geographical separation. The Pedra Branca has been separated from the poopulation in Tasmania by a large body of water. Hence, no gene flow. The genetic differences accumulate due to different natural selective pressures acting on the different populations to a significant extent such that interbreeding cannot produce fertile offspring (reproductive isolation).

17. a) These are analogous features.

    b) Convergent evolution is characterised by evolution in separate species causing them to both evolve similar features in response to similar natural selective pressures e.g. hunting, foraging for ants/termites in this case.

    c) Birds and bats have both evolved wings for flight. Flight enables individuals to either seek new habitats to avoid competition, to find new food sources or new niches, to escape predators or a range of other selective pressures.

18. a) The main abiotic factors are water, nutrients and light. This may have a detrimental effect as the tussock grass may compete with native grasses, which would be deprived of essential factors for their survival.

    b) By destroying much of the undergrowth and shrubs there are now resources and niches for colonising species to begin growing in the burnt area. Such conditions are ideal for secondary succession.

    c) If the introduced grasses rapidly spread, this would out-compete native grasses. These introduced species may be unsuitable food for many native animals etc. which may lead to a very different ecosystem to the original.

19. *Note: answers are expressed in dot points here for clarity. In extended answer questions in tests and/or exams, students should write their answers in paragraphs.*

    a) Answers should identify the pattern of the graph and explain link to natural selection:

    - The graph indicates that as the area of the island increases, the rate of extinction of species decreases rapidly to a very low rate.
    - With bigger islands there are greater numbers of niches or habitats available for communities of organisms and, as such, generally more individuals and larger populations would be expected.
    - With larger populations, it is likely that there is more genetic diversity in the gene pool-a range of different alleles for various characteristics.
    - Natural selection operates where there is a struggle for survival caused by both biotic and abiotic factors. This operates or acts on the variation that exists between members of the population.
    - The best adapted individuals are more likely to survive to pass on their favourable genes to the next generation. Therefore, with more diversity and a larger population size, it is more likely that at least some of the population will survive.

    b) Answers should address both the management of reserves and land clearance:

    - This indicates to scientists, Park managers and governments that ecosystems need sufficiently large habitats and reserves compared to smaller fragments.
    - Likewise with logging and agriculture, it is better to leave a few large areas untouched compared to many smaller fragments.

20. a) Mutation

    b) Variation exists in populations of gonorrhoea bacteria through mutation. If a random mutation is beneficial and confers resistance to an antibiotic, that individual is more likely to survive the presence of that antibiotic. Those individuals that do not possess this gene are likely to be susceptible to the antibiotic and not pass on their disadvantageous genes. Therefore, the frequency of the antibiotic resistant gene will increase in the gonorrhoea gene pool and lead to evolution through natural selection. Over time, with exposure to multiple antibiotics acting as selection pressures, gonorrhoea bacteria also develop resistance to the additional antibiotics through the same process. This has resulted in super bugs such as “super gonorrhoea”.

    c) This can accelerate the effects of natural selection as the rate at which bacteria reproduce gives opportunity for increased mutations to occur and therefore increased chance of beneficial mutations that confer resistance to an antibiotic (i.e. short generation times allows natural selection to occur more quickly).

d) (i) Some possible answers include:

- Suitable temperature (37°C)
- Suitable pH
- Nutrients (e.g. glucose, amino acids, salts etc.)
- Suitable osmotic pressure
- Sterile conditions

(ii) It is likely not to be super gonorrhoea because there is one antibiotic that still works; however, it is multi resistant. Only ceftriaxone was able to prevent the patients strain of gonorrhoea from growing (i.e. it's the only antibiotic with a zone of inhibition). The gonorrhoea bacteria were able to grow in the presence of all other antibiotics tested (hence no zones of inhibition).

(iii) Some possible answers include:

- Effects of higher concentrations of antibiotics still need to be tested to confirm the effect is the same across multiple concentrations.
- It is unclear if more than one trial has been conducted. Multiple trials should be conducted to ensure reproducibility of the results.
- Only 8 antibiotics have been shown to be tested. Are there any other antibiotics that could be tested on this strain of gonorrhoea?

e) Some possible answers include:

- The application of FMTs could reduce number and severity of ongoing C. diff cases in the UK. As a result, the heavy strain on the NHS health system could somewhat be reduced. This could free up beds for patients with other medical issues to also be treated.
- The application of FMTs for C. diff infections could have a snowball effect and generate further research and approval for other uses such as other antibiotic resistant infections and other conditions associated with gut health.
- The approval to apply FMTs could generate further interest from the public and media. This could generate more interest in faecal donations, fuelling extra research and applications of FMTs.
- The use of FMTs for antibiotic infections is limited to C. diff infections only. This is not a suitable treatment for respiratory or sexually transmitted antibiotic resistant infections.
- The human gut microbiome is incredibly complicated and not much is known about its overall complexity. Therefore, a limitation of using FMT for C. diff infections is the unknown side effects that could occur, especially in the long term. Patients still have to consent to such a treatment and they may choose not to, if they are unsure of the possible side effects, limiting its application.

Appendix

C Intercultural understanding: Biology as a global endeavour

Biological science today is a global human endeavour involving millions of people that is supported by contributions from diverse cultures that stretch back more than 3000 years.

Breakthrough moments in biology took place in the ancient world (prehistory to 1500 AD) but this happened slowly and only involved the very few people who could read and write. The earliest origins of medicine and surgery can be traced back to the ancient Chinese and Egyptians (c. 2500 BCE) and the Greek physician Galen in the 2nd century AD provided the first theories about blood and its role in the body (though many were eventually disproved). Hospitals of a sort and pharmacies arose in what is today modern day Iraq in the 8th century AD and Islamic thinkers like ***Avicenna*** in the 11th century AD were among the first to apply experimental methods to the emerging science of medicine.

Avicenna - An 11th century scholar from Iran

From around 1500 AD European biological thinking started to be enriched by the work of Italian, Dutch and English scientists, all of whom were influenced by the re-emergence at the time of the discoveries made in the ancient world. There were advances in surgery, early attempts to more systematically use medical drugs and a more accurate understanding of the inner structure and function of the human body was revealed for the first time. Work done in the 19th and 20th centuries by German, French and American scientists gave rise to fields as diverse as genetics, disease treatments, molecular biology and ways to boost food production.

The arrival of modern education and mass communication systems in the 20th and early 21st centuries have seen more people doing science and being aware of its contribution to society. Mass media made possible for the first time greater international collaboration in biology, and peer review. Today, for example, a global quest is underway to develop technologies to use to identify breast cancer in women before they even start to develop it. One way this is being attempted is to measure the levels of mRNA produced by breast cancer cells and to use this to develop indicators that would signal breast cancer is about to start. Cancer biologists from Australia, South Korea and Japan and many others are all involved.

You may need to refer to the online resources below to answer the questions that follow.

1. Read this article carefully and make a list of the various cultures that have contributed to the development of biology as a global endeavour.

2. Cancer was first named by the ancient Greeks. Do some research and explain why it was given this name and describe what they thought about the causes and treatments for the disease.

Helpful online resources

What Ancient Greek Physicians Knew About Cancer

<http://greece.greekreporter.com/2013/11/17/what-ancient-greek-physicians-knew-about-cancer/>

C Critical and creative thinking: Pharmacogenetics

Genes are segments of DNA that carry the genetic instructions for cells to synthesise a protein or an RNA molecule. Proteins made by cells include molecules called enzymes.

As will be discussed in more detail in Chapter 1.4, enzymes speed up or catalyse specific biochemical reactions in cells. Many of these reactions form part of metabolic pathways in which there are chains of many different reactions, each one catalysed by a specific enzyme. Some of these metabolic pathways take place in liver cells e.g. drug metabolism pathways that are responsible for the breakdown of all drugs that enter the body, including medicines.

Although the use of medical drugs over the last few decades has transformed health care, most medicines are still developed and go to market where a 'standard dose' is used. Although this is safe and works well for most patients, for others using the standard dose leads to unwanted side-effects. One of the reasons this happens is that the efficiency of people's drug metabolism pathways varies. A drug taken by one person may be broken down efficiently without side-effects while in someone else with a less efficient metabolic pathway it is broken down more slowly, causing side-effects because it stays in the body longer.

You may need to refer to the online resources below to answer the questions that follow.

1. One imaginative solution to this problem has been to look for genes liver cells use to produce enzymes involved in drug metabolism pathways, and then determine how active the genes are. The lower the activity of these types of genes, the less efficiently the drug is metabolised by the body. Speculate about what benefits to patients, such an approach can deliver.

2. The identification of genes that influence the body's ability to metabolise drugs efficiently is called 'pharmacogenetics testing'. Although this type of testing is still in its infancy, it probably won't be long before it is used by doctor's to make predictions on behalf of their patients in their care. Envisage how this type of testing could benefit both the doctor and the patient.

Helpful online resources

Megan Ensinger: Introduction to Pharmacogenetics 2.0

<https://www.youtube.com/watch?v=AXi68Qp3hQ0>

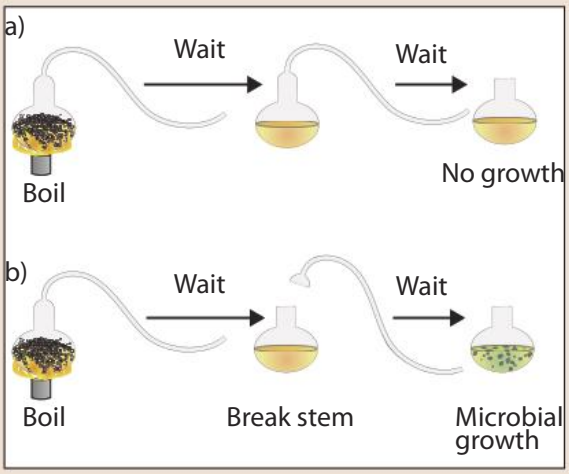
Helpful online resources

Max Lounsbury: Phamacogenetics

<https://www.youtube.com/watch?v=8Zspb6Z0RRs>

C Critical and creative thinking: Food spoilage

The problems caused by the spoilage of food are as old as human civilisation itself. Generally, microbes in or on the food, produce chemicals which change it chemically and physically, so that it is no longer pleasant or safe for humans to consume. One of the first scientists to investigate this problem was *Louis Pasteur,* a French biologist, sometimes called the 'father of microbiology'. He was particularly interested in whether it was the air itself, or particles (i.e. bacteria and fungi) in the air, that caused wine to go sour. He devised a very creative and famous experiment using a 'swan-necked' flask to demonstrate that it was actually microorganisms in the air that caused wine to go sour {*see Figures a) and b)*} rather than just the air itself.



Milk is a very important food, particularly for young mammals and is consumed directly and indirectly in very large amounts in our society; milk products include cream, ice cream, yoghurts, flavoured milk, junket etc. In the supermarket milk will normally be sealed, refrigerated and have a 'use-by-date' printed on the container. Usually, sometime after this 'use-by-date', depending on conditions, the milk will go 'sour'.

To help understand this process, it is important to know that milk is a mixture of water, lipids, proteins, carbohydrates and mineral ions. Milk from a supermarket has usually been processed which includes heating and cooling it rapidly to kill microbes (pasteurisation) and being forced through a small filter to reduce the size of lipid globules to prevent them floating to the top forming cream (homogenisation).

The souring of milk is caused when a particular species of bacteria (***Lactobacillus***) converts the sugar lactose ($C_{11}H_{22}O_{12}$) to lactic acid ($C_3H_6O_3$) by anaerobic respiration. In doing so, it increases the acidity of the milk (i.e. decreases pH) which then denatures a protein (caseinogen) to form an insoluble product (casein) which settles to the bottom. In addition gases are produced which cause the milk to 'smell'. These changes can be observed qualitatively by changes in colour, taste, smell and seeing the products settle on the bottom of the container. Changes can also be measured quantitatively by using instruments to analyse the changing pH and the varying concentrations of other chemicals involved.

The souring of milk is an ideal 'everyday' problem that can be considered and investigated in a scientific way. Sometimes this is referred to as the 'scientific method', a process used by scientists to gather information about 'cause' and 'effect'. In this SACE Biology course, students are expected to 'deconstruct' problems, such as this, to determine the most appropriate method of investigation.

To do this, make a copy of the following page and answer the questions as if you were going to conduct an experiment to investigate one particular aspect of this problem in a scientific way. Keep the completed page as evidence of your **deconstruction of the problem**.

If time permits at school, you may be able to do a simple experiment. If not, you could possibly do a simple and safe experiment at home to investigate this problem.

C Critical and Creative thinking - Deconstruction Template

Name: .....**Class:**..... **Date:**.....

Consult also the 'Glossary of Practical Terms' on pages 513, 514 in the Appendix.

1. Describe the problem to be examined by a practical investigation.

2. List all of the variables that could impact on this problem.

3. Select one of these variables and include it in an 'Inquiry Question' (IQ) that could be used to investigate this problem further.

Use this format as a guide: *What effect does ..... (variable) have on .....(result)?*

4. Select the variable from the IQ above that is the:
   a) Independent variable:
   b) Dependent variable:
5. State three variables that you would need to keep constant, and how they will be controlled.
   a) Controlled variable 1:
   b) Controlled variable 2:
   c) Controlled variable 3:
6. Briefly state why the controlled variables need to be kept constant.

7. Identify any variables you are unable to control, and state why not.

8. List the materials required in this investigation:

9. Briefly describe the procedure to be followed in this investigation:

10. Describe the types of data (qualitative and quantitative) to be collected:

11. Identify relevant ethical and safety considerations to be observed during this investigation:
    a) Ethical considerations:

    b) Safety considerations:

C Personal and social - Epigenetics

It has already been stated that factors in an organism's environment influence the expression of its genes. This occurs through environmental factors interacting with a complex framework of chemicals that covers chromatin, called the epigenome. Some epigenetic factors modify gene expression by causing more DNA coiling, which switches genes off while others open chromatin up, switching genes on. The study of the epigenome and factors influencing it, and thus gene expression, is called **epigenetics**.

Unlike changes to characteristics or traits caused by mutations that are due to changes to the DNA base sequence of genes (to be discussed in Chapter 1.6), epigenetics changes are only caused by modification of gene expression; for example, changes to how much DNA is methylated. Like changes brought about by mutations, however, there is evidence that epigenetic changes to the DNA of sperm or ova may be inherited or be passed down to future generations. This is called epigenetic inheritance. If true, then things like the type or amount of food a person eats or other environmental factors before fertilisation of sperm and egg could affect a future child.

DNA methylation is involved in the epigenetics of cells that control cell division; it is often used as an epigenetic signalling tool that tends to switch specific genes off.

You may need to refer to the online resource below to answer the question that follows.

1. Put forward your opinion about how the diet and lifestyle of a person could possibly influence the health of their children. Provide support for your opinions.

Helpful online resources

SciShow: Can Your Environment Affect Your DNA? | Epigenetics Explained

<https://www.youtube.com/watch?v=kp1bZEUgqVI>

C Intercultural understanding - Sun-tanning

Exposure of skin cells to UV leads to the production of a brown-coloured pigment called melanin. The longer the UV exposure the more melanin is produced and the darker the skin or 'tan'. Less and less exposure to UV results in paler, more fair skin.

Prior to the early part of the 20th century, people of Western cultures considered pale skin to be a mark of beauty, wealth and refinement. Tanned skin was associated with manual labourers (who spent long periods of time outside) and therefore, people of lower class. However, around the 1920s tanned skin began to be seen as epitomising physical beauty, health and vitality. Despite early evidence that people from fair-skinned Western cultures risked premature aging of the skin and skin cancer, the desirability of tanned skin has survived well into the 21st century. In recent decades this was facilitated by the operation of commercial solariums that emit UV onto people's skin to 'improve their tan'.

As new information about the danger posed by exposure to UV radiation appeared in the early 2010s, questions began to be asked about the safety of commercial solariums. At that time, South Australia, had around 70 solariums that were licenced to operate legally. Evidence put forward that linked solarium use with skin cancer proved to be compelling. Despite entrenched intercultural views that associate physical appearance with tanned skin, laws were introduced nation-wide in 2016 outlawing their use. Today commercial solariums are banned and anyone caught operating one will be prosecuted and fined.

C Critical and creative thinking - Cystic fibrosis

Cystic fibrosis (or CF) is a genetic disease that is caused by a base deletion mutation that occurs in one gene that is located on chromosome 7. CF sufferers have a wide range of symptoms, including the production of thick, sticky mucus by the lungs. This leads to lung infections and difficulty breathing. Today, about 3000 Australians live with CF and 1 in 25 (just less than one million) are carriers for CF. This means that although they do not have CF, they could have children who are born with CF.

A variety of treatments are available to use to help improve the quality of life of CF sufferers. These include drugs that break up the mucus, antibiotics and, in extreme cases, a lung transplant. It may become possible though to cure CF using a relatively new medical technology called gene therapy.

1. *Watch the first online resource video (below)* about cystic fibrosis in Australia. Note the part that shows a brief animation about how to treat CF using gene therapy. Study the animation closely and note that it contains misconceptions about CF and its treatment using gene therapy. Identify one of the misconceptions and then describe and analyse it .

2. *Watch the second online video (below)* about a gene therapy for liver cells and note the clever way biological knowledge is used to deliver working copies of the required gene only to liver cells using a virus. A major hurdle for any gene therapy is how to introduce functional copies of the gene that is being targeted for therapy into cells that carry faulty or non-functional copies of it. Investigate whether this method is being used in CF gene therapy, or if one just as creative, is being used. Describe the method you discovered and explain its significance in CF gene therapy.

Helpful online resources

WCH Gene Therapy: Cystic Fibrosis Gene Therapy

<https://www.youtube.com/watch?v=8QKT28A-tbM>

Helpful online resources

Surengnani: 3D Animation Gene Therapy

<https://www.youtube.com/watch?v=X7eiYRBDAT4>

C Intercultural understanding: Inclusive genetic testing

It is now possible to test for hundreds of human genetic disorders. In many cases this involves using PCR with primers that bind to the genes associated with them. The presence or absence of the disease-causing mutation in the amplified DNA can then be determined by DNA sequencing. Common genetic tests include those for sickle-cell anaemia, cystic fibrosis and the blood clotting disorder called haemophilia. The use of such tests permits the identification of the disease before the onset of symptoms. Many can also be used to identify carriers of faulty-disease causing genes who do not have the disease but have the potential to have children with the disease. In some cases, identification of a genetic disease can even be confirmed before birth. Many genetic tests are in development and new ones are introduced every year; for example, a more accurate test for bowel cancer called ***Colvera*** that became available in Australia for the first time in 2017.

Until recently, genetic testing required the patient to go to a clinic or hospital, have the test there, and then have a follow-up with a doctor or genetic counsellor to accurately interpret the results. This helps people begin to come to terms with what can be confronting information and the fact that genetic tests do not always provide 'clear-cut' results. Furthermore, the implications of confirmation of a serious genetic disease go well beyond the self – they have implications for family members, employment and decisions about how lifestyle should or can be adjusted. It is possible to advise and counsel patients like this in a way that is culturally inclusive as well. This is important because people of different cultural origin may hold different views and customs that influence how they receive, process and react to information like genetic test results and related advice that may be about having blood tests, decisions about family planning, or the termination of a pregnancy.

Direct-to-consumer (DCT) genetic testing provides a more patient-independent way to get genetic information about the risks of a genetic disease developing at some point in the future. On paying for the test, a person sends a sample (usually saliva or an inner cheek swab) which is analysed by a laboratory overseas who then send the results directly back to the person who sent the sample. There is no involvement of a health or genetic professional which promotes inaccurate processing of the information and incorrect decisions about how it should be used. While DCT genetic testing may appeal to some whose cultural views forbid for instance blood tests (a blood test is not required), transmission of genetic information like this is very unlikely to be respectful of or engage with broader cultural views thereby undermining its inclusiveness.

C ICT: Genome sequencing

The development of the technique of genome sequencing provides a good example of the impact of ICT on the development of biology. The first genome sequencing methods took a long time and were very expensive. The determination and then publication of the human genome sequence in 2003 was a major achievement but it took over 14 years and cost about $3 billion. By 2013, the development of advanced high speed ICT-driven automated DNA sequencers was yielding human genome sequences in only three days for as little as $1000. In December 2016, the UK-based company Oxford Nanopore Technologies announced genome-sequencing-in-a-day capability using an easy to operate portable DNA sequencer called a MinION.

The applications for super-fast, cheap genome sequencing are numerous and very wide-ranging. It is already possible for biotechnology companies to sequence thousands of genomes a year. This greatly increases the ability of them to contribute to major research projects; for example, those looking into understanding and developing new treatments for cancers or genetic disorders. The technologies also make possible more personalised medicines that, informed by an individual's own genome, respond more effectively to drug treatments with less side-effects. Even more ground-breaking is the potential ability to sequence genomes from a huge number of people so that in the not too distant future analysis of them may usher in what might be called prognostic genomics – an individual's genome will be used to discover vulnerability to disease and to inform the steps to be taken before it develops, or to assist treatment choices if it has developed.

C Ethical understanding: Using CRISPR

The overwhelming potential of the CRISPR technology creates pressure to apply it. However, the ability to edit genetic material raises bioethical issues, or questions about if or how CRISPR-enabled developments should proceed, as breakthroughs rapidly come to light.

Some examples of the bioethical issues associated with CRISPR include:

- CRISPR makes it possible to carry out genetic research on a wider range of organisms than is presently possible. Will this cause more animals used in this way to become unhealthy, suffer or experience pain?
- Might a gene edited in an organism then go on to function in an unforeseen manner? If the organism or parts of it were consumed, could this trigger cancer or another human disease?
- If it is possible to edit the genomes of disease-causing animals in such a way that it is no longer possible for them to transmit the disease to humans, isn't it ethical to do this because it greatly reduces human suffering? e.g. the malarial mosquito that results in hundreds of thousands of people dying from malaria each year, most of them children.
- CRISPR can be used to edit sperm, ova or early embryos using something that is known as germline editing (this will be looked at in Chapter 2.7). Is this the right thing to do because it provides a way to deliberately design heritable changes to pass to future generations?
- The DNA of an organism can be altered without the addition of any other genetic material. Are existing laws that regulate genetic modification of organisms – that does involve addition of new genetic material – adequate to regulate CRISPR-edited organisms? If this is not the case, how can CRISPR-enabled technologies be properly regulated?

Some possible implications of the use of CRISPR include:

- Ecosystem damage is more likely. Gene-edited plants and animals that 'escape containment' out-compete or consume wild populations, leading to food web disruption, reduced biodiversity and thus permanently altered ecosystems.
- There are less job opportunities in some sectors of the economy. CRISPR technology favours food and production of other items by multinational companies over small farm or smaller scale business. This accelerates the closure of them and tends to drive production off-shore.
- More organs are available for transplantation into human patients. Editing pig genomes provides a way for them to grow organs that can be harvested for transplantation operations that do not lead to rejection or the transmission to humans of pig-born viral diseases.
- People live longer and healthier lives. More foods are produced that are more nutritious and contain lower quantities of lifestyle disease-causing substances, the long-term consumption of which reduces life expectancy.
- Human suffering is greatly reduced. CRISPR promises to be a major driver in the quest to discover cures for many more human diseases.

It is clear that CRISPR has the potential to open a new era of scientific research and development. But the technology comes with striking bioethical issues that need to be addressed at an international level to discuss and agree on the most responsible way forward.

Student Task: *Imagine that you are a bioethicist and have been asked to recommend some guidelines that will be used in making grants to assist in 'CRISPR' research. List 5 criteria for this purpose.*

C Ethical understanding: Using CRISPR

To learn more about technologies used to study cells and organisms, use the QR codes below:

The invention of light microscopes in the 16th century changed the understanding of organisms. Through only simple lenses, that provided limited magnification, these devices revealed a microscopic world for the first time. Thereafter, all animals and plants were seen to consist of cells and detail about organisms once far too small to see, was suddenly accessible and spectacularly clear. It was even discovered that cells contained even tinier components, eventually called organelles.

C Intercultural understanding: Where do we come from?

There are many different cultures of people on Earth. Most are defined by a specific language and a different set of cultural views and beliefs. One question asked by people for thousands of years, irrespective of their cultural identity, has been 'Where do we come from?'

Nearly all cultures have 'creation stories' which describe the earliest beginning of the Earth and the origin of human-kind. Some of these imagine the origin of the Earth and the first people to be a kind of birth in which the world developed and was born in some way, like a foetus in the womb. Others tell of an ancestral mother and father, sometimes represented by the sky and Earth, who came into existence and created life just as the parents of humans and other animals create life. For Aboriginal Australians the Earth and the present-day world was created by a series of ancestors during the 'dreamtime'. For the Birpi Nation on the mid-north coast of NSW, the formation of a billabong and three mountains that overlook it is explained in the dreamtime story of the three brothers (*see pic*) .

For many cultures, their existence is the product of a supreme being who triggered a chain of events that led to the creation of the Earth and, subsequently, human beings and all other life. Some kind of Earth-life creating god, or gods, are a feature of cultures as diverse as the Maori in New Zealand, the Cherokee Native Americans in North America and the ancient Egyptians. Christians, regardless of the exact nature of their faith, for instance, understand the origins of humanity in terms of 'God' who created the world and the first people as well as the first animals and plants. The descendents of these; all humans and other organisms, populate the world today.

For many scientists the origin of life and ourselves is simply a product of natural processes that have taken place over billions of years, rather than an act or acts of creation. There is still debate, however, as to how the first life actually originated on Earth, and thus how we came to be here. There is widespread support for the first prokaryotic cells evolving in seawater at least 3.5 billion years ago and the idea that these originated in the warm water of hydrothermal vents at the bottom of the ocean is gaining momentum. The hypothesis will receive strong support if life is discovered on a moon in the solar system with an ocean and maybe hydrothermal vents, such as Europa, one of the many moons of Jupiter. The 'Science as a Human Endeavour' activity at the end of this chapter looks at if there could be life on Europa and what is being done to find out.

Student Task: Do some research on the creation stories of other cultures e.g. Japan, or China.

C Critical and creative thinking: Growing tomatoes in the desert

As they are photo-autotrophs, flowering plants obtain chemical energy by carrying out photosynthesis to make glucose. Some energy stored in glucose is transferred to ATP during aerobic respiration to provide energy for plant life processes like growth and reproduction.

Flowering plants reproduce by growing flowers that once pollinated, develop into fruit and seeds. Many fruits are soft and edible and a lot of commonly eaten vegetables are in fact the fruit of a species of flowering plant e.g. pumpkins, beans, cucumbers and tomatoes.

The health benefits of regularly eating vegetables are beyond doubt but growing enough of them in a dry, hot country like Australia has always been a challenge. In recent years many vegetable growers have turned to greenhouses in an attempt to do this in a way that is more profitable. Using greenhouses requires a lot of sunlight which ideally need to be located in places where there are a large number of sunshine days. Such places, however, tend to be hot for much of the year and lack suitable amounts of freshwater. Greenhouses also need a lot of electricity.

You may wish to refer to the online resources below to answer the questions that follow.

1. Using your understanding of the resources required to grow tomatoes in these quantities, suggest some creative solutions that the ***Sundrop Farm*** might have implemented to create a successful farm in such an inhospitable environment

2. The ***Sundrop Farm*** near Port Augusta gets 320 sunshine days per year but the area is hot and very dry. There are four greenhouses 20 hectares in size (about three Adelaide ovals) and so a great deal of electricity is needed. Put forward logical and reasoned solutions to the problem of how the Sundrop Farm obtains the electricity and freshwater it requires and how it keeps greenhouse temperatures cool enough for optimum tomato growth.

Helpful online resources

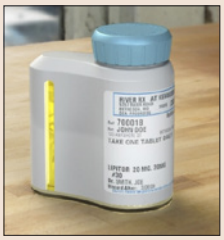
SundropFarmsTV: Sundrop featured on ABC Landline - October 2016

<https://www.youtube.com/watch?v=laTS00Df5jY>

C ICT: Smart pill bottles

Modern health care is served by an incredible array of different types of medicines. Many are taken in pill form. As discussed in Chapter 1.2, advances in the science of pharmacogenetics is beginning to make possible more personalised medical drugs with fewer side-effects.

For many people, it is one thing to be prescribed a medicine and obtain it from a chemist but something entirely more challenging is remembering to take the correct dosage at the right time. Failure to take the correct medication properly reduces the efficiency of patient treatment and leads to masses of unusable drugs costing the tax payer millions of dollars every year. In the case of serious illnesses missing a dose is a leading cause of pre-mature death.



One technology that is being developed to help patients to stay on pill-based medication is a type smart pill bottle. These products come with sensors and a wireless chip aimed at tracking patient usage of the medication and alerting the patient and/or their doctor if they miss a dose. Bottles now produced by *AdhereTech* in the United States are powered by a battery that can last for six months, is rechargeable and can be used for up to five years. The alerts come in the form of adjustable lights and chimes and are sent as a text message to patient's phones.

Data generated and communicated by ICT-enabled devices like this is designed to be safe and secure and permit patients to take a greater amount of responsibility for their health care with better treatment outcomes for them and members of their immediate family.

Student Task: *Read this information carefully and make some notes to consider the potential benefits and limitations of these smart pill bottles.*

C Ethical understanding: Using DDT to control malaria

Malaria is a serious infectious disease caused by several species of the genus *Plasmodium,* a unicellular eukaryote. These are transmitted from person to person by female members of the *Anopheles* mosquito. Every year several hundred million people are infected with malaria. Symptoms include repeating bouts of fever and chills, severe headaches and anaemia. The disease kills around a million people a year, mostly children in Africa under five years of age.

The substance dichloro-diphenyl-trichloroethane (or DDT) is an insecticide that has been in use since the 1940s. One major use of DDT has been its use to kill mosquitoes that transmit species of *Plasmodium* to people. Using DDT to control malaria like this was very successful initially, but the discovery in the 1960s, that using it came with ecological costs and health risks to humans, led to it being banned in many developed countries in the 1970s. Many poor developing countries, however, still use DDT because they have large populations of *Anopheles* mosquitoes and, as a result, malaria remains a major public health problem.

The reasons for using DDT to control malaria include the right of poor, developing countries have the right to be able to plan for the future. This means that they should be able to take steps to improve the quality of life for their present and future citizens. Malaria exerts a tremendous negative impact on the health and well-being of hundreds of millions of people worldwide, the majority of whom do not have access to adequate health care. If the global community has a technology that is relatively cheap and easy to apply to help alleviate human suffering, like using DDT to control malaria, then, why not use it?

The reasons against using DDT to control malaria include the observation that, even though using DDT reduces human suffering from malaria, the global community has a responsibility to protect its citizens and sustain the biosphere. This cannot be achieved using a substance considered a probable human carcinogen (cancer-causing chemical) and one that bio-accumulates in the lipid-based structures of a wide range of predators, like cell membranes and fat stores, killing them. All species have a right to life. So,is it right to use it?

Student Task: Imagine you are preparing to be in a debate about the use of DDT, as described. Note three arguments for or against the case to use this chemical to reduce malaria.

C Critical and Creative Thinking: Ticking of the baby clock

Germline cells start to meiotically divide to produce ova before birth. This means girls are born with thousands of immature ova. From the age of puberty, structures in ovaries called follicles carry ova at various stages of development. Usually one matures every 28 days after which a mature ovum is released into a fallopian tube (oviduct). This continues until a stage in a woman's life called menopause, after which no more ova mature. For most women this occurs 35-40 years after puberty, sometime in their late forties or early fifties.

Women are most fertile – likely to conceive and give birth to a child – in their early twenties. The realities of modern life, however, mean that many choose to delay having children. Today, more than half of all South Australian babies are born to women aged 30 and older. This is despite evidence that female fertility begins to decrease around this age, and drops steeply after the age of 35. At this age, many women feel their 'baby clock is ticking loudly', a phrase that means it won't be long before they may be too old to bear a child.

There are now about 12,000 IVF babies born in Australia every year. The procedure, however, only delays decline in fertility for so long. Some women choose to have their 'eggs frozen' until they feel they are prepared for motherhood. Egg freezing is a $billion business in the United States.

You may need to refer to the online resources below to answer the question that follows.

1. Suggest possible consequences and speculate about possible outcomes for both individuals and society for (a) delaying pregnancy and (b) the further development of these technologies.

Helpful online resources

TED-Ed: How in vitro fertilization (IVF) works - Nassim Assefi and Brian A. Levine

<https://www.youtube.com/watch?v=P27waC05Hdk>

Helpful online resources

Seiden NYC: Extend Fertility

<https://www.youtube.com/watch?v=wWHvYKw7HGE>

C Critical and creative thinking: Analysing claims

A claim is a statement or a point of view about data or a piece of research. Scientific claims are made all the time. Some examples include video can be stored using DNA and the consumption of some foods improves memory. Before a claim can be accepted or used to modify or replace models, it should be analysed for its validity and reliability.

The credibility of the claim is dependent upon the qualifications of the author or authors or the organisation that where the research was done. Claims are likely to be credible if there is evidence of the author's qualifications, the legitimacy or appropriateness of the organisation and if the contact details for the author or organisation are clear, accurate and up-to-date.

A claim may be described as valid if the data that has been collected meets all of the requirements of the scientific method; for example, it has been obtained via a carefully controlled investigation that is a fair test. Claims supported by related scientific theory are more likely to be valid.

The reliability of a claim refers to the repeatability of data that has been collected and used to support the claim. Data that is not a 'one-off' that can be obtained by others is likely to be more reliable than data where this seems difficult or impossible to achieve, or confirm.

Consider the following claim that cell-cultured chicken meat has been produced for human consumption in the United States as reported by The Australian newspaper on 16th March 2017. An adaptation of the article appears below.

Chicken meat grown from self-reproducing cells in the US

JACOB BUNGE

A food technology start-up says it has created the world's first chicken strips grown from self-reproducing cells. It pretty much tastes like real chicken, according to people who were offered lunchtime samples in San Francisco yesterday.

Scientists believe the new product could revolutionise the $US200 billion US meat industry. Their goal: replace billions of cattle, pigs and chickens with animal meat they say can be grown more efficiently and humanely in steel bioreactor tanks.

Memphis Meats argues the technique will help the food industry avoid the costs of grain, water and waste-disposal linked with livestock. Scientists at the company have already produced beef, grown from bovine cells and made into a meatball.

Uma Valeti, Memphis Meats' chief executive, said the cell-cultured chicken represented a technological leap, and opened up an important market. "Chicken is the most popular protein in our country," he said. US consumers ate an average of 41.2kg of chicken each in 2016, according to the US Department of Agriculture, nearly as much as beef and pork combined.

Worldwide, about 60 billion chickens are eaten annually. The UN Food and Agriculture Organization predicts that chicken — cheap to produce with less religious and cultural barriers — will top pork as the world's most-consumed meat by 2020.

Memphis Meats estimates its current technology can yield 450 grams of chicken meat for less than $US9000, about half the cost to produce its beef meatball about a year ago. It hopes to begin selling its meat commercially by 2021.

1. Using only the article and information above, analyse the claim for and validity and reliability.

C Ethical understanding: Vaccinating children

A vaccine is a liquid that is deliberately introduced into the body (usually via injection) to greatly reduce or eliminate infection by a pathogen and thus a disease. Vaccines routinely given to children include the MMR vaccine which acts against three common and debilitating diseases; measles, mumps and rubella. Children given a vaccine are said to have been vaccinated.

According to data published by the Federal Government's Immunise Australia Program, the number of Australian children that receive standard childhood vaccinations is put at around 93%. That the figure is not 100% is in part due to lingering fears about the side effects of vaccines. These range from temporary redness and swelling at the injection site, to a mild temperature and, in very rare cases, an allergic reaction. To not vaccinate a child, however, not only puts them at risk of a disabling or even life-threatening disease, but also threatened the health and well-being of other children, e.g. at preschools or childcare centres.

For many, the benefits of vaccinated children seem obvious, but small numbers of parents reluctant to have their children vaccinated exist across the nation. What should be done?

To reflect on this dilemma, think about and discuss with others the following:

1. In January 2016, in a deliberate attempt to provide additional incentive for all parents to agree to vaccinate children, the Australian Government proposed to withdraw childcare subsidies from those families that had unvaccinated children. This policy was implemented in South Australia in September 2017. Discuss whether you agree this was the right thing to do.
2. The so called 'no jab, no play' policy includes a provision for exemption. Describe under what conditions a child might be entitled to be exempt from a vaccination.

C Personal and social capability: The limits of perception

Stimulus-response pathways help provide organisms with the ability to collect and interpret information about the world around them. The fundamental ability of organisms to 'sense' their external environment is called perception. In many animals this involves sense organs packed with sensory receptors and five basic senses; sight, hearing, smell, touch and taste.

Human senses have provided us with every experience we have ever known – the serenity of a mountain lake, the call of a baby and a re-assuring pat on the shoulder to consider just three. There are, however, limits to the range of things humans can sense. Take, for example, sight. What we 'see' is caused by how the brain interprets light reflected or emitted from objects. But what we perceive as light (visible light) is actually only a portion of the energy that leaves the surface of objects. In addition to visible light, objects may reflect ultraviolet radiation (UV) or give out infra-red (IR) radiation (see pic), both of which we cannot perceive by sight.

Although our eyes only sense visible light, there are organisms with eyes or other light-sensing structures that enable them to perceive infra-red radiation. Such an animal looking at a scene would see something that is very different from what we do (*see image*). Human hearing is likewise limited when compared with other animals. The sense of hearing in part depends on how the brain interprets the vibrations of a surface. In the case of humans, sound is only perceived if the surface vibrates between 20 and 20,000 times per second. Some animals can hear sounds generated by surfaces that vibrate up to ten times faster than that, something that is usually referred to as ultrasound.

You may need to refer to the online resources below to answer the questions that follow.

1. Technologies are used to extend the human perception of sight. Describe some examples.

2. Sounds produced by insect pests that cannot be perceived by human hearing can nonetheless be used to locate them. One example is called WiSPr (Wireless Smart Probe) that is used to determine if wooden structures are infested by termites.

Helpful online resources

Jason Silva Shots of Awe: Expanding our Perception

<https://www.youtube.com/watch?v=NzZJQrPPv0M>

Helpful online resources

Edith Cowan University: Environmental Monitoring with WiSPr, the Wireless Smart Probe, A/Prof Adam Osseiran Research@ECU

<https://www.youtube.com/watch?v=XQZAknn0F8c>

C Critical and creative thinking: Reversal of type 2 diabetes

Diabetes is a disease characterised by an inability to regulate blood glucose levels within normal tolerance limits. In the case of type 2 diabetes this is due to the body's response to insulin weakening as people age. Many type 2 diabetics have to control blood glucose levels by regularly injecting themselves with insulin (***see image***). The number of Australians with type 2 diabetes is now about one million, and increasing.

Recent studies using mice, however, suggest that it might be possible to treat type 2 diabetics by returning the response to insulin back to normal. One drug that looks very promising is an inhibitor of an enzyme that causes cells to lose sensitivity to insulin called 'low molecular weight protein tyrosine phosphatase' (LMPTP).

Its use in diabetic mice caused a significant increase in the activity of insulin receptors on the cell membranes of liver cells. As a result, they could take up glucose from the blood just like those in non-diabetic mice.

You may wish to refer to information in the online resources below to answer the questions that follow.

1. Interpret these findings and make a reasonable prediction about the possible mode of action of the drug that may enhance its use as a treatment of diabetes.

2. So far the drug has only been tested in mice. Speculate about possible limitations in our knowledge that may need to be explored before the drug is cleared for use in clinical trials.

Helpful online resources

TEDx Talks: Reversing Type 2 diabetes starts with ignoring the guidelines - Sarah Hallberg

<https://www.youtube.com/watch?v=da1vvigy5tQ>

C Personal and social capability: Anabolic steroids and sport

The benefits of regular exercise are well known. These include maintaining bone and muscle mass, healthy circulatory system function and blood pressure and decreasing the chance of developing chronic diseases like type 2 diabetes and heart disease. One way to exercise is to play a sport.

For many, playing sport is a social activity that encourages or reinforces friendships between peers and adults. Team sports are a particularly useful way for children to learn about leadership, accountability, time organisation, and dedication. Adults who play team sports often do so to stay in shape, reduce stress, boost self-esteem and establish relationships.

Most sports involve competition and a healthy associated drive to win. Even everyday competitors find the joy of working hard to win and succeeding, rewarding and often compelling. Those who choose to pursue a sport professionally give a great deal of themselves to be able to compete, and more is asked of them. While the goal for many athletes is to compete at the highest level, modern professional sport is now littered with cases of elite athletes who have turned to drug-taking to enhance their performance and thus success.

In 1999 an organisation called the *World Anti-Doping Authority* (WADA) was formed to help to identify, track and monitor the use of performance enhancing drugs used in sports. Since then, the work they undertake has been supported by the establishment of similar bodies in other countries including the *Australian Sports Anti-Doping Authority* (ASADA) in 2006.

You may need to refer to the online resources below to answer the questions that follow.

1. One category of performance enhancing drug is called an anabolic steroid. These are produced using testosterone that is a steroid hormone produced naturally by the body. Explain, by referring to a particular sport, why an athlete might choose to use an anabolic steroid.

2. Describe the short-term effect of anabolic steroids on the human body, and some of the longer-term health risks associated with their use.

Helpful online resources

Australian Academy of Science: Drugs in sport

<https://www.science.org.au/curious/people-medicine/drugs-sport>

Helpful online resources

ABC Science: Doping to Win | Steroids, peptides, EPO - What do performance enhancing drugs do?

<https://www.youtube.com/watch?v=11-sP2IE-mQ>

C Critical and Creative Thinking: Managing stress

The perception of a dangerous situation triggers the human body to use an ancient survival strategy; this basically involves either standing your ground and fighting, or running away.

This fight or flight response is delivered and controlled by the endocrine and nervous systems. Collectively, they make it possible for the body to respond like this very quickly and vigorously. This is achieved by the secretion of adrenaline that brings about an array of short-term physiological changes that, amongst other things, 'prime' the skeletal muscles for action. Should it be necessary to fight or run, the body will be ready!

There are times, however, when the brain 'mis-interprets' information sent to it about the world around us leading to a 'perception of mortal danger' when, in fact, danger isn't at hand. One modern example of this is the way we tend to respond to other stressful situations that do not require any fighting or running away. For many this might be the time leading up to and while giving an oral communication, or thinking about exams. Situations like these trigger adrenaline secretion as if the individual was fighting a bear or running away from an avalanche. Without the need to respond physically, however, this leaves us feeling tense, anxious and 'stressed out'.

Although adrenaline breaks down once danger has passed, allowing the body to 'calm down', long-term exposure to stress leads to the secretion a hormone called cortisol. This helps maintain high blood glucose levels and partly suppresses the immune system, both of which help the body to function while under stress without triggering any harmful inflammatory responses. Over time, however, cortisol makes the body vulnerable to colds, the flu and atherosclerosis (accumulation of fatty deposits in arteries) that increases the risk of heart attack or a stroke.

You may need to refer to the online resources below to answer the questions that follow.

1. Envisage situations that are most likely to lead to increased levels of your cortisol and other stress hormones.

2. Speculate about possible solutions regarding how you may be able to modify your behaviour or plan differently, to reduce stressful situations.

Helpful online resources

Learning Junction: The Stress Response- Fight or Flight

<https://www.youtube.com/watch?v=mtRrxNTnyh8>

Helpful online resources

TED-Ed: How stress affects your body - Sharon Horesh Bergquist

<https://www.youtube.com/watch?v=v-t1Z5-oPtU>

C ICT: Sensitive bandages

An important part of post-operative medicine is monitoring and tracking patient health. Traditionally this has meant staying in hospital and needing to make regular return visits.

In September 2014 a team of computer scientists and engineers presented the results of a technology called ***Bioscope***. This is a system that consists of a sensor-packed bandage that, when applied to a patient, delivers medical information about them wirelessly to a computer. This includes skin temperature and heart rate that are early signs of post-operative infection. ***Refer to the photograph.***

In the last few years the original design has been refined to include the capacity to transmit information to a smartphone that is updated as change to the patient's condition is detected. Work is underway to achieve not just real-time monitoring of patient's post-operative health like this but tracking of it in a way that is both automated and able to be sent out daily to their doctor.

You may need to refer to the online resources below to answer the questions that follow.

1. Describe how sensitive bandages are designed so that they are able to collect data that can be used to indicate post-operative complications.

2. The widespread use of effective sensitive bandages has the potential to usher in 'remote health care'. Explain what is meant by this statement.

Helpful online resources

3DPrint.com: The Band-Aid of the Future — NTU Creates the 3D Printed BioScope
<https://3dprint.com/31983/3d-printed-bioscope/>

Helpful online resources

Mayo Clinic: Patients and Remote Patient Monitoring
<https://www.youtube.com/watch?v=D-Eeygrp6rU>

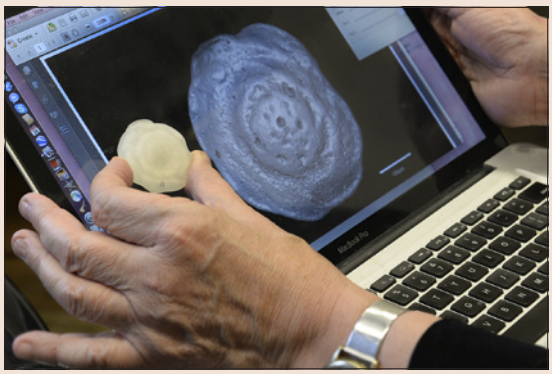
Helpful online resources

Chris Moody: Daphnia Heartbeat

<https://www.youtube.com/watch?v=2g-04Uk0ut0>

C ICT: 3D printing fossils

The use of 3D printing technology to 'print' human tissue was first mentioned in the Stage 1 Biology course. These 'bio-printers' use a liquid that contains functional human cells and have already been used to create human tissue associated with bone, skin and blood vessels.



3D printers are also revolutionising the science of palaeontology, including the study of microfossils. This is because microfossils are not only very fragile and thus easily damaged but incredibly small. In the case of fossilised prokaryotes, this means of the order of one micron, or 0.01mm, or even smaller. Traditionally this meant cutting incredibly thin pieces of surrounding rock and then using a high performance microscope to observe and study them.

It is now not only possible to produce high resolution 3D images of micro-fossils to sizes thousands of times larger than the actual specimens, these can be made into '3D pdf files' which scientists can use to study, manipulate and accompany research papers. Furthermore, the images can also be printed to produce exact 3D replicas – inside and out – of the fossils. 3D models of micro-fossils are now widely used in the teaching of micro-palaeontology.

1. Explain how the use of ICT has enhanced the ability to extract information from the fossil record.

2. Outline some possible reasons to explain why the use of 3D microfossil models is proving to be an effective teaching tool.

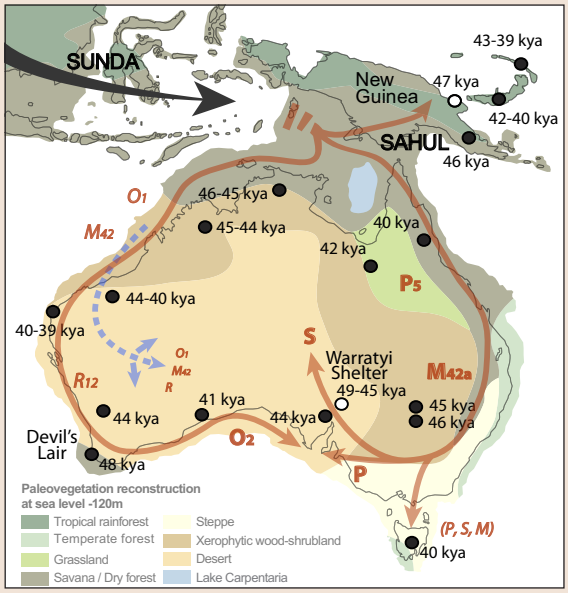
C Personal and social capability: Who are Aboriginal Australians?

Aboriginal Australians are known to be one of the oldest populations of humans on the planet. What is less clear, however, is when their ancestors first arrived in Australia, and where these ancestors originally came from. Other questions remain unanswered too. For instance, what were the ancient migration routes that led to the distribution of Aboriginal people across the continent, and how long have Indigenous Australians been living there?

The sequencing of the first Aboriginal genome in 2011 started to provide some of the answers. Shortly afterwards an international team of academics in collaboration with elders and leaders sequenced and analysed the complete genome of 83 Aboriginal Australians. Five years later the results of the study were published in a paper in ***Nature*** magazine. This work provided for the first time a genomic history of Aboriginal Australians as well as significant new findings about the origins of modern humans. For instance, the paper shows that all non-African populations of humans are descendents of a single wave of human migration out of Africa around 72,000 years ago and that Aboriginal Australians were the first humans to diverge from them.

Around the same time scientists associated with the Aboriginal Heritage Project (AHP) were working with Aboriginal communities around Australia to assemble a timeline for Aboriginal Australian's arrival and settlement in Australia. To do this they used cultural information and hair samples collected during a series of expeditions across Australia that ran from the 1920s to the 1960s that are stored at the South Australian Museum known as the Board for Anthropological Research (BAR) Collections. The hair samples consist of clippings taken with consent from the head of individuals which still contain DNA despite being decades old. Mitochondrial DNA (or mtDNA) was used for DNA sequencing because it is abundant in hair and has been used extensively to map genetic information to geography, a method called phylogeography.

Phylogeographic research is based on the fact that as DNA is passed from parent to child over successive generations, it accumulates genetic changes in a gradual clock-like fashion. This means closely related people have quite similar DNA since much of it comes from a recent common ancestor while more distantly related people have increasingly different DNA. Importantly, if families live the same area for long periods of time, there is a strong positive relationship between genetic and geographical distance. This relationship begins to weaken when people move away from their ancestral homelands and go on to have children with more distantly related people.



Phylogeographic research makes it is possible to learn about the history of human populations, including the timing of colonisation events, and ancient migration routes.

The work done by the AHP indicates that Aboriginal people most likely first arrived in Australia in a single migration around 50,000 years ago, at a time when Australia and New Guinea were connected in a single landmass known as Sahul (*pic*). It reveals that the founding population arrived near present-day Northern Australia or New Guinea, before migrating around the coasts of Australia and meeting again in South Australia. The migration around the coasts appears to have been rapid, probably taking no longer than 2-3,000 years. Somewhat surprisingly, there is little evidence for any other migrations over the 50,000 years that followed, despite significant environmental and climate changes that took place during this period.

Although the work of the AHP is ongoing, it has already proved to be of great significance and provides a very good example of the impact of genetic research in society. For one thing it shatters colonial descriptions of Aboriginal Australians as a nomadic people with no interest living in one location. It also provides an insight into why Aboriginal Australians have such a strong connection to the same Country, something to be expected given the very long periods of time populations have inhabited their place.

The AHP received international acknowledgement when a paper about their research was published in the journal ***Nature*** in April 2017. Later in the same year the Australian Research Council (ARC) awarded the AHP team the prestigious Eureka Prize for Excellence in Interdisciplinary Scientific Research. The prize was presented by the Australian Museum in recognition of the team's efforts to work in partnership with Aboriginal families and communities to construct a genetic history of Indigenous Australians, and for making a valuable contribution to the reconciliation process.

Written in collaboration with Dr Ray Tobler from the SA Museum and Adelaide University.

C Personal and social capability: Who are Aboriginal Australians? (cont.)

You may need to refer to the online resources below to answer the questions that follow.

1. Describe the migration of the first humans out of Africa and the eventual arrival of the first Aboriginal people in Australia.

2. Explain how DNA sequencing has been used to confirm that Aboriginal Australians are more closely related to Asian populations of humans than European ones.

3. The work by researchers at the AHP thus far defies some of the beliefs and attitudes of colonial Australians. Describe one example of this.

4. Reflecting on your own beliefs and attitudes towards Aboriginal Australians explain how significant you consider the AHP's findings to be?

Helpful online resources

NaturalHistoryDK: The genetic history of Aboriginal Australians

<https://youtu.be/_kbRxSzDE4k>

Helpful online resources

Department for Industry, Innovation and Science: Aboriginal Heritage Project - Winner Excellence in Research Collaboration

<https://www.youtube.com/watch?v=RwriJbJ1w1Q>

C Critical and creative thinking: Digital morphology of fossils

There is a lot to be learned through the study of fossils. As has been discussed in this book this includes determining how long life has been on Earth, discovering now extinct groups of organisms and piecing together the evolution history of life on our planet to the present day. Fossils of plants and animals can also be used to learn about their structure, how and where they lived and to better understand the long since vanished environments they inhabited.

For many decades the collection and analysis of fossils of bones, shells, teeth and footprints have been used to help determine the degree of relatedness between groups of organisms. Work like this has made clear a common ancestry among groups of vertebrates; for example, the origin of all birds from feathered dinosaurs and the evolution of whales and dolphins from a four-legged common ancestor that walked on land about 50 million years ago.

Learning about the origin of internal, softer structures, however, has been more difficult because they tend to decompose after the death of organisms instead of fossilising and because the fragility of the fossils makes them hard to access without damaging the specimen. One imaginative solution to this problem emerged with the invention and application of a type of X-ray scanning system called high resolution X-ray computer tomography (HRCT). Using this breakthrough technology, it became possible to digitally dissect a fossil to uncover its internal structure in high resolution 3D (see image). The digital morphology of fossils the technique provides is now collected, stored and used by palaeontologists all over the world.

You may need to refer to the online resources below to answer the questions that follow.

1. HRCT is a relatively new technology that is still being refined. Discuss why this is an example of creative thinking, some benefits associated with its use, and some of the limitations of HRCT.

2. Scientists at the Australian National University (ANU) and the Queensland Museum applied a HRCT-like technique to the study of the origin of teeth. Describe the type of fossil organism the scientists used in the study and explain how their technique was used to interpret and evaluate data to make predictions about the likely origin of teeth.

Helpful online resources

National Science Foundation News: DigiMorph: Bringing Fossils to Life - Science Nation
<https://www.youtube.com/watch?v=zh8yllfzZt0>

Helpful online resources

ANU TV: 3D printed fish fossil may reveal origin of human teeth

<https://www.youtube.com/watch?v=NU978-sDi9A>

C Intercultural understanding: 'The Secret of Dreaming'

Charles Darwin in the 19th century provided Western cultures with a scientific explanation for the origin and diversity of species. Essentially, they are the products of divergent evolution. In other words, each one arose from an ancestral population that became separated into two or more groups that experienced unique selection pressures. These evolved differently, gradually became reproductively isolated and thus emerged as populations of new species. This process has occurred many, many times over hundreds of millions of years to give rise to the diversity of species that inhabit the planet today.

Aboriginal Australians have inhabited Australia for at least 50,000 years. They also observed the diversity of animals and plants and wondered how they came into existence and, where the first people came from. For the first Australians, however, the answers to these and related questions have nothing to do with evolution. Instead, they are provided by an ancient oral tradition of storytelling called the 'Dreamtime'.

You may need to refer to the online resources below to answer the questions that follow.

1. Describe how the first animals and plants came into existence as told by the Dreamtime story 'The Secret of Dreaming'. *To answer this you will need to view the video below.*

2. Speciation through divergent evolution means that there must be at least some genetic interconnectedness between all species. The Secret of Dreaming refers to life being interconnected too. Use your understanding of this Dreamtime story to explain how living things have come to be interconnected and the implications this has for humans today.

Helpful online resources

Redbackrock: Aboriginal dreamtime

<https://www.youtube.com/watch?v=Mntq_zD54Ys>

Helpful online resources

Midnight Sun - El Sol de Medianoche: The Secret of Dreaming: An Australian Aboriginal Myth of Creation

<https://www.youtube.com/watch?v=gYgdBRCb88o>

C Critical and Creative Thinking: Analysing claims

A claim is a statement or a point of view about data or a piece of research. Scientific claims are made all the time. Some examples include video can be stored using DNA and the consumption of some foods improves memory. Before a claim can be accepted or used to modify or replace models, it should be analysed for its reliability and validity.

The credibility of the claim is dependent upon the qualifications of the author or authors or the organisation that where the research was done. Claims are likely to be credible if there is evidence of the author's qualifications, the legitimacy or appropriateness of the organisation and if the contact details for the author or organisation are clear, accurate and up-to-date.

A claim may be described as valid if the data that has been collected meets all of the requirements of the scientific method; for example, it has been obtained via a carefully controlled investigation that is a fair test. Claims supported by related scientific theory are more likely to be valid.

The reliability of a claim refers to the repeatability of data that has been collected and used to support the claim. Data that is not a 'one-off' and can be obtained by others is likely to be more reliable than data where this seems difficult or impossible to achieve, or confirm. Consider the following claim that Australia's parrots have evolved longer wings in response to climate-changed temperature as reported by *The Australian* newspaper on 4th January 2017. An adaptation of this article appears below.

Scientists hail climate-changed evolution

BERNARD LAGAN

Australia's wild parrots, which are increasingly being exposed to some of the world's highest temperatures, have evolved to grow longer wings to cope with extra heat. Scientists at the University of Notre Dame, Australia have found that the wings of ringnecked parrots, which live in Western Australia, have grown by 4-5 mm over the past 45 years.

Researchers claim the adaptations mean the birds commonly called '28s' for their whistle have become adapted so that they can shed more heat when they fly. Professor Dylan Korczynskyi said the enlarged wings could be attributed to climate change because the extremities of animals in the hottest climates tend to be longer. …

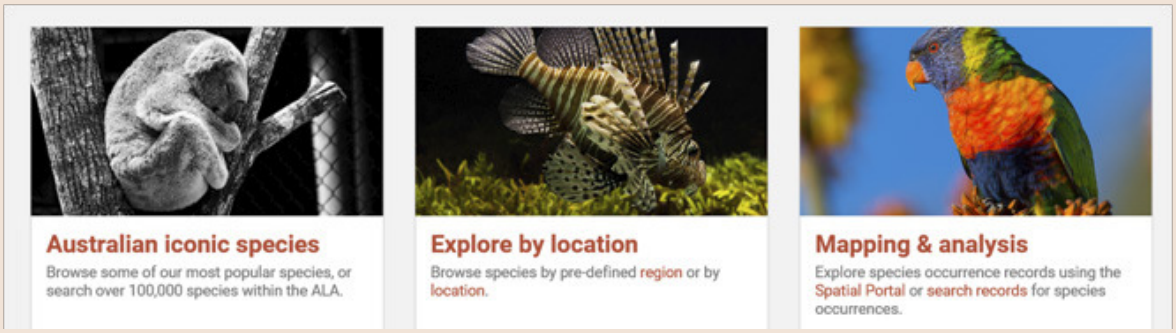
"Our results are only preliminary, but we might be seeing evolution in action" he said.

"The biggest changes in wing length had taken place since the 1970s" he said, with that timeframe correlated with increasing temperatures in Western Australia. By contrast, a sub-species of ringnecked parrot in the north and east of Western Australia, which have not experienced the same temperature shifts, have not evolved with larger wings. Prof. Korczynskyi said that even small temperature changes, such as 0.1°C a decade, could have a large impact on animals.

1. Using only the article and information above, analyse the claim for reliability and validity.

C ICT: The Atlas of Living Australia

Most estimates put the number of species that inhabit Australia somewhere between 500,000 and 600,000. Fewer than a third of them, however, have been formally named and described. The challenge to discover and document the rest is considerable, particularly given the impact of human activities on ecosystems across the nation, and the threat posed by climate change.



One government-funded initiative that has greatly improved our understanding of species diversity in Australia is the Atlas of Living Australia (ALA). Launched late in 2010, the ALA today is a vast web-based infra-structure that is used to capture, accumulate, manage and analyse data about the biodiversity of Australia's flora and fauna. ***Refer to screenshot above.*** Its Director, ***John La Salle***, and his team of scientists and bioinformatics experts manage, update and make accessible biodiversity data and online mapping and analytical tools for use by scientists, government, industry and interested community groups. The ALA holds a rich collection of data on more than 110,000 different species all of which is freely available and useable online.

You may need to refer to the online resources below to answer the questions that follow.

2. The mapping and analytical tools on the Atlas can be employed to generate information about future trends; for example, to map the current distribution of a species as determined by climate and then predict its future distribution as climate changes. Describe examples of where being able to do this accurately might be useful.

3. The Atlas can be used to inform revegetation or landscape restoration programs in light of the fact that the climate is changing. By referring to your answer in the Question above, explain how ALA data could be used to improve the long-term success of such programs.

Helpful online resources

Environment Institute: The Atlas of Living Australia. Dr John La Salle
<https://www.youtube.com/watch?v=1e6oJrKDmHo>

Helpful online resources

Atlas of Living Australia: Open access to Australia's biodiversity data
<www.ala.org.au>

C Ethical understanding: Biodiversity

The term biodiversity in part refers to the variety of living organisms on Earth. This includes vertebrates, invertebrates, flowering and non-flowering plants from all corners of the planet, and not just the species that are easy to see; bacteria, protists and fungi all count as well. More complete descriptions of biodiversity, however, also include the genetic diversity of the genes within each species and the diversity of the ecosystems that those species make up. Ecosystems, for example coral reefs and rainforests, have a high degree of biodiversity.

The Earth's biodiversity evolved over billions of years shaped by a huge number of abiotic and biotic factors. In recent decades, planet-wide biodiversity has been greatly affected by the activity of humans, mainly because of the sheer size of the global human population, which according to the United Nations now stands at 7.5 billion. People everywhere depend on ecosystems for food, freshwater and raw materials for construction and energy production. But globally huge numbers of people and their demands for agricultural land, housing, fuel and energy can only be met if habitat destruction is both ongoing and extensive. Supporting the human population then comes at a cost because to do this lessens biodiversity.

Seeking to maintain biodiversity is an excellent example of an ethical issue. This is because there are sound reasons for implementing strategies to limit biodiversity loss yet modern day living in many countries depends on products and energy use that threaten biodiversity. What is the correct way forward? Should biodiversity be maintained or shouldn't that matter?

You may need to refer to the online resources below to answer the questions that follow.

1. One point of view about global biodiversity loss is presented below:

"Every species has a right to life, so it is wrong to let the size of the human population continue to increase when it is clear that this is the main cause of species' extinction".

Do you agree? Give reasons for your answer.

2. Hundreds of millions of people live in developing countries without access to electricity. Providing them with fossil fuel-produced power contributes to global biodiversity loss. Not giving them access to power reduces the chance of leading a better quality of life. Explain what you think should be done.

Helpful online resources

TED-Ed: Why is biodiversity so important? - Kim Preshoff

<https://www.youtube.com/watch?v=GK_vRtHJZu4>

Helpful online resources

CSIRO: What is biodiversity and why is it important?

<https://youtu.be/7tgNamjTRkk>

Science Inquiry Skills 1.1 - Extracting and Modelling DNA

Introduction

Nucleic acids are present in all living cells and carry the information necessary for the functioning and reproduction of the cell. In this practical, the focus will be on DNA (deoxyribonucleic acid) which is present as very long, helical molecules and is found in the chromosomes of the cell. The building blocks of DNA molecules are called DNA nucleotides and each nucleotide consists of a sugar, a phosphate and an organic base.

This investigation is in two sections; a simple method will be used in Part A to extract DNA from fresh fruit material, and in Part B models will be used to help understand the structure and function of these various molecules in the process of DNA replication.

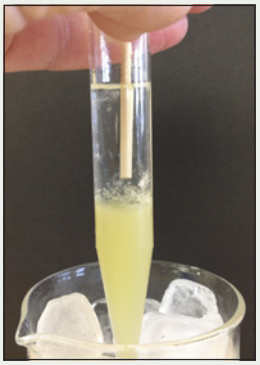
Part A Extracting DNA

Aim

To extract DNA from fresh plant tissue e.g. fruit.

Materials (per group)

- 95% alcohol (ethanol or iso-propanol) in a plastic dropper bottle then placed on ice
- 2 or 3 thin slices of kiwi fruit or strawberry, sealed in a small zip lock bag (pre-frozen)
- test tubes (25mm diameter) with stopper and test tube rack
- extraction solution (pre-prepared)
- ice/water bath (in 250mL beaker)
- 10mL and 20mL measuring cylinders
- stopwatch
- small funnel and small square of 'Chux' cloth
- 100mL conical flask
- plastic pipettes
- protease enzyme - meat tenderiser powder
- spatula
- piece of wooden skewer



Method

1. Add 20mL of extraction fluid to the zip-lock bag containing the slices of fruit.
2. Close the bag, removing as much air as possible.
3. Hold the bag, and squeeze the fruit with thumb and fingers several times to mix the fruit and extraction fluid.
4. Place the bag and fruit into the ice water bath for 5 minutes, gently mixing every minute.
5. Place the 'Chux' cloth into the funnel and filter the fruit mixture into the conical flask.
6. Carefully transfer the solution to a clean test tube.
7. Add a small spatula full of protease to the test tube, stopper, and invert gently to mix.
8. Place the test tube in the rack for 10 minutes.
9. Carefully transfer 10mL of the solution to a clean test tube, and place back in the ice bath for 5 minutes.
10. Tilt the test tube slightly and run ice cold alcohol down its wall to form a layer on top, approximately 2cm deep.
11. Place the test tube in the ice bath and leave for 10 minutes.
12. Observe the precipitate of DNA that forms at the interface of the two fluids. Note that it may float up into the alcohol.
13. Use the piece of wooden skewer to lift a small amount of the DNA out to examine.
14. Dispose of fruit solution/alcohol in the test tube as directed.

Science Inquiry Skills 1.1 - Extracting and Modelling DNA (continued)

PART B Modelling DNA Replication

Nucleic acids are the molecules that carry and transmit information to other parts of the cell, from cell to cell and from generation to generation. The molecules are able to do so because of a 'code' that consists of a sequence of different organic bases. In DNA, these bases are adenine (A), thymine (T), guanine (G) and cytosine (C).

DNA replication is a process in which a double-stranded DNA molecule makes an exact copy, or replica, of itself. This is sometimes called 'semi-conservative' replication because each 'daughter' molecule has one original strand and one new strand of DNA.

Aim

To cut out and use paper models to represent the process of DNA replication.

Materials (per group)

photocopies of the pattern sheets (*see Laboratory Notes and provided by your teacher*)

scissors glue stick/small stapler

newspaper poster paper and highlighter pens

Method

1. This is best done on a white background e.g. butcher's paper or A3 cartridge paper
2. Carefully cut out a section of 9 nucleotides and 18 separate bases (delete 'U' on the green bases)
3. Randomly glue/staple a base onto each of the TABs on the sugar molecules on one strand of DNA.
4. Take another strand of 9 nucleotides and lay it in the opposite direction near the first strand and again glue/staple the complementary bases to the TABs. Identify a nucleotide, a base triplet, and the original and complementary strands.
5. Cut out another two strands of DNA nucleotides - together with another 18 bases (delete 'U' again).
6. Separate the two original strands of the DNA model and use the other strands and bases to show the process of DNA replication, resulting in a segment of a DNA molecule that has been replicated.
7. Label:
   a) the two 'old' strands i.e. the original strands
   b) the two 'new' strands i.e. the complementary strands

Discussion

1. List a few of the steps or molecules required for the process that might not have been included in the modelling activity.

2. Explain why this process is described as 'semi–conservative'.

3. State why this process needs to occur in the life of a cell.

Science Inquiry Skills 1.2 - Modelling Transcription and Translation

Introduction

Nucleic acids are the molecules that carry and transmit information to other parts of the cell and from generation to generation. The molecules are able to do so because of a 'code' of different 'organic bases'. In DNA, these are adenine (A), thymine (T), guanine (G) and cytosine (C). In RNA, these are adenine (A), uracil (U), guanine (G) and cytosine (C).

There are three fundamental processes involving these nucleic acids which occur in cells, namely:

1. **DNA Replication,** in which a double-stranded DNA molecule makes an exact copy or replica of itself. This is sometimes called 'semi-conservative' replication because each 'daughter' molecule has one original strand and one new strand of DNA. *This process was modelled in SIS 1.1.*
2. **Transcription**, in which the DNA strands separate and a single-stranded molecule of 'messenger RNA' is made using one of the strands as a template. Remember that the base uracil (U) replaces thymine (T) in RNA to pair with adenine (A).
3. **Translation**, in which the base sequence on the 'messenger RNA' molecule is used to construct a chain of amino acids (a polypeptide) on the ribosomes in the cytoplasm. This involves 'transfer RNA' molecules that have the specific anticodon that is complementary to the mRNA codons and carry specific amino acids into position on a ribosome. The amino acids link together to form a polypeptide chain, that may either fold to form a protein itself or link with other polypeptide chains to form a completed protein.

Aim

In this activity you will be able to cut out and use paper models of these molecules to represent the process of protein synthesis.

Materials (per group)

photocopies of pattern sheets from SIS1.1 (*included in the SIS 1.1 Laboratory Notes*)

photocopies of extra pattern sheets (*included in the SIS 1.2 Lab Notes and provided by your teacher*)

sharp scissors glue (preferably a gluestick)/small stapler tiny paper clips

butcher's paper or poster paper and coloured pens

Method

1. Carefully cut out a section of nine DNA nucleotides and 18 separate bases (delete the U's).
2. Glue a base onto each of the TABs on the sugar molecules, in random order.
3. Take another strand of nine DNA nucleotides and lay it in the opposite (anti-parallel) direction, near your first strand.
4. Attach the complementary bases to the TABs on this strand, so that the shapes match up. This represents a double-stranded molecule of DNA. Identify a nucleotide, DNA base triplet, the template strand, and the complementary strand.
5. Cut out a section of another nine (RNA) nucleotides and nine RNA bases to represent a molecule of mRNA (this time delete the T's on the green shape). Ensure that your strand is 'complementary' to the DNA template, so it models transcription. Label the codons clearly.
6. Cut out three tRNA models. At this stage, number the models 1, 2 and 3 to match codons 1, 2 and 3 on the mRNA. Attach the complementary bases to Tab 2 (T2) to match the codon on the corresponding mRNA molecule. Label the anticodon.
7. Attach the amino acid molecule by paper clips to TAB 3. It would also be a good idea to do some research to work out the actual amino acid carried by each of the tRNA molecules and to write this on the model also. The amino acids can be joined by gluing or stapling the TAB 4's together.

Discussion

1. Can this model be used to effectively show how a chain of amino acids can be assembled into a polypeptide during translation? Justify your conclusion using information and evidence gathered during the activity. (*Use separate paper or a screen as directed.*)

Science Inquiry Skills 1.4 – Investigating the activity of catalase

Introduction

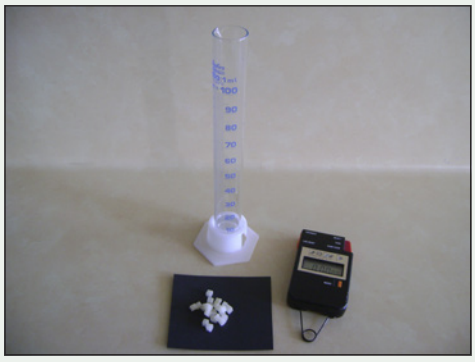
An enzyme is a protein molecule that increases the speed (catalyses) a specific biochemical reaction in cells. One example of an enzyme is called catalase. This enzyme increases the rate of breakdown of a product a certain biochemical reactions, called hydrogen peroxide, which is harmful to cells. In the presence of catalase, hydrogen peroxide is rapidly broken down to form two harmless products, water and oxygen, as illustrated by the following equation:

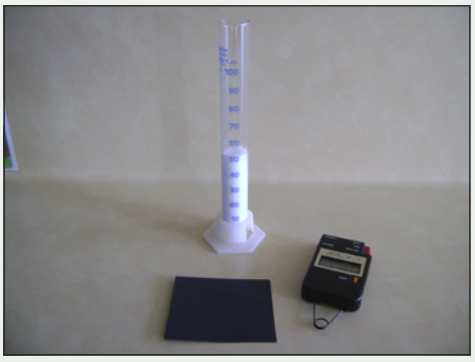
$2H_2O_2 \rightarrow 2H_2O + O_2$

hydrogen peroxide → water + oxygen

Catalase may display different levels of activity. The higher the activity of catalase, the greater the rate of the hydrogen peroxide-breakdown reaction, and the faster water and oxygen form.

Refer to the photographs, which shows a 'measuring cylinder-detergent' apparatus and foam level.





Oxygen diffuses out of potato cells into the detergent. This causes the detergent to form into a foam (see pointer). The volume of the foam after one minute indicates the rate of formation of oxygen and thus the rate of breakdown of hydrogen peroxide by the enzyme catalase, or how active catalase is.

Your task is to design an investigation about this, then carry it out.

Part A: Designing the investigation

Aim

To design an investigation about catalase activity using the Template provided on the previous page.

Information to take into consideration

- Use a measuring cylinder-detergent apparatus of the type shown above.
- Use 3 cubes of potato with 10x10x10mm sides, then cut each cube into 8 pieces (1/2x1/2x1/2).
- Only use potato cubes like this for all tests unless investigating the effect of the type of tissue.
- Only use 6% hydrogen peroxide solution unless investigating the effect of concentration.
- Only use the stock hydrogen peroxide solution unless investigating the effect of pH.
- Only use room temperature unless investigating the effect of temperature.

Method

1. Make a copy of the 'Deconstruction Template' (previous page) and answer the questions with reference to a problem to do with catalase activity.
2. Consult also the '*Glossary of Practical Terms*' on pages 513, 514 in the Appendix.
3. Develop the procedure further to include how the independent variable will be changed and how the dependent variable will be measured.
4. Ensure the procedure permits the collection of data that is reliable, and accurate. Include in the procedure steps where there is individual and collaborative work.
5. Have another student peer-assess your work for completion and accuracy by reading your Deconstruction template and your responses to Questions 3, 4 above.

Science Inquiry Skills 1.4 – Investigating the activity of catalase (cont.)

Part B: Carrying out the investigation

Aim

To carry out the investigation about catalase activity as designed in Part A.

Materials (per group)

- 6% hydrogen peroxide solution
- 10mL measuring cylinder
- 50mL beaker
- Plastic pipette
- 1 potato
- Sharp knife
- Cutting board or mat
- 300 mm plastic ruler
- Dropper bottle of detergent solution (1: 2 dilution of standard dish washing liquid)
- 100 mL measuring cylinder
- Stopwatch

Method

6. Place the 100mL measuring cylinder on the bench.
7. Carry out the design – be sure to change the independent variable at least three times
8. Be sure to take steps to collect data that is reliable.
9. Work independently and collaboratively.
10. Record relevant raw data in a rough table or in some other suitable format.

Part C: Producing and displaying secondary data

1. Produce processed data by calculating the rate of catalase activity (mL/min) using the equation:

   $$\text{Rate of breakdown of hydrogen peroxide} = \frac{\text{total volume of foam} - 13\ \text{mL}}{\text{time (minutes)}}$$

2. Display processed data using a table that includes using a table that includes appropriate column headings, significant figures, SI units and symbols.
3. Prepare at least one hand-drawn graph of the processed data that includes an appropriate scale, axes headings and line of best fit.
4. Include for both the table and the graph a title that links the independent and dependent variable.

Part D: Analysing, evaluating and formulating conclusions

1. Analyse the data and discuss the relationship (if any) between the independent and dependent variable – write your work on paper or type it electronically as directed by your teacher.
2. Evaluate the procedure to identify sources of uncertainty including random and systematic errors, and effective control of variables.
3. Discuss the impact that sources of uncertainty have on the results e.g. the effect of random and systematic errors on reliability, precision, and accuracy of the results, and the effective control of variables on the validity of the investigation.
4. Use evidence and biological understanding to formulate and justify conclusions.
5. Recognise the limitations of the conclusions.

Part E: Preparing a formal practical report

1. Use work done in Parts A-D to prepare a practical investigation report about catalase activity.
2. Your teacher will advise you of the appropriate format to use and the Assessment Design Criteria to be assessed.

Guidelines to help you prepare a formal Practical Report can be found in the Appendix, on page 484. Also in the Appendix, on page 485, is a sample Task Sheet for a practical investigation.

Science Inquiry Skills 1.8 - Bringing extinct species back to life

This activity is an opportunity to practice the skills of scientific communication in an oral format that must not exceed 5 minutes.

Introduction

The loss of a species from the wild is called extinction. Many species have become extinct for one reason or another and the rate at which this is occurring now is the highest it has been for at least 65 million years, mostly as a result of human activities.

Mammoths were a kind of large 'woolly' elephant that lived in the northern hemisphere until they became extinct about 4,000 years ago. *The photograph below shows some mammoth bones found in Russia.*

In early 2017 scientists from Harvard University in the United States made public plans to produce a living baby mammoth that would then go on to grow into an adult mammoth. The stated goal of the so-called *Harvard Woolly Mammoth Revival* is to achieve this in a couple of years. If the project is successful, it will be the first example of reversing the extinction of a species, something that is now being called de-extinction.

The production of a 'mammo-phant' is possible due to CRISPR technology. Using this technique, genes from preserved mammoth tissue can be extracted and then inserted into the DNA of modern Asian elephants (the closest genetic relative), thus creating intact DNA. If this hybrid mammoth-Asian elephant DNA is then inserted into an ovum from a female Asian elephant, which in turn is placed in the uterus of the elephant, it will grow and develop into a baby mammoth.

Work is going on around the world to allow 'de-extinction' of other recently extinct animals too.

Part A: Selecting an animal to 'de-extinct'

1. Choose an extinct species of mammal or a bird to investigate e.g. Tasmanian tiger, dodo.
2. Describe how the CRISPR method could be used to form intact DNA of the extinct species.
3. Include detail about the use of a genetically close living relative of the extinct species.
4. List some of the main reasons for the de-extinction of the species.
5. Consider and list some reasons for why extinct species should not be revived in this way.
6. Decide whether or not the extinct species should be brought back to life using CRISPR. Justify your decision using evidence and biological knowledge and understanding.

Part B: Preparing for and giving the oral presentation

1. Finalise the content for the oral communication.
2. Prepare the oral communication.
3. Trial the oral presentation to ensure that it will not exceed 5 minutes.
4. Give the oral presentation.
5. Submit a list of sources of information, and any other notes for assessment.

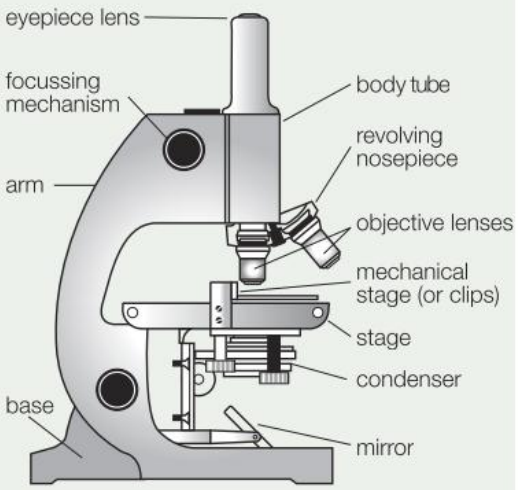
Science Inquiry Skills 2.1 - Revising the microscope

Introduction

If you have not previously used microscopes, it may be useful to refer to Chapters 1.1 and 1.2 in the SACE 1 Essentials Biology Workbook.

The first simple microscopes were invented in the late 16th Century. Refinements of these microscopes led to the discovery of cells and major cell-related findings continued well into the next century. By the 1890s scientists had determined that all organisms consisted of cells, some of which were microscopic and single-celled and that all organisms that could be seen were made up of vast collections of different types of cells. It was widely understood that cells had a nucleus and other sub-cellular structures like mitochondria, and that they divided.

This investigation is in three sections; a method will be used in Part A to estimate the field of view at different microscope magnifications (as explained in Part B) and in Part C the skills associated with viewing a specimen will be practiced.



Part A - Estimating the diameter of the field of view

Aim

To estimate the diameter of the field of view at 40×, 100× and 400× magnifications.

Materials (per group)

- Light microscope
- Mini grid

Method

1. Obtain a microscope and transport it carefully to a bench – ensure one hand supports the base.
2. Review the different parts of the microscope and what they do (***refer to the diagram above***).
3. Turn on the light and adjust the iris diaphragm to form a white 'circle of light'. This is the field of view.
4. Put a mini grid in the centre of the stage and secure it with the stage clips.
5. Read about the field of view, and a mini grid – refer to Part B on the next page.
6. Adjust the coarse focus until the 4× lens and stage are as close together as they can get.
7. Look through the eyepiece and adjust the coarse focus until the mini grid comes into view.
8. Adjust the fine focus slowly until the large squares with 1 mm sides come into sharp focus.
9. Use the mini grid to estimate the diameter of the field of view at this magnification (i.e. 40×).
10. Establish a magnification of 100× and estimate the diameter of the field of view at 100X.
11. Establish a magnification of 400× and estimate the diameter of the field of view.
12. Draw a table to record the diameter of the field of view at 40×, 100× and 400× magnification.

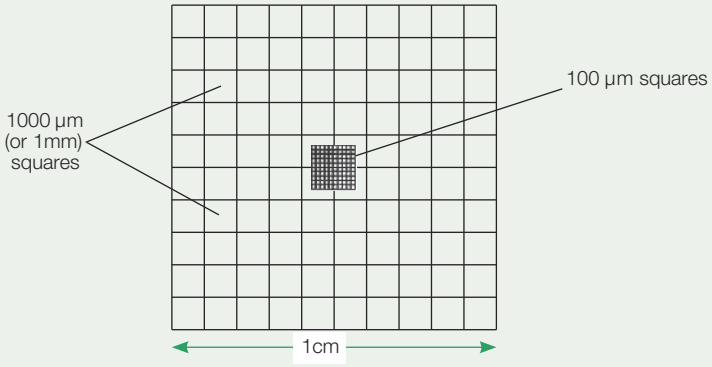
Science Inquiry Skills 2.1 - Revising the microscope (continued)

Part B - Determining the diameter of the field of view and using a mini grid

The field of view is the white 'circle of light' that is seen when viewing a specimen using a light microscope. The actual diameter of the field of view can be determined by using a special microscope slide that is marked with a mini grid. A mini grid is a collection of clearly marked squares, the sides of which are measured using the micrometre scale – one micrometre (1µm) is equal to 1/1000 of a millimetre (0.001mm).

In a typical mini grid, most of the squares have sides that are 1000µm (or 1mm) long. At the centre of the mini grid there is a region that consists of even smaller squares that have sides of only 100µm (or 0.1mm).

One example of a mini grid is shown below.



13. To estimate the diameter of the field of view at 40× magnification:

- Put the mini grid slide on the centre of the stage of the microscope and secure it with the stage clips.
- Adjust the microscope for viewing at 40× magnification.
- Use the coarse and fine focus to bring the mini grid into focus until the 'large' 1000µm (1mm) squares can be clearly seen – ***refer to the diagram above***.
- Count from left to right how many 1000µm squares span the field of view – the number of them is equal to the diameter of the field of view.

14. To estimate the diameter of the field of view at higher magnifications:

- Adjust the microscope to the required magnification.
- Bring the mini grid into focus until the 'small' 100µm squares can be clearly seen.
- Count from left to right how many 100µm squares span the field of view.

15. Use a sharp pencil to draw a diagram of the mini grid at the largest possible magnification in the space below.

Science Inquiry Skills 2.1- Revising the microscope (continued)

Part C - Viewing a specimen

Aim

To view a specimen or something that is viewed using a microscope.

Materials (per group)

- Clean microscope slide
- Small watch glass or petri dish containing the specimen e.g. a wing from a fly, bee or wasp
- White tile
- Forceps
- Clear sticky tape
- Sharp pencil

Method

1. Obtain a microscope slide and the specimen.
2. Place a white tile on the bench and put the slide on it.
3. Carefully remove the specimen using forceps and place on the slide.
4. Fix in place with a piece of sticky tape. Ensure the tape is not marked with fingerprints, and that any 'excess tape' is trimmed not wrapped around the slide.
5. Use the microscope to view the specimen at 40× magnification.
6. Adjust the microscope to view the specimen at 100× magnification, and then at 400×.
7. Use a sharp pencil to draw a diagram of the specimen in the space below.
8. Use the techniques in Parts A and B to estimate the dimensions of the specimen and record in the space below.
9. If time permits, you may wish to do the same for another specimen.

Science Inquiry Skills 2.1- Revising the microscope (continued)

Discussion

1. Both the coarse and fine focus are needed to clearly view a specimen. Describe the role played by coarse focus and how does this differ from the role played by fine focus.

2. A student observes a specimen first at 40×, then 100× and finally at 400×. Describe what happens to the magnification of the specimen and the diameter of the field of view.

3. Explain why is it important to ensure that slides of specimens are as free from fingerprints as possible.

4. Evaluate the method used here to view a specimen including its effect on the quality of the image of the specimen obtained.

Science Inquiry Skills 2.2 - Comparing the size of plant and animal cells

Introduction

Different types of cells have a different structure to permit them to carry out a specialised function. Many types of cells are different in size as well. As a rule, plant cells are larger than animal cells.

It is possible to see plant and animal cells by making wet-mount slides of plant and animal tissue. Once viewed using a light microscope at a particular magnification, the diameter of the field of view and the number of cells that span it can be used to estimate the size of individual cells.

This investigation is in three sections; a method will be described in Part A to make a wet-mount slide and then used in Part B for onion cell tissue to estimate the size of onion cells and in Part C the size of cheek cells will be estimated using wet-mount slides of cheek tissue.

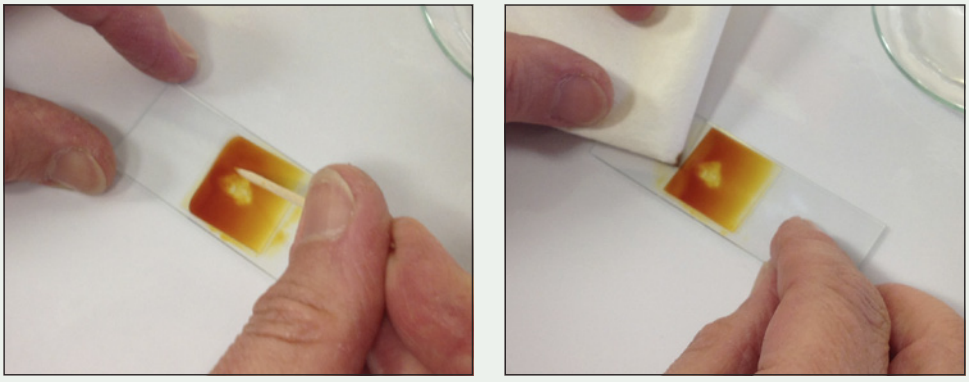
Part A - Practicing how to make a wet-mount slide

A prepared slide consists of a rectangular piece of glass, a specimen mounted onto the slide and a thin, square piece of glass called a coverslip. If the specimen was covered with a drop of liquid before being placed under the coverslip the slide is called a wet-mount slide. The liquid used to make a wet-mount slide may be a stain of some kind that is used to improve the visibility of certain cell structures. One common stain used to make wet-mount slides of plant tissue is iodine solution. Methylene blue solution is one stain used to make wet-mount slides of animal tissue.

Note: Making a wet-mount slide requires a great deal of care and will require practice.

Making a wet-mount slide:

1. Obtain a clean slide and coverslip – place both on a white tile (or similar) until needed.
2. Prepare a specimen that is very thin.
3. Transfer the specimen to the slide. For a specimen floating in a watch glass of water use a fine paint brush to place the specimen onto the slide. For a specimen on a cotton bud rub the cotton bud onto the slide.
4. Add a drop of a stain. For a specimen from a plant carefully add a drop of iodine solution on top of the specimen. For a specimen from a person or other animal carefully add a drop of methylene blue solution.
5. Use a wooden-handled needle (or similar) to carefully lower the coverslip onto the specimen to minimise the trapping of bubbles of air. To do this, make sure that water fills the space between the edge of the coverslip and the slide.
6. Use a piece of tissue paper to gently remove any stain that may have leaked out from underneath the coverslip.



(a) Lowering the coverslip onto the specimen and (b) draining excess liquid

Notes

Science Inquiry Skills 2.2 - Comparing the size of plant and animal cells

Part B - Estimating the size of onion cells

Aim

To make a wet-mount slide of onion tissue and use it to estimate the size of onion cells.

Materials (per group)

- Light microscope
- Clean microscope slides
- Coverslips
- Forceps
- Fine paint brush
- Watch glass
- Wooden-handled needle (or similar)
- Small wedge of onion with the dry outer layers removed
- White tile (or similar)
- Iodine solution (0.4% w/v in distilled water)
- Tissue paper
- Mini grid

Method

1. Half-fill a watch glass with water.
2. Carefully bend the surface of the onion sample that is curved inwards until it snaps.
3. Use a pair of forceps to gently pull away a small section of transparent plant tissue.
4. Float this tissue (the specimen) in the water in the watch glass.
5. Make a slide of the specimen using iodine solution – see '*Making a wet-mount slide*'
6. Set the microscope up for viewing and put the wet-mount slide on the stage.
7. Establish a magnification of 40×.
8. Use the coarse then fine focus to bring the specimen into view.
9. Establish a magnification of 100× and adjust the focus to see the specimen.
10. Revise the diameter of field of view at 100× magnification – see SIS 2.1 Part A.
11. Count the number of onion cells that span the field of view.
12. Estimate the size of individual onion cells in micrometres (µm). *Show your working*.

Science Inquiry Skills 2.2 - Comparing the size of plant and animal cells (cont.)

Part C: Estimating the size of cheek cells

Aim

To estimate the size of cheek cells and compare them with the size of onion cells.

Materials (per group)

In addition to the materials used in Part A:

- Clean cotton buds
- Methylene blue solution (0.1% w/v in distilled water)

Method

1. Use a clean cotton bud to rub the inside of your cheek to remove cheek tissue (the specimen).
2. Make a slide of the specimen with methylene blue solution – see *'Making a wet-mount slide'*
3. Use the light microscope to locate and view cheek cells at 100x magnification.
4. Estimate the size of individual cheek cells in micrometres (µm). *Show your working*.

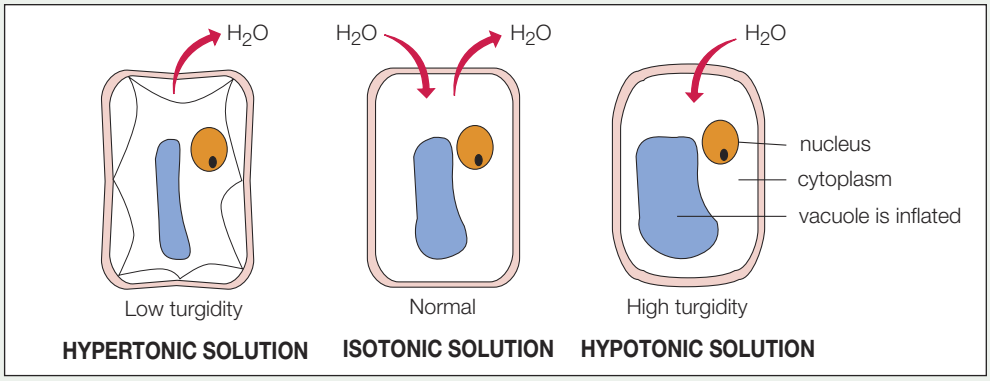
Discussion

1. Were the onion cells larger than the cheek cells? Use evidence to support your answer.
2. The making of wet-mounts method included using a stain. Why was a stain used?
3. Why is it important to carefully lower the coverslip onto the specimen and stain?
4. Both onion and cheek cells are eukaryotic cells. Outline why.
5. Were any membrane-bound organelles observed? If yes, name them.
6. Although they are a type of plant cell, why do onion cells never have chloroplasts?

Science Inquiry Skills 2.4 – Investigating osmosis in plant tissue

Introduction

Osmosis is the nett movement of water molecules across a semi-permeable cell membrane from a region of low solute concentration (hypotonic) to a region of high solute concentration (hypertonic). There is a nett movement of water out of plant cells if the external environment is hypertonic causing the cytoplasm and vacuole to deflate. If the external environment is hypotonic there is a nett movement of water into plant cells causing the cytoplasm and the vacuole to inflate. There is no nett movement of water in or out of plant cells if the external environment is isotonic and therefore no change to how inflated or deflated its contents are.



The term 'turgidity' is a measure of how inflated with water plant cells are. When fully inflated, the plant cells contain a greater volume of water (i.e. more turgid), making the tissue higher in mass. Less inflated plant cells contain a smaller volume of water (i.e. less turgid), making the tissue lower in mass.

A potato cylinder is submerged in a salt solution for 20 minutes. The higher the solute concentration of the salt solution the more water moves out of the potato tissue into the surrounding salt solution.

Refer to the information, which shows the mass of a potato cylinder before and after being submerged in a salt solution for 20 minutes.

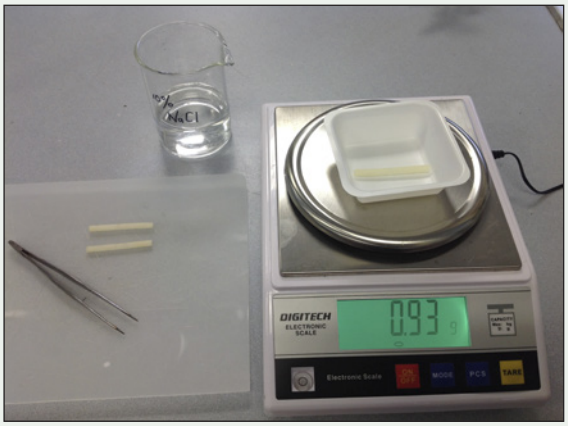


Photo 1
Potato cylinder, and mass; Time = 0 mins

Photo 2
Same potato cylinder, and mass; Time = 20 mins

How much water moves out of the potato cylinder relative to the mass of the whole cylinder can be measured by calculating the percentage change in mass as follows:

$$\text{Percentage change in mass (\%)} = \frac{\text{final mass} - \text{initial mass}}{\text{initial mass}} \times 100\%$$

In this case: -0.21/0.93 = -23%

(i.e. the potato cylinder has lost 23% of its original mass)

Science Inquiry Skills 2.4 – Investigating osmosis in plant tissue (cont.)

Part A: Designing the investigation

Aim

To design an investigation about osmosis using information provided on the previous page.

Information to take into consideration

- Use the percentage change in mass information shown on the previous page.
- Without peeling it, place a potato on a cutting board or mat and firmly push a cork borer vertically downwards all the way through the potato.
- Push the potato cylinder out using a pen or pencil. Remove the 'skin' at the ends with a knife.
- Only use cylinders of potato tissue like this for all tests unless investigating the effect of SA: V.
- Only use 5% salt solution unless investigating the effect of concentration of salt solution.
- Only use 100 mL salt solution unless investigating the effect of volume of salt solution.
- Only use room temperature unless investigating the effect of temperature.

Method

1. Make a copy of the 'Deconstruction Template' (page 60) and answer the questions with reference to a problem to do with osmosis.
2. Consult also the '*Glossary of Practical Terms*' on pages 513, 514 in the Appendix.
3. Develop the procedure further to include how the independent variable will be changed and how the dependent variable will be measured.
4. Ensure the procedure permits the collection of data that is reliable, and accurate. Include in the procedure steps where there is individual and collaborative work.
5. Have another student peer-assess your work for completion and accuracy by reading your Deconstruction template and your responses to Questions 3, 4 above.

Part B: Carrying out the investigation

Aim

To carry out the investigation about osmosis in plant tissue as designed in Part A.

Materials (per group)

- 5% salt solution
- Cork borer
- 2 potatoes
- Forceps
- Sharp knife
- Cutting board or mat
- 250 mL beakers
- 100 mL measuring cylinder
- Stopwatch
- Plastic spoon
- Access to electronic balance (0.01g)

Method

1. Place the 250mL beakers on the bench.
2. Carry out the design; be sure to change the independent variable at least three times.
3. Be sure to take steps to collect data that is reliable.
4. Work independently and collaboratively.
5. Record relevant raw data in a rough table or in some other suitable format.

Science Inquiry Skills 2.4 – Investigating osmosis in plant tissue (cont.)

Part C: Producing and displaying secondary data

1. Produce processed data by calculating the average percentage change in mass using:

   $$\text{Average \% change in mass} = \frac{\text{\% change in mass 1} + \text{\% change in mass 2}}{2}$$

2. Display processed data using a table that includes using a table that includes appropriate column headings, significant figures, SI units and symbols.
3. Prepare at least one hand-drawn graph of the processed data that includes an appropriate scale, axes headings and line of best fit.
4. Include for both the table and the graph a title that links the independent and dependent variable.

Part D: Analysing, evaluating and formulating conclusions

1. Analyse the data and discuss the relationship (if any) between the independent and dependent variable – write your work on paper or type it electronically as directed by your teacher.
2. Evaluate the procedure to identify sources of uncertainty including random and systematic errors, and effective control of variables.
3. Discuss the impact that sources of uncertainty have on the results e.g. the effect of random and systematic errors on reliability, precision, and accuracy of the results, and the effective control of variables on the validity of the investigation.
4. Use evidence and biological understanding to formulate and justify conclusions.
5. Recognise the limitations of the conclusions.

Part E: Preparing a formal practical report

1. Use work done in Parts A-D to prepare a practical investigation report about osmosis.
2. Your teacher will advise you of the format and the Assessment Design Criteria to be assessed.

Guidelines to help you prepare a formal Practical Report can be found in the Appendix, on page 484. Also in the Appendix, on page 485, is a sample Task Sheet for a practical investigation.

Science Inquiry Skills 2.6 – Observing mitotic division

Introduction

Much of what is known today about mitotic division originates from the observations made by the German biologist *Walther Flemming* in the 1870s. *Flemming* used stains to show the nucleus was full of a material he called "chromatin". He discovered that chromatin doubles at the start of mitosis and traced the movement of the mitotic threads (later called chromosomes) through the rest of the process. *Flemming's* research was published in a landmark text in 1882 called *Zell-substanz, Kern und Zelltheilung (Cell-Substance, Nucleus, and Cell-Division)*.

Part A Looking for evidence of mitotic division

Aim

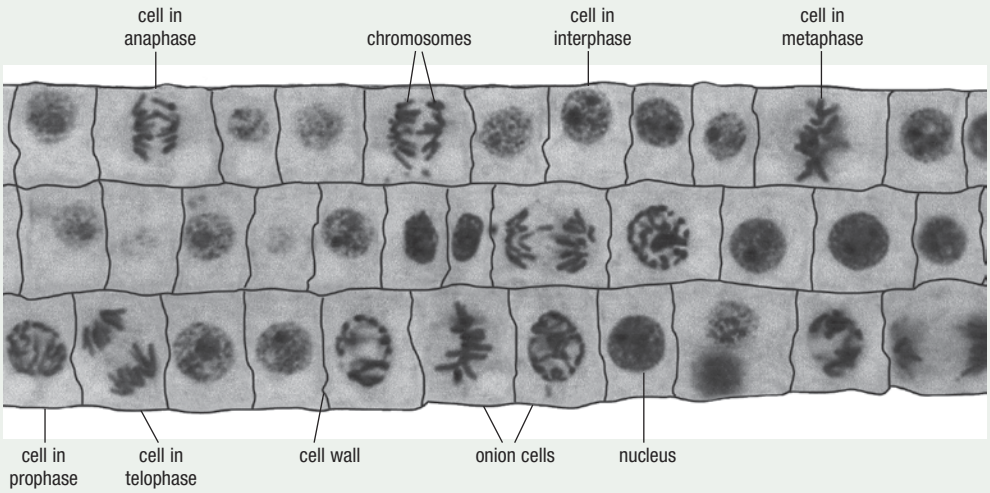
To observe a prepared slide of an onion root tip and look for evidence of mitotic division.

Materials (per group)

- Light microscope
- Prepared slide of onion tissue, stained to show chromosomes in the nucleus of cells

Method

3. Set up the microscope and establish a magnification of 40x.
4. Place the prepared slide on the stage and secure it using the stage clips.
5. View the onion root tip at 40x magnification.
6. Adjust the microscope to view the specimen at 100x magnification, then at 400x.
7. Examine closely the nucleus of some of the onion cells to observe chromosomes.
8. Look for evidence of cells that are in interphase (no distinct chromosomes). Use the photograph below to help you.
9. Look for evidence of cells that are in one of the stages of mitosis.



10. Use a sharp pencil to draw a diagram of a cell in interphase and a cell in one of the stages of mitosis. Label any relevant cell structures.

Science Inquiry Skills 2.6 – Observing mitotic division (continued)

Part B Learning about raw and processed data

Aim

To collect, and distinguish between, raw and processed data.

Materials (per group)

As for Part A

Method

11. Use the microscope to carefully survey 200 cells in the same region of the root tip.
12. Count the number of cells (/200) with visible chromosomes.
13. Also count the number of cells (/200) that are in interphase, prophase, metaphase, anaphase, or telophase.
14. Draw a table to record the **raw data** that you collected in steps 2 and 3 above.

15. Use the raw data above to make a series of calculations to produce **processed data.** See the suggestions that follow.
    a) Calculate the mitotic index of the tissue you surveyed. Use the equation below.

$$\text{Mitotic index} = \frac{\text{number of cells with visible chromosomes}}{\text{total number of cells}} \times 100$$

    b) Calculate the percentage of cells you surveyed that are:

- not undergoing mitotic division
- in prophase
- in metaphase
- in anaphase
- in telophase

Science Inquiry Skills 2.6 – Observing mitotic division (continued)

Discussion

1. As significant as Flemming's discoveries were, they were not without their limitations. He did not realise, for instance, that chromosomes in metaphase consists of two copies of the genetic material. What are the copies called, and what happens to them in anaphase?

2. The prepared slide mostly consists of tissue just behind a root tip called a meristem. Mitotic division occurs rapidly in this region. Suggest why.

3. The end of the root tip is protected by a layer of cells called the root cap. Suggest what they being protected from.

4. Even the most detailed surveys of the prepared slide will come to the following conclusion – there are no cells with chloroplasts. Suggest why none of these cells have chloroplasts.

5. Part B of this activity involved collecting raw data. What is meant by the term raw data? You may wish to consult the *Glossary of Practical Terms* that is located in the Appendices.

6. This activity included using raw data that had been collected to produce processed data. What has been done in this activity to convert raw data into processed data?

7. Cells further away from the root tip are larger, and more fully developed. Suggest why this is to be expected.

8. The outer layer of cells in the prepared slide is called the root epidermis. Many epidermis cells have extensions called root hairs (these may not be present in the prepared slide). Describe the function of root hairs, and suggest how their structure assists their function.

Science Inquiry Skills 3.2 – Perception in the animal kingdom

This activity is an opportunity to practice the skills of communication in an oral format that must not exceed 5 minutes.

Introduction

Many animals have senses of sight, hearing, smell, touch, and taste that are far greater than those possessed by humans. Vultures and some birds of prey like eagles see a magnified image at the centre of their field of view that permits them to see prey from great distances or heights. Bats fly, guided by an echo-location system not too dissimilar from radar. Grazing animals, like deer and antelopes, routinely stop eating and look up to 'sniff the air' to check for predators.

Other examples include seals that have whiskers that extend the sense of touch beyond their body – they use them to detect tiny water movements associated with fish, and thus to help locate prey. Snakes use their tongue to collect scent particles from the air that they then 'taste' on the surface of an organ at the back of their mouth called the Jacobson's organ (*see image*).

New discoveries about the sensory abilities of animals continue to be made. Each one allows us to better understand another way of perceiving the natural world.

Part A: Selecting a sense

9. Choose a sense to investigate.
10. Outline how the sense works in humans e.g. how humans are able to see things.
11. Include details about the stimulus, sensory receptors, and the sense organ.
12. Describe some examples of the capabilities of different animals with respect to this sense.
13. Explain how the sensory capabilities of the different animals (above) improve their survival.

Part B: Preparing for and giving the oral presentation

1. Finalise the content for the oral communication.
2. Prepare the oral communication.
3. Trial the oral presentation to ensure it will not exceed 5 minutes.
4. Give the oral presentation.
5. Submit a list of sources of information, and any notes for assessment.

Science Inquiry Skills 3.4 – Looking for evidence caffeine raises heart rate

Introduction

There are many kinds of performance enhancing drugs (PEDs). One, anabolic steroids, was the subject of an activity in Chapter 3.3. Another type of PED is called a stimulant. These act directly on the central nervous system (CNS), particularly the brain. Stimulants increase heart rate, so using them significantly reduces tiredness, and increases alertness and competiveness.

One stimulant used in sport is caffeine. Though not banned by the World Anti-Doping Authority (WADA), it is nonetheless 'being observed' in order to detect possible patterns of mis-use. Does caffeine really increase heart rate, and can evidence be obtained to confirm it?

This investigation is in two sections; a method will be used in Part A to estimate normal heart rate of *Daphnia* (a minute genus of freshwater crustacean that has a translucent outer surface) and in Part B the effect of different coffee (hence caffeine) concentrations will be explored.

Part A – Estimating the normal heart rate of Daphnia

Aim

To capture a specimen of *Daphnia* and determine its heart rate.

Materials (per group)

- Light microscope
- A container with about 10 *Daphnia* in pond water
- Cavity slide and coverslip
- Teat pipette
- Tissue paper
- Stopwatch
- *Daphnia* 'Recovery Tank' with pond water

Method

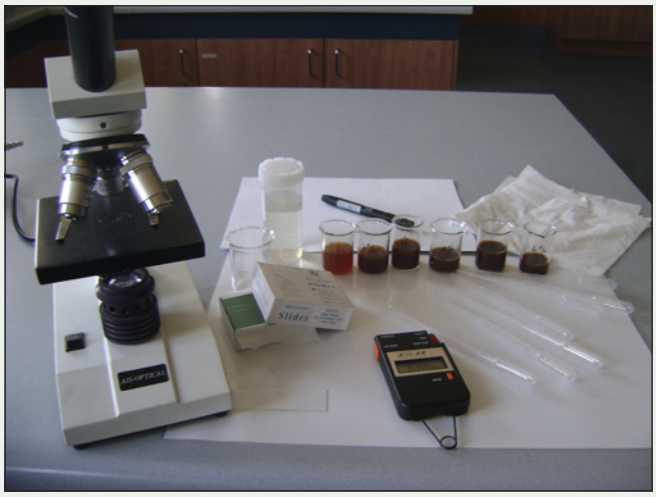
1. Set the microscope for viewing at 40x.
2. View the beating heart of *Daphnia* by referring to the Helpful Online Resources Box below.
3. Use a teat pipette to transfer a *Daphnia* and a drop of solution it was in to a cavity slide.
4. Slow the movement of the *Daphnia* by removing fluid from the slide using tissue.
5. Transfer the cavity slide to the microscope and focus until the *Daphnia* comes into view.
6. Establish a magnification of 100x and adjust the focus to see the *Daphnia*.
7. Leave the *Daphnia* to 'acclimatise' for 3 minutes. During this time, locate the heart.
8. Use a 'dot method' (i.e. mark a dot on paper every time the heart beats) and work with a partner to count and record the number of times the heart beats for 10 seconds .
9. Wait 30 seconds, then count the heart beats again for 10 seconds.
10. Wait another 30 seconds, then do a third count of heart beats for 10 seconds.
11. Return the specimen of *Daphnia* to the Recovery Tank.
12. Calculate the average heart rate of the *Daphnia* (beats/min). ***Show your working.***

Science Inquiry Skills 3.4 – Looking for evidence caffeine raises heart rate (cont.)

Part B - Exposing Daphnia to different concentrations of caffeine

Aim

To determine whether different concentrations of caffeine affect *Daphnia* heart rate, or not.



Materials (per group)

In addition to the materials used in Part A:

- Instant coffee (e.g. NESCAFE)
- Bottled spring water
- Scales (0-2000g)
- Spatula
- Plastic stirring rod
- 100 mL beaker a
- 100 mL measuring cylinder

Method

1. Prepare a 1% coffee solution by stirring 1g of coffee into 100 mL of bottled spring water until it has completely dissolved .
2. Transfer one drop of water containing a specimen of *Daphnia* (not the one used in Part A) to a cavity slide and let it adjust for 3 minutes.
3. Add one drop of 1% coffee, then carefully transfer the slide to the microscope.
4. Leave the *Daphnia* for about 30 seconds to allow caffeine to enter its body.
5. Use the method in Part A to calculate the average heart rate of the *Daphnia* at 1% coffee.
6. Return the *Daphnia* to the Recovery Tank.
7. Rinse the 100 mL beaker using distilled water, then prepare a 2% coffee solution.
8. Carry out steps 3-5 above using 2% coffee solution.
9. Continue using coffee solutions of 3, 4, 5 and 6%. Make sure a different specimen of *Daphnia* is used for each coffee concentration, and that each specimen post-testing is returned to the Recovery Tank.

Discussion

1. The method used provided a way to collect reliable data about the effect of coffee concentration on the heart rate of *Daphnia*. Explain why. *You may wish to consult the document 'Glossary of Practical Terms' on pages 513, 514 in the Appendix to help with your answer.*

2. The validity of the data collected can be questioned. For instance, the investigation was not a true fair test. Describe what is meant by the term 'fair test' and thus explain why data collected by this investigation is not completely fair.

Science Inquiry Skills 3.4 – Looking for evidence caffeine raises heart rate (cont.)

3. Use the grid to plot a graph of the concentration of coffee (X axis) and the average heart rate of *Daphnia* (Y axis). Draw a scale for each axis and label it with the correct units.

4. Identify and interpret the trend (if any) displayed by the data.

5. On the basis of this investigation alone describe the relationship between the use of caffeine and the heart rate.

6. Explain why data collected about the effect/non-effect of caffeine on heart rate of *Daphnia* cannot, on its own, be used to inform inquiries by organisations like WADA about the use of caffeine in sport.

7. The investigation conducted here included a provision for ethical considerations. Discuss, for example, the reason for using a Recovery Tank.

It might be possible to use your work to prepare a practical report about this activity. If so, your teacher will advise you of the format and the Assessment Design Criteria to be assessed.

Science Inquiry Skills 4.4 - Modelling natural selection

Introduction

Natural selection is a process occurring in ecosystems where certain individuals in a population are more suited to the environment and therefore have a greater chance of surviving and passing on their genes to the next generation. Natural selection can be driven either by biotic (living) or abiotic (non-living) factors or both.

In this investigation you will be modelling natural selection in two different environments; a woodland and wetland.

For this simulation, only two species in these ecosystems will be considered:

- The predator is a snake
- The prey is a frog

These frogs can occur in three colours; yellow, blue and green, although they are members of the same species. This is an example of intermediate inheritance; the phenotype (colour) of each frog is determined by the genotype (pair of alleles inherited) as follows: yellow (YY), blue (BB) and green (BY).

There are differences in the environmental conditions between the **woodland** and the **wetland**, and you are going to investigate some possible differences that may arise in the population of frogs in each area over (up to) a 10-year period as a result of the different environmental conditions. In particular, the **wetland** area has a lot of plants that are yellowish in colour and provide camouflage for many of the frogs. The **woodland** has leafy green vegetation which again will provide some camouflage. A fast flowing river effectively separates populations of the species from each other and prevents any migration and interbreeding (and thus gene flow) during the course of this modelling exercise.

Aim

To model the process of natural selection in two populations of frogs.

Materials (per group)

Sufficient copies of coloured frog cards from the master page in the Laboratory Notes – 35 of each colour are recommended (i.e. 3 copied sheets per group)

one cubic die (i.e. singular of dice), scissors.

Method

In this modelling exercise, the following assumptions are made:

- There are 2 separate areas, a wetland and a woodland
- In each area you will start with 24 frogs. The 24 frogs consist of 8 blue, 8 green and 8 yellow.
- Each year mating occurs between the 12 pairs in each area. Mating is completely at random.
- Each pair of frogs produces 1 offspring each year (refer to Tables 1 and 2).
- 12 frogs are killed each year as a result of predation by snakes (refer to Table 3).

Part A To simulate breeding in each area

1. Allocate 8 ‘frog cards’ of each colour to the wetland area, a total of 24.
2. Shuffle the 24 cards thoroughly and deal them at random into 12 pairs.
3. To each pair, add 1 frog card from the remaining ‘bank’ of cards, to simulate their offspring. To work out the colour of the offspring in the first 3 possible matings (a, b, c), use Table 1.
4. To work out the colour of the offspring in the last 3 possible matings (d, e, f) roll a die and use Table 2.
5. When this breeding cycle is complete there should be 36 frogs in the population.
6. Mix up these cards which represent the breeding population or gene ‘pool’.

Science Inquiry Skills 4.4 - Modelling natural selection (continued)

Table 1

	Parents		Offspring	
Mating	**Phenotypes**	**Genotypes**	**Phenotypes**	**Genotypes**
a)	blue x blue		all blue	
b)	yellow x yellow		all yellow	
c)	blue x yellow		all green	
d)	blue x green		½ blue, ½ green	
e)	green x yellow		½ green, ½ yellow	
f)	green x green		¼ blue, ½ green ¼ yellow	

Table 2

	Mating		
Number on the die	**d) blue x green**	**e) green x yellow**	**f) green x green**
1	blue	green	blue
2	blue	green	green
3	blue	green	green
4	green	yellow	yellow
5	green	yellow	Roll again
6	green	yellow	Roll again

Part B To simulate predation by snakes in each area

In the wetland the ratio of predation is 3 blue, 2 green and 1 yellow.

In the woodland the ratio of predation is 3 yellow, 2 blue and 1 green.

7. To work out which 12 frogs are eaten, throw the dice 12 times and use Table 3 to assist you in working out which coloured frog is eaten in each case. Use the 'snake cards' on the desk to remind you what is happening here.
8. Remove the appropriately coloured frog,that has been eaten, from the 'pool' of cards each time and return it to the 'bank' of frog cards.

Table 3

Number on die	Wetland	Woodland
1	blue	yellow
2	blue	yellow
3	blue	yellow
4	green	blue
5	green	blue
6	yellow	green

9. Tally the numbers of the different coloured frogs remaining in the wetland area at the end of this generation and record this data in the appropriate following table. The total should be 24.
10. Carry out this breeding/predation procedure for 10 years, or until all of the frogs are the same colour.
11. Knowing the genotypes of the different phenotypes, you can now calculate the numbers of B and Y alleles and calculate their frequency 'f' for each generation in the following table. A hypothetical example has been given in the bottom row of the tables.

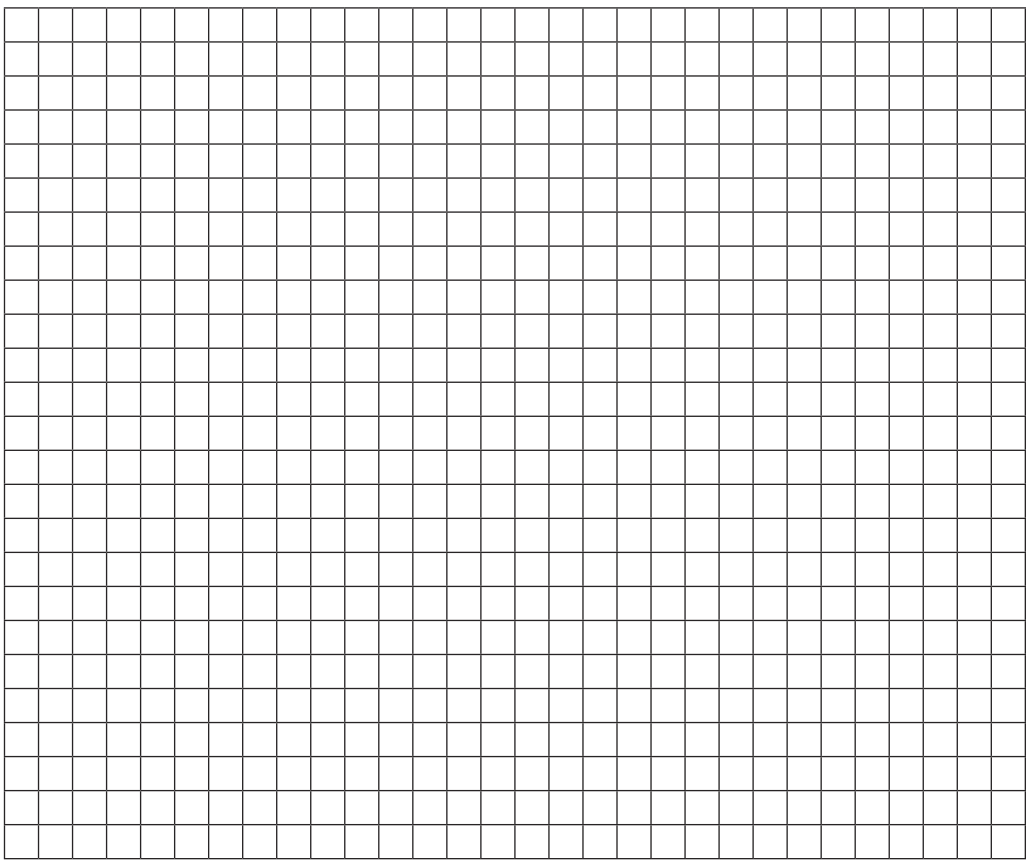
Science Inquiry Skills 4.4 - Modelling natural selection (continued)

Results

Wetland

12. Label and use an appropriate scale for the left hand axis (Y) and the horizontal (X) axis to plot the values of the population numbers of coloured frogs over a ten year (or less) period. Draw the graphs, using respective coloured pens or pencils if possible.
13. Also label and draw an appropriate scale for the right hand axis to show the gene frequencies (%) for the B and Y alleles.
14. Plot the points and use different colours/styles to draw the graphs. A key may be useful.

Year	Blue frogs (BB)	Yellow frogs (YY)	Green frogs (BY)	Blue (B) alleles	Blue (B) 'f' (%)	Yellow (Y) alleles	Yellow (Y) 'f' (%)
1	8	8	8				
2							
3							
4							
5							
6							
7							
8							
9							
10							
e.g.	1	11	12	14/48	29%	34/48	71%



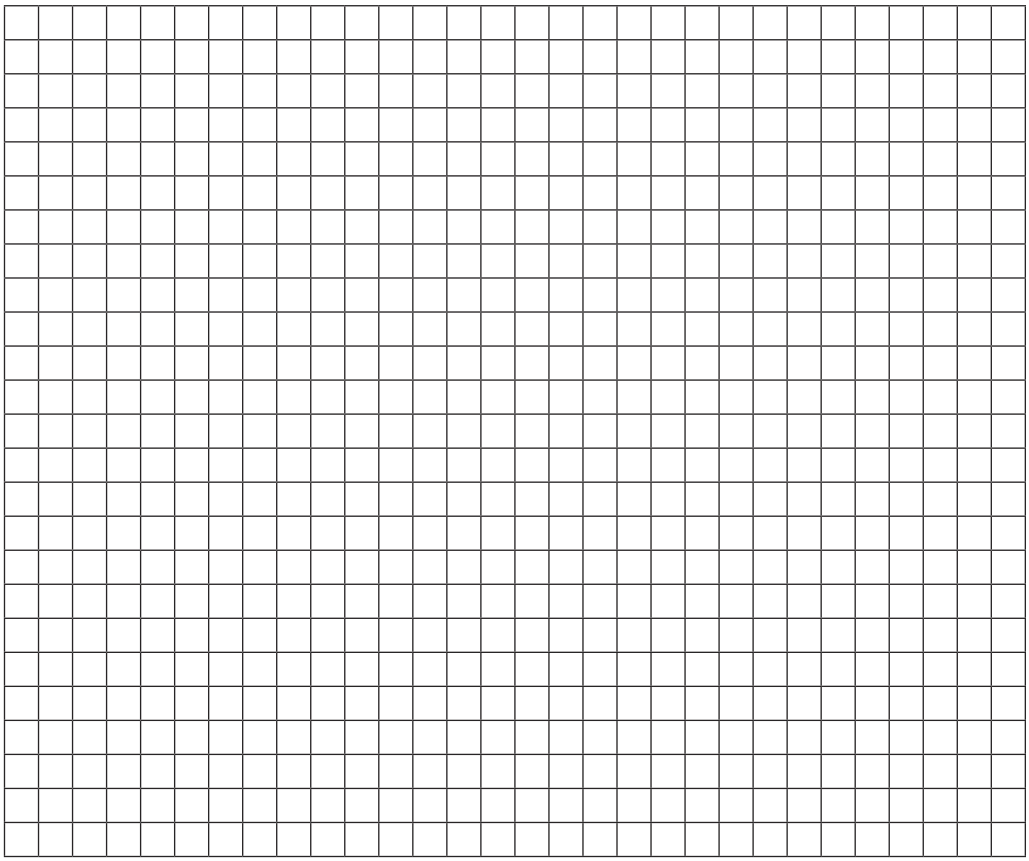
Science Inquiry Skills 4.4 - Modelling natural selection (continued)

Results (continued)

Woodland

Go through the same steps for breeding and predation for the frog population living in the woodland and use the data to complete this table and graph.

Year	Blue frogs (BB)	Yellow frogs (YY)	Green frogs (BY)	Blue (B) alleles	Blue (B) 'f' (%)	Yellow (Y) alleles	Yellow (Y) 'f' (%)
1	8	8	8				
2							
3							
4							
5							
6							
7							
8							
9							
10							
e.g.	0	16	8	8/48	17%	40/48	83%



Science Inquiry Skills 4.4 - Modelling natural selection (continued)

Discussion

15. Analyse the data collected about natural selection in the **wetland** and the **woodland** over the ten-year period.

16. On the basis of this investigation alone describe the relationship between natural selection and gene frequency in both environments.

17. Use detailed understanding of natural selection to justify the conclusion formed by answering the previous question.

18. Describe any changes to the method used by this activity you think would improve its ability to model natural selection .

19. In light of your response to the previous question explain to what extent has the data collected been affected by the method used .

It might be possible to use your work to prepare a practical report about this activity. If so, your teacher will advise you of the format and the Assessment Design Criteria to be assessed.

Science Inquiry Skills 4.6 – Convergent evolution

This activity is an opportunity to practise the skills of communication in an oral format that must not exceed 5 minutes.

Introduction

It is easy to understand why organisms closely related in evolutionary terms look very similar, or have a very similar phenotype. After all, they have diverged from a common ancestor relatively recently and so have a very large number of DNA sequences in common. Sharing a lot of DNA means producing many of the same proteins and, thus, the growth and development of a lot of shared characteristics. Consider polar bears. They resemble the brown bears of North America for a reason – they and brown bears separated from a common ancestor a mere 150,000 years ago.

It is common, however, for organisms to look very similar to one another despite not being closely related to them at all. Consider, for instance, bats and birds. Although they are both vertebrates (have a backbone) they are distantly not closely related. And yet species of both have wings, which they use to fly (see image).

The evolution of wings in bats and birds is a product of convergent evolution. The wings that have independently arisen in both are said to be analogous features; this means they share a common function but have not arisen as a product of common ancestry.

Part A: Selecting an example of convergent evolution

1. Choose an example of the convergent evolution of two types of animals to investigate.
2. Outline the general body form of both animals.
3. Describe the structure of at least one analogous structure both animals share.
4. Discuss the function of any analogous structures
5. Explain how an analogous structure the animals share improves their survival.

Part B: Preparing for and giving the oral presentation

1. Finalise the content for the oral communication.
2. Prepare the oral communication.
3. Trial the oral presentation to ensure it will not exceed 5 minutes.
4. Give the oral presentation.
5. Submit a list of sources of information, and any notes for assessment.

SIS 1.1 Laboratory Notes

This activity provides a hands-on opportunity to collect impure but visible quantities of DNA and represent the process of DNA replication using paper models.

Part A Extracting DNA

Materials

- Plant material has been selected to avoid health and ethical considerations associated with collecting DNA from fresh animal tissue.
- Fruit is used instead of onion or split peas to avoid the unpleasant odours produced if used. Good options include kiwi fruit and strawberries.

To prepare 1L of extraction solution

1. Add 15g of sodium chloride to 900mL of deionized or distilled water.
2. Mix until the sodium chloride is dissolved, then make up to 1L with a wool mix liquid detergent (or a clear, uncoloured shampoo). Do this by gentle inversion, or by using a stirrer, to prevent foaming.
3. If using store-purchased salt, use the uniodised type – note most uniodised salt contains an anti-caking agent, which does not dissolve and will make the final solution cloudy.
4. The solution can be made the day prior to the practical session and stored in the refrigerator until needed. It will remain usable for at least several months.

Method

1. Use snack-size (15 x 10cm) zip-lock bags.
2. A good source of protease is 'meat tenderizer' powder; for example, the Master Foods brand available from most supermarkets.
3. Cut the fruit into slices about 5mm thick. It is not necessary to remove the kiwi fruit skin.
4. Use 2-3 slices of kiwi fruit (or equivalent strawberry) per bag, laid flat with as much air removed as possible, then seal the bag and freeze until needed (up to 12 months).
5. Use the fruit while still frozen (this helps to keep the mixture cold during extraction).
6. Mixing is best done by holding the bag upright and squeezing gently between the fingers.
7. After the protease is added mix gently so as not to break up the DNA double helices.

- In step 6, an alternative is to use a 10mm centrifuge tube (see in photo). These come with a screw cap and may be obtained from ***Livingstone International*** at approx. $25 for 100. For ***Livingstone International*** see <www.livingstone.com.au>.
- Care must be taken to ensure that the cold alcohol is added slowly to the test tube so as to produce a layer on top of the fruit solution. DNA precipitating at the interface can then be drawn up into this layer with a piece of wooden skewer – note the rough surface of a wooden skewer 'catches DNA' better than a glass instrument such as a stirring rod.
- Collect test tubes containing fruit solution/alcohol at the end of the practical session. The mixture can be pooled in a large beaker and left in a fume cupboard to evaporate the alcohol before washing the rest of the mixture down the sink with water.

• Additional information

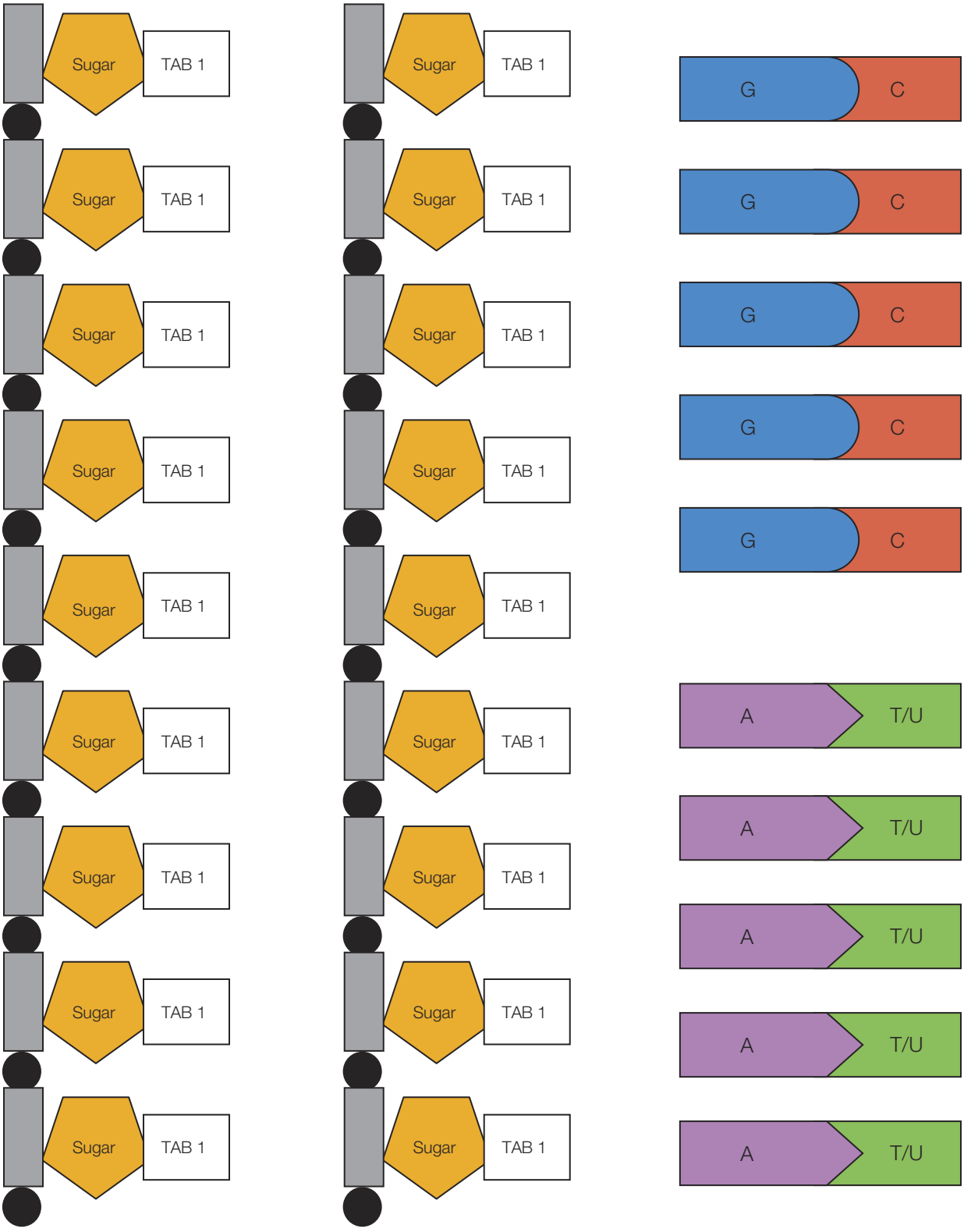
Freezing the fruit pieces, and mixing the fruit and extraction fluid in the zip-lock bag, breaks down cell walls in the plant tissue. The detergent dissolves the lipid molecules present in the cell membranes, which releases the DNA into solution. Salt improves cohesion between the DNA strands, and helps to stabilise the molecule, as does the low temperature. Most meat tenderisers contain papain which is a protease that will digest the histones associated with DNA. Note that kiwi fruit contains its own proteases so, if using kiwi fruit, the meat tenderiser is not actually required. DNA precipitates quite well in very cold and concentrated alcohol.

Part B Modelling DNA replication

These models may be photocopied and used in class to help model DNA replication, possibly as a poster.

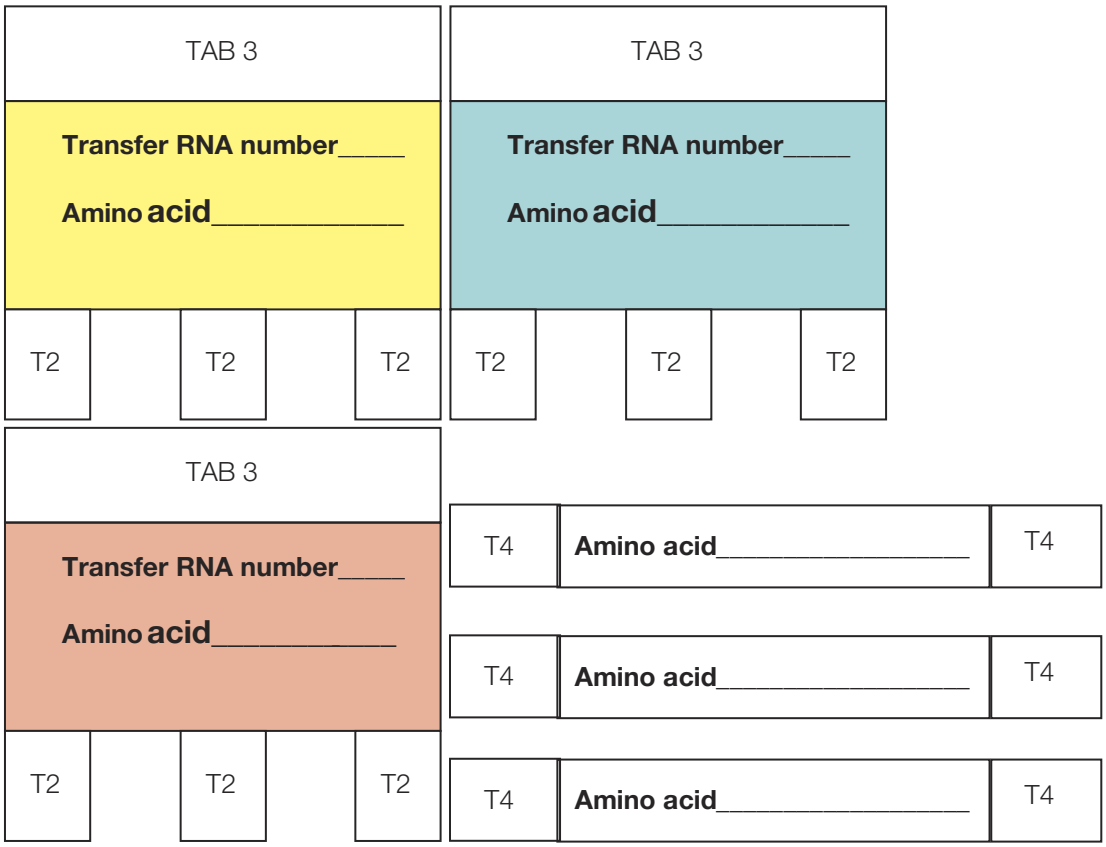
We suggest that students work in pairs and are given two sheets per group initially.

Similarly there are models on the next page for SIS 1.2; the page may also be copied, again two sheets per group initially, to help model transcription and translation.



SIS 1.2 Laboratory Notes

Please copy and cut out as required.



SIS 1.4 Laboratory Notes

This activity provides an opportunity to design a practical investigation about the activity of catalase consistent with the guidelines in the Stage 2 Biology Subject Outline, then carry out the investigation and collect data. The activity includes the option to analyse and evaluate the data, formulate conclusions and submit a formal practical report for summative assessment.

Designing and carrying out the investigation

Materials

- Fresh 'stock' hydrogen peroxide is usually 6% by volume. As hydrogen peroxide breaks down over time in the presence of light and heat, it is strongly recommended Lab staff do a 'trial run' to ensure that the hydrogen peroxide concentration in lab storage is suitable.
- Solutions of varying concentration or pH can be prepared by Lab staff the day prior and stored in brown glass or dark plastic bottles (or in foil wrapped clear glass or plastic bottles) in the fridge.
- Plant material has been selected to avoid the unpleasant odour associated with animal tissue like liver. Potato is an ideal source of catalase although silver beet, capsicum, baby spinach can all be used.
- Extracts of the vegetable sources may also be prepared just prior to use if a solution of catalase is preferred.

Method

8. Use a 100mL measuring cylinder.
9. It is a good idea to demonstrate to students a basic test to familiarise them with the apparatus.
10. For this add 24 pieces of potato (3 cubes 10x10x10mm, each cut into 8) to the measuring cylinder. Also add 10mL of 6% hydrogen peroxide and 2 drops of detergent to a 50mL beaker and swirl gently to mix.
11. Carefully run the hydrogen peroxide-detergent mixture down the side of the 100 mL measuring cylinder (to avoid producing bubbles to start with) and start the stop watch. Note that the initial volume is 13 mL – hydrogen peroxide is 10mL, potato is 3mL.
12. Allow the reaction to proceed for 10 minutes, and measure the total volume of foam.
13. Use this equation to calculate the rate of breakdown of hydrogen peroxide (mL/min):

$$\text{Rate of hydrogen peroxide breakdown} = \frac{\text{total volume of foam} - 13}{10}$$

Independent variables to test

Type of plant tissue

- **Potato**

Use 2-3 potatoes. Peel, then cut tissue into small pieces, then measure their mass. Place the potato and an equal volume of ice cold distilled water (e.g. 100g of potato, 100mL of water) in a cold blender. Blend until smooth. Strain through 'Chux' cloth. Keep cold on ice until use.

- **Silver beet**

Use ½ bunch of fresh silver beet. Chop then blend with 50-100mL of ice cold distilled water. Strain through chux cloth. This will produce approximately 500mL of extract. Keep cold on ice until use.

- **Capsicum**

Use 2-3 fresh green capsicum. Chop into small pieces, then blend until smooth - it may be necessary to add 50-100mL of ice cold distilled water to help start the blending process. Strain through Chux cloth. This will produce approximately 200mL of extract. Keep cold on ice until use.

- **Baby spinach**

Use 100g of baby spinach with 100mL of ice cold distilled water. Blend, then strain through chux cloth. Keep cold until use.

Concentration of hydrogen peroxide

The 6% 'stock' hydrogen peroxide solution can be diluted with distilled water to provide additional concentrations of 1, 2, 3, and 4%.

pH of hydrogen peroxide

The pH solutions suggested will be 3% hydrogen peroxide. Use a pH meter if possible as pH papers give less reliable results. The pH optimum of catalase is approx. pH 7. The methods suggested make 100mL of stock solution. Always use eye protection when making up or using strong acid or strong alkali solutions. Avoid making solutions higher than pH 12 as hydrogen peroxide spontaneously decomposes.

- **pH 1**

60 mL of 6% H_2O_2, 40 mL of 2M hydrochloric acid.

- **pH 3**

To 60 mL H_2O_2 add 35 mL of distilled water. Test the pH. It will be approx. pH 5. Add drops of 2M HCl until the pH is 3 and then top up to 100 mL with distilled water.

- **pH 6, 7, 8, 10**

Take 10 mL of 2M sodium hydroxide and make it up to 100 mL with distilled water. Reserve this solution.

Take 60 mL of H_2O_2 and add 30 mL of distilled water. Add the NaOH solution until the required pHs are reached and then make the solution up to 100 mL with distilled water.

- **pH 12**

To 60 mL of H_2O_2 add 35 mL of the diluted NaOH solution and measure the pH. If it is approximately pH 12, add distilled water to make it up to 100mL. If not, add drops of 2M NaOH before making up to 100 mL.

Temperature of hydrogen peroxide (and potato tissue)

- The temperature of hydrogen peroxide and potato tissue should both be manipulated – separately bring them to the required temperature using a thermostatically controlled water bath, then mix as outlined in the measuring cylinder-detergent apparatus above.
- Temperatures of approx. 6, 20, 30, 40 and 50°C are useful.
- 6°C can be made available by storing hydrogen peroxide and potato separately in a fridge.
- 20°C is room temperature, thus anything around that temperature on the day is adequate.
- 30, 40 and 50°C are best achieved using thermostatically controlled water baths
- Avoid providing temperatures higher than 50°C as decomposition of hydrogen peroxide will begin to noticeably alter its concentration as well.

Additional information

For each independent variable conduct a pre-test to ascertain suitable volumes of hydrogen peroxide, tissue (or tissue extracts if used) and reaction times. Likewise, annual review of concentrations, pH and temperatures to use will provide a richer student experience.

SIS 2.1 Laboratory Notes

This activity provides an opportunity to learn how to estimate the diameter of the field of view of a microscope and then use a microscope correctly to view a specimen.

Part A Estimating the diameter of the field of view

- Stress frequently the importance of carrying a microscope correctly (hand underneath) and how to focus properly (coarse adjustment first).
- If possible it is a good idea to demonstrate the whole activity using a digital eyepiece attachment of some kind to project what is being viewed on a screen so students know what they are aiming to see before the activity is undertaken.

Part C Viewing a specimen

- It is worth taking the time to clearly go over step 4.
- Point out the fact that a microscope drawing is a form of communication and so needs to be done carefully. In particular, it should be done using a sharp pencil, not a pen.
- Emphasise the correct use and return of mini grids. Risk assessments for Part C of the activity should include risk of an allergic response.

SIS 2.2 Laboratory Notes

This activity provides the opportunity to learn how to make wet-mount slides of plant and animal cells and to estimate and then compare the size of them.

Part A Estimating the size of onion cells

- Refrigerate the onion before the activity to reduce the volatility of any irritants it contains.
- One 'less mess' method for iodine-staining involves putting a drop of iodine solution on the slide next to the coverslip instead of on the specimen. If a piece of tissue is put on the opposite side of the coverslip, the tissue will draw the iodine stain under the coverslip and across the specimen.
- Reduce iodine staining of the skin by instructing students to hold the slide with a peg or by wearing disposable gloves.

Part B Estimating the size of cheek cells

- To reduce 'clumping of cheek cells', smear the cotton bud onto the slide and then use a tooth-pick to stir the cheek cells in a drop of (methylene blue) stain.
- Use a 0.1-0.01 % solution of methylene blue stain; for example, a 0.1 % solution which is prepared using 0.1 g of methylene blue powder in 100 mL of distilled or de-ionised water.
- Reduce methylene blue staining of the skin as for iodine staining above.
- After the activity has been completed Lab staff should use gloves to handle and then wash slides to protect against body fluids and staining of the skin.
- Slides and coverslips can be cleaned using an acid/alcohol solution; for example, to 100 mL of 70 % ethanol add 1 mL of 1 % hydrochloric acid. Soak them in this for an hour then rinse in water.

SIS 2.4 Laboratory Notes

This activity provides an opportunity to design a practical investigation about osmosis in potato tissue, consistent with the guidelines in the Biology Subject Outline and then carry out the investigation and collect data. The activity includes the option to analyse and evaluate the data, formulate conclusions and submit a formal practical report for summative assessment.

Materials

- Use 5% sodium chloride solution unless the effect of changing the concentration of sodium chloride solution is being investigated.
- Solutions of varying sodium chloride concentration can be prepared by Lab staff the day prior and stored in the fridge.
- Obtain cork borers from Omega Scientific Pty Ltd <www.omegascientific.com.au> in packs of six (sizes 1-6) for about $75. Size 2 is ideal but sizes 3 and 4 can also be used. The use of a cork borer greatly improves the reliability of the size of the cylinders used.

- Large, round and unpeeled potatoes are best to ensure complete cylinders can be cut. Then trim with a knife to remove 'skin' at the end so they are about 5cm – students will need to realise this is an important controlled variable.
- Changes in mass are measurable but will require a good electronic balance (0.01g).

Method

- Use a 250mL beaker – students will need to decide on an appropriate fixed number of potato cylinders per test of the independent variable.
- It is important to stress to students that they should not touch the cylinders – skin oils may interfere with the movement of water by osmosis.
- The initial mass of each potato cylinder is best done individually.
- Allow the cylinders to rest in the salt solution for something like 20 minutes – again, this is something for students themselves to realise needs to be controlled.
- Note that hinting about 'rolling the cylinders on tissue' to remove excess water adhered to the outside of the cylinders is a good idea, but this should be brief, and controlled.
- The final mass of each potato cylinder post salt solution is also best done individually.
- Use this equation to calculate the percentage change in mass of the potato cylinders:

$$\text{Percentage (\%) change in mass} = \frac{\text{final mass} - \text{initial mass}}{\text{initial mass}} \times 100$$

Independent variables to test

Concentration of sodium chloride solution

- Solutions of varying sodium chloride concentration can be prepared by Lab staff the day prior and stored in in the fridge.
- Concentrations of 1, 2, 5, 10 and 20% are useful.

Temperature of sodium chloride solution (and potato tissue)

- The temperature of sodium chloride and potato cylinders should both be manipulated – separately bring them to the required temperature using a thermostatically controlled water bath. Most procedures, however, should give meaningful results if only the temperature of the sodium chloride solution is manipulated.
- Temperatures of approx. 8, 20, 30, 40 and 50°C are useful.
- 8°C can be made available by storing sodium chloride and potato cylinders separately in a fridge.
- 20°C is room temperature, thus anything around that temperature on the day is adequate.
- 30, 40 and 50°C are best achieved using thermostatically controlled water baths.
- Avoid providing temperatures much higher than 50°C as thermal breakdown of the potato cylinders will begin to interfere with the validity of the investigation.

Surface area to volume ratio of the potato tissue

- A good way to do this is to change the diameter of the potato cylinders.
- The use of a sharp knife is essential.
- Diameters of 0.5, 0.6, 0.7, 0.8 and 0.9 mm are useful – a diameter of 0.5cm provides the largest SA: V while a diameter of 0.9cm provides the smallest.

Volume of sodium chloride solution

- Worth doing for those students who routinely mistake volume and concentration as the same concept.
- A range of beakers of different volumes will be needed – the potato cylinders must be fully submerged.
- Volumes of sodium chloride solution of 20, 50, 150 and 200 mL are useful.

Additional information

It is well worth finding a way to hint at staggering the tests per independent variable i.e. the fixed number of potato cylinders are first massed, placed separately in the salt solution and then, perhaps 2 minutes later, the next set of cylinders is set up, and so on. The removal of the potato cylinders needs to be done carefully with a spoon, or loss of data will occur!

SIS 2.6 Laboratory Notes

This activity provides an opportunity to use microscope skills developed in Chapters 2.1 and 2.2 to view onion cells at different stages of mitotic division.

Prepared onion root tip slides showing mitotic division can be obtained from Southern Biological <www.southernbiological.com.au> or Omega Scientific Pty Ltd <www.omegascientific.com.au>.

How many cells students should survey depends on the extent to which mitotic division was taking place in the tissue used to make the prepared slides. Observe them beforehand, then increase or decrease the number as appropriate.

A good extension is to give students the chance to make root tip slides themselves to see evidence of (mitotic) cell division. One standard method uses aceto-orcein stain. To make this add 1g synthetic orcein to 25 mL glacial acetic acid and 20 mL distilled water. Gently boil for 4-5 minutes using reflux apparatus and filter the solution while hot. Alternatively, prepared aceto-orcein stain is available from Omega Scientific Pty Ltd <www.omegascientific.com.au>.

To make the slides:

- Cut a few millimetres off the dried root zone of an onion bulb.
- Place 3-4 toothpicks in the onion bulb, then suspend it on a beaker filled with water so that the 'rootlet zone' just touches the water.
- Place the beaker in a dark cupboard for a few days until rootlets emerge.
- When they are 2 cm long cut rootlets off.
- Put cut rootlets in a 'fixative' (3:1 ratio of absolute alcohol to glacial acetic acid) for 12-24 hours.
- Cut 2-3 mm off the tip of a rootlet and place on a slide then add a single drop of acid aceto stain (5 mL glacial acetic acid added to 10 mL of aceto orcein stock solution).
- Heat the slide on a hot plate at approx. 60°C for 2-3 minutes. Watch carefully - it is important to not let the stain boil or dry out.
- Macerate the root tip using forceps. Add another drop of acid aceto orcein stain and repeat the heating process.
- Blot away any excess stain and add a drop of fresh aceto orcein (not acid aceto orcein stain).
- Lower a coverslip onto the rootlet tip.
- Put the slide between two pieces of paper towel and gently press down with the thumb to crush the cells. Do not move the coverslip sideways or the cells will be distorted.
- View the slide under a microscope and follow the instructions as for Parts A and B.

SIS 3.4 Laboratory Notes

This activity provides an opportunity to use a microscope to collect evidence to find out whether caffeine in coffee increases the heart rate of *Daphnia*, a small species of crustacean.

Part A Estimating the normal heart rate of Daphnia

Materials

Daphnia can be obtained from Southern Biological <www.southernbiological.com> for about $45 including postage. The order should contain enough *Daphnia* specimens for one class. This service is normally available year round.

Pond water, not chlorinated tap water, should be used for the Recovery tank to maximise the chance of survival of the *Daphnia* specimens. One tank per class may be used or each group of students could use a 100mL beaker. The inclusion of the tank can be optional but it provides an opportunity for students to discuss and consider ethical considerations.

Method

- Care is needed when removing fluid from the slide using tissue, as in step 4, or the *Daphnia* specimen may be absorbed into the tissue.
- The suggested method has used 10 seconds as the period of time for counting heart beats. The heart rate can be very high (in excess of 200 beats per minute) so counting for a quite short period of time will maximise the reliability of the measurement. Obviously, heart rate (beats per minute) is the measurement multiplied by six.

Part B Exposing Daphnia to different concentrations of caffeine

Materials

Bottled Spring Water provides the best results. Distilled (or de-ionised) water can interfere with Daphnia function (and thus provide another factor affecting heart rate).

Method

- Stress to students the importance of making the coffee concentrations very carefully. To avoid caffeine toxicity, also remind them to use a different specimen of *Daphnia* for each concentration.
- The effect of caffeine (if any – see Additional information) is very quick but students should still provide a short 'experience' time e.g. 30 seconds, or maybe slightly less.
- *Daphnia* in the Recovery tank can be returned to a pond on completion of the activity.

Additional information

At the end of the activity, return to the questions posed in the Introduction. Many students go into the investigation thinking that caffeine increases human heart rate, and transfer this to anything with a heart. It may be the case that data supporting this for *Daphnia* is collected.

Some studies, however, suggest that caffeine is not a stimulant in *Daphnia*, or its effect is either minimal, or inconclusive. The activity therefore provides a very good opportunity to address student/observer bias – did students really observe an increase in heart rate in *Daphnia* as concentration was increased, or was 'expecting to see an increase in heart rate' influencing the counts? If this unfolds, or if the data is inconclusive, simply take students back to the original context of the ASADA inquiry and sport i.e. the *Daphnia* investigation cannot be used in support of caffeine as a stimulant.

SIS4.4 Laboratory Notes

This activity is fairly self explanatory, but in addition it is suggested that:

- 3 sheets of 'frog cards' (***next page***) be copied in advance and provided for each group
- These are best copied onto white card and can also be laminated for re-use if required
- The coloured cards are best stored in separate containers for easy collection and return by students
- If possible, you may also wish to provide large yellow and green sheets of paper as the 'environment' for the students to work on, to further develop their ideas about camouflage, predation and selection
- The snakes don't breed or die, they are simply there to remind them of predation
- We have only provided one graph grid for each environment, so they will need to use a colour key for the various lines as suggested to avoid confusion.
- The axes provide for relatively easy graduation
- We have found that in most cases, all of the frogs in the wetland ecosystem will 'evolve' to become yellow and all of the frogs in the woodland will become green within 10 generations.

Capabilities Summary Topic 1: DNA and Proteins

Chapter	Literacy	Numeracy	ICT Capability	Critical and Creative Thinking	Personal and Social Capability	Ethical Understanding	Intercultural Understanding
1.1 **DNA structure**	DNA model Interpreting the work of scientists across disciplines, using biological knowledge	DNA structure Accessing and interpreting secondary data		DNA data storage Analysing and interpreting problems from different perspectives	SIS DNA extraction Planning effectively, managing time, following procedures effectively, and working safely		
1.2 **DNA and protein synthesis**			Protein synthesis Locating and accessing information	Pharmacogenetics Devising imaginative solutions and making reasonable predictions			A global endeavour Recognising that biology is a global endeavour with contributions from diverse cultures
1.3 **Structure and function of proteins**	All about proteins Extracting biological information presented in a variety of modes		Protein structure Modelling concepts and relationships		Formative questions Seeking, valuing, and acting on feedback		
1.4 **Enzymes**		SIS Catalase activity Measuring with appropriate instruments	SIS Catalase activity Collecting, analysing, and representing data electronically	Food spoilage Deconstructing the parts of a problem to determine the most appropriate method for investigation	SIS Catalse activity Making decisions and taking initiative while working independently and collaboratively	SIS Catalse activity Using data and reporting the outcomes of investigations accurately and fairly	
1.5 **Gene expression**	All about genes Using a range of communication formats to express ideas logically and fluently		Regulation of genes Communicating biological ideas, processes, and information		Epigenetics Recognising the role of their own beliefs and attitudes in gauging the impact of biology in society		
1.6 **Mutations**	Pathway diagrams Communicating appropriately for specific purposes and audiences			Cystic fibrosis Recognising the significance of creative thinking on the development of medical treatments			Sun-tanning Being open-minded to change in light of scientific thinking based on new information
1.7 **Biotechnology: tools and techniques**		Biotech problems Solving problems using calculations and critical thinking skills	Genome sequencing Understanding the impact of ICT on the development of biology and its application in society		SIS Electrophoresis Planning effectively, managing time, following procedures effectively, and working safely		Inclusive genetic testing Respecting and engaging with different cultural views and customs
1.8 **Biotechnology: applications**	Using biotech Synthesising evidence-based arguments about the use of a biotechnology				Views about biotech Discussing biological developments while respecting the perspectives of others	CRISPR Making ethical decisions based on understanding of biological principles	

Capabilities Summary Topic 2: Cells as the basis of life

Chapter	Literacy	Numeracy	ICT Capability	Critical and Creative Thinking	Personal and Social Capability	Ethical Understanding	Intercultural Understanding
2.1 **The cell theory**		SIS The microscope Estimating the diameter of the field of view at different microscope magnifications	The cell membrane Locating and accessing information		SIS The microscope Seeking, valuing and acting on feedback while re-visiting the microscope and how to use one correctly		
2.2 **Two types of cells**		SIS Size of cells Measuring with appropriate instruments and scales the size of different cells	Cells and organisms Using technologies to create new ways to look at and study cells and organisms		SIS Size of cells Planning effectively, managing time, following procedures effectively, and working safely		
2.3 **Energy transformations**		Photosynthesis Identifying and interpreting trends and relationships		Desert tomatoes Recognising the role played by creative thinking on the development of new ways to produce food			Where do we come from? Being respectful of different cultural views about the origin of the present day world
2.4 **Movement of substances**		SIS Osmosis Measuring with appropriate instruments	SIS Osmosis Collecting, analysing, and representing data electronically	SIS Osmosis Deconstructing the parts of a problem to determine the most appropriate method for investigation	SIS Osmosis Making decisions and taking initiative while working independently and collaboratively	SIS Osmosis Using data and reporting the outcomes of investigations accurately and fairly	
2.5 **Cell metabolism**	Metabolic pathways Extracting biological information presented in a variety of modes		Small pill boxes Using wireless phone technology to track and improve adherence to the correct medication			Use of DDT Controlling malaria means using DDT but there is a need to protect and sustain the biosphere as well	
2.6 **Binary fission and mitotic division**	SIS Mitotic division Describing, and distinguishing between, primary and secondary data	Binary fission Accessing and interpreting secondary data	Mitosis Modelling concepts and relationships		Formative questions Seeking, valuing, and acting on feedback		
2.7 **Meiotic division**	In-vitro fertilisation Synthesising evidence-based arguments about the use of a reproductive technology		Meiotic division Communicating biological ideas, processes, and information	The baby clock Recognising the role played by creative thinking on the development of ways to delay motherhood	Freezing eggs Discussing biological developments while respecting the perspectives of others		
2.8 **Control of cell division**				Analysing claims Analysing interpretations and claims for reliability and validity		Vaccinated children Making ethical decisions based on understanding of biological principles	

Capabilities Summary Topic 3 Homeostasis

Chapter	Literacy	Numeracy	ICT Capability	Critical and Creative Thinking	Personal and Social Capability	Ethical Understanding	Intercultural Understanding
3.1 **Maintaining the internal environment**	Flow charts Communicating appropriately for specific purposes and audience				Limits of perception Recognising human perception has limits and that these influence the way the world is understood		
3.2 **The nervous system**	Nervous system Extracting biological information presented in a variety of modes				Animal perception Planning effectively, managing time and following procedures effectively		
3.3 **The endocrine system**				Reversing diabetes Envisaging consequences and speculating on possible outcomes	Anabolic steroid use Understanding the importance of biological knowledge on health and well-being		
3.4 **Comparing the nervous and endocrine systems**		SIS Caffeine Identifying and interpreting trends and relationships about caffeine use and heart rate	Sensitive bandages Using technologies to create new ways to monitor and track patient's health	Managing stress Devising new solutions and making reasonable predictions			

Capabilities Summary Topic 4: Evolution

Chapter	Literacy	Numeracy	ICT Capability	Critical and Creative Thinking	Personal and Social Capability	Ethical Understanding	Intercultural Understanding
4.1 **The origin of life on Earth**	How life started Interpreting the work of scientists across disciplines, using biological knowledge		3D printing fossils Understanding the impact of ICT on the development and teaching of micropalaeontology				
4.2 **Comparative genomics**			Genome analysis Recognising ICT is used to advance biological understanding and investigations		Aboriginal ancestry Recognising the role of their own beliefs and attitudes in gauging the impact of biology in society		
4.3 **Reproductive isolation**	Isolation of species Using a range of communication formats to express ideas logically and fluently			Digital morphology Devising imaginative solutions and making reasonable predictions			
4.4 **Genetic variation**		SIS Natural selection Calculating and predicting values by manipulating data and using scientific conventions			Sickle cell anaemia Understanding the importance of biological knowledge on health and well-being		
4.5 **Evolutionary change**	Evolution Extracting biological information presented in a variety of modes		Speciation Modelling concepts and relationships				
4.6 **Convergent and divergent evolution**				Analysing claims Analysing interpretations and claims for reliability and validity	Formative questions Seeking, valuing, and acting on feedback		Secret of dreaming Respecting and engaging with different cultural views and customs
4.7 **Human impacts**			Living Australia Atlas Using technologies to share and improve biodiversity knowledge			Biodiversity Acknowledging the need to plan for the future and to protect and sustain the biosphere	

Science Investigation Skills Summary (Topics 1 and 2)

Topic 1: DNA and Proteins

Chapter	IAE1	IAE2	IAE3	IAE4	KA4
1.1 **DNA structure**					Questions **What have you learned?**
1.2 **DNA and protein synthesis**			Discussion **SIS 1.2**		
1.3 **Structure and function of proteins**					Questions **What have you learned?**
1.4 **Enzymes**	Design an investigation **SIS 1.4**	Carry out an investigation **SIS 1.4**	Analyse data collected **SIS 1.4**	Evaluate the procedure **SIS 1.4**	
1.5 **Gene expression**			Questions **What have you learned?**		
1.6 **Mutations**					Questions **What have you learned**
1.7 **Biotechnology: tools and techniques**		Set up and run the gel **SIS 1.7**		Discussion **SIS 1.7**	
1.8 **Biotechnology: applications**		De-extinction of an animal **SIS 1.8**	De-extinction of an animal **SIS 1.8**		

Topic 2: Cells as the Basis of Life

Chapter	IAE1	IAE2	IAE3	IAE4	KA4
2.1 **The cell theory**				Discussion **SIS 2.1**	
2.2 **Two types of cells**		Estimate the size of cells **SIS 2.2**			Questions **What have you learned?**
2.3 **Energy transformations**			Questions **What have you learned?**		
2.4 **Movement of substances**	Design an investigation **SIS 2.4**	Carry out an investigation **SIS 2.4**	Analyse data collected **SIS 2.4**	Evaluate the procedure **SIS 2.4**	
2.5 **Cell metabolism**					Questions **What have you learned?**
2.6 **Binary fission and mitotic division**		Evidence of mitotic division **SIS 2.6**			
2.7 **Meiotic division**			Questions **What have you learned?**		
2.8 **Control of cell division**					Questions **What have you learned?**

Science Investigation Skills Summary (Topics 3 and 4)

Topic 3: Homeostasis

Chapter	IAE1	IAE2	IAE3	IAE4	KA4
3.1 **Maintaining the internal environment**			Questions **What have you learned?**		Questions **What have you learned?**
3.2 **The nervous system**		Perception of an animal **SIS 3.2**	Perception of an animal **SIS 3.2**		
3.3 **The endocrine system**					Questions **What have you learned?**
3.4 **Comparing the nervous and endocrine systems**		Estimate the heart rate **SIS 3.4**	Caffeine and heart rate **SIS 3.4**	Discussion **SIS 3.4**	

Topic 4: Evolution

Chapter	IAE1	IAE2	IAE3	IAE4	KA4
4.1 **The origin of life on Earth**			Questions **What have you learned?**		
4.2 **Comparative genomics**					Questions **What have you learned?**
4.3 **Reproductive isolation**					Questions **What have you learned?**
4.4 **Genetic variation**		Simulate breeding **SIS 4.4**	Simulate predation **SIS 4.4**	Discussion **SIS 4.4**	
4.5 **Evolutionary change**					Questions **What have you learned?**
4.6 **Convergent and divergent evolution**		Evolution of two animals **SIS 4.6**	Evolution of two animals **SIS 4.6**		
4.7 **Human impacts**			Questions **What have you learned?**		Questions **What have you learned?**

Science as a Human Endeavour Summary (Topics 1-4)

Communication and collaboration	Development	Influence	Application and limitation
Clear communication, international conventions and review of results 1.6 Gene therapy clinical trials Info Box 2.8: Profile of a medical scientist	Development of models and use of evidence 1.1 A model for the structure of DNA	Advances in science in one field influence/ are influenced by another field 3.2 A bionic spinal cord	Science understanding/inquiry enables scientists to develop solutions 1.8 Transgenic salmon
Collaboration between agencies 2.8 Stem cell research Info Box 4.7: Profile of an environmental scientist	New technologies improve procedures and data collection 1.7 PCR and gene cloning	Acceptance/use of science is influenced by social and economic considerations 3.3 Hormone replacement therapy	Science understanding/inquiry enables scientists to make discoveries 2.6 Telomerase and anti-aging 4.1 Life on Earth for how long?
	New technologies reveal new evidence that may modify/replace models 1.5 DNA is not mostly 'junk' after all 2.3 Life elsewhere in the solar system	Acceptance/use of science is influenced by cultural and ethical considerations 4.4 Antibiotics	Science understanding/inquiry enables scientists to design sustainable action 4.7 Red crabs on Christmas Island
			Science understanding/inquiry enables scientists to evaluate economic, social, cultural, and environmental impacts Info Box Ch 4.7: Grey-headed flying foxes
			Science understanding/inquiry enables scientists to offer valid explanations 4.2 Why is there multicellular life?
			Science understanding/inquiry enables scientists to make reliable predictions 1.3 Pregnancy testing
			The use of science knowledge may have beneficial or unexpected consequences 3.1 Are you about to catch a cold?
			Science informs public debate and in turn is influenced by public debate 2.7 Gene editing and genetic disorders

Performance Standards for Stage 2 Biology *(adapted from SACE Guidelines)*

	Investigation, Analysis and Evaluation (IAE)	Knowledge and Application (KA)
A	(IAE1) Designs a logical, coherent, and detailed biological investigation. (IAE2) Obtains records, and represents data, using appropriate conventions and formats accurately and highly effectively. (IAE3) Systematically analyses data and interprets data and evidence to formulate logical conclusions with detailed justifications. (IAE4) Critically and logically evaluates procedures and their effects on data.	(KA1) Demonstrates a deep and broad knowledge and understanding of a range of biological concepts. (KA2) Develops and applies biological concepts highly effectively in new and familiar contexts. (KA3) Critically explores and understands in depth the interaction between science and society. (KA4) Communicates knowledge and understanding of biology coherently, with highly effective use of appropriate terms, conventions and representations.
B	(IAE1) Designs a well-considered and clear biological investigation. (IAE2) Obtains, records, and displays findings of investigations, using appropriate conventions and formats mostly accurately and effectively. (IAE3) Logically analyses and interprets data and evidence to formulate suitable conclusions with reasonable justification. (IAE4) Logically evaluates procedures and their effects on data.	(KA1) Demonstrates some depth and breadth of knowledge and understanding of a range of biological concepts. (KA2) Develops and applies biological concepts mostly effectively in new and familiar contexts. (KA3) Logically explores and understands in some depth the interaction between science and society. (KA4) Communicates knowledge and understanding of biology mostly coherently, with effective use of appropriate terms, conventions, and representations.
C	(IAE1) Designs a considered and generally clear biological investigation. (IAE2) Obtains, records, and displays findings of investigations, using generally appropriate conventions and formats with some errors but generally accurately and effectively. (IAE3) Undertakes some analysis of interpretation data and evidence to formulate generally appropriate conclusions with some justification. (IAE4) Evaluates some procedures and some of their effects on data.	(KA1) Demonstrates knowledge and understanding of a general range of biological concepts. (KA2) Develops and applies biological concepts generally effectively in new or familiar contexts. (KA3) Explores and understands aspects of the interaction between science and society. (KA4) Communicates knowledge and understanding of biology generally effectively, using some appropriate terms, conventions, and representations.
D	(IAE1) Prepares the outline of a biological investigation. (IAE2) Obtains, records, and displays findings of investigations, using conventions and formats inconsistently, with occasional accuracy and effectiveness. (IAE3) Describes data and undertakes some basic interpretation to formulate a basic conclusion. (IAE4) Attempts to evaluate procedures or suggest an effect on data.	(KA1) Demonstrates some basic knowledge and partial understanding of biological concepts. (KA2) Develops and applies some biological concepts in familiar contexts. (KA3) Partially explores and recognises aspects of the interaction between science and society. (KA4) Communicates basic biological information, using some appropriate terms, conventions, and/or representations.
E	(IAE1) Identifies a simple procedure for a biological investigation. (IAE2) Attempts to record and display some descriptive results of an investigation, with limited accuracy or effectiveness. (IAE3) Attempts to describe results and/or interpret data to formulate a basic conclusion. (IAE4) Acknowledges that procedures affect data.	(KA1) Demonstrates limited recognition and awareness of biological concepts. (KA2) Attempts to develop and apply biological concepts in familiar contexts. (KA3) Attempts to explore and identify an aspect of the interaction between science and society. (KA4) Attempts to communicate information about biology.

Suggested Guidelines for preparing a formal Practical Report

The report of the investigation needs to be a maximum of 1500 words ,or 10 minutes for oral presentations, for the introduction, analysis, evaluation and conclusion. In-text referencing and a Reference list are also not included. The word count should be clearly written on the front of the Report.

You should consult the following documents to help you to do this to the best of your ability.

1. **Deconstruction Template** (*refer to page 505*).
2. **Glossary of Practical Terms,** also located in the Appendix.
3. An adaptation of the **Performance Standards for Stage 2 Biology** (*refer to the previous page*).
4. **Other information** provided by your teacher, and/or the SACE Biology website.

The Practical Report should address the headings below and their dot-point indicators.

Introduction

- Relevant biological theory that relates to the investigation.
- The purpose of the investigation.

Problem

- The problem is stated as an Inquiry Question (IQ).
- The independent and dependent variables are identifiable.

Deconstruction of the problem

- Attach a completed 'Deconstruction Template' for the investigation.
- Write your name, class and date in the spaces provided on the template.

Hypothesis

- The hypothesis is derived from the IQ.
- Correctly written and links the independent and dependent variable.

Procedure

- The procedure is detailed using clear steps.
- The way the independent variable is changed is clear.
- The way the dependent variable is measured is clear.
- There is evidence of individual and collaborative work.
- The procedure permits collection of data that is reliable, and accurate.

Results

- There is evidence of obtaining primary data.
- Secondary data is displayed using a table that includes appropriate column headings, significant figures, SI units and symbols.
- At least one hand-drawn graph of the data is drawn that includes an appropriate scale, axes headings and line of best fit.
- There is a title for each table and graph that links the independent and dependent variable.
- There are mathematical calculations, appropriate equations and sample calculations.

Analysis

- The relationship between the independent and dependent variable is clearly discussed.

Evaluation

- Sources of uncertainty are identified and discussed.
- The impact sources of uncertainty had on the results is discussed.

Conclusion

- Evidence and biological understanding is used to formulate logical conclusions with detailed justification.
- The limitations of the conclusions are recognised.

Sample 'Task Sheet' for a summative Practical Investigation

Name: _____ Deadline _____

Practical Investigation: Photosynthesis

Task

In this task you need to design and implement a practical investigation about the effect of one factor on photosynthesis.

Process

Part A: Deconstruct a problem concerning photosynthesis with one or two other students and then individually design an investigation to address it that includes an appropriate hypothesis, variables and procedure.

Part B: Carry out the practical design to obtain, record and present data using appropriate conventions and format. Use biological knowledge and understanding to analyse and interpret data collected, and form and justify conclusions. Critically evaluate the procedure to determine the limitations of the conclusions.

Time and assessment conditions

Class time will be made available to deconstruct a problem and then to individually design a procedure to investigate it. One double lesson will be needed to carry out the design.

You will be required to submit a practical report consistent with the guidelines in the *Biology Subject Outline*. One draft opportunity will be provided for written feedback. The final report may be typed or be an oral presentation. The Assessment Design Criteria are listed in the 'Criteria' column in the table below.

Word count

Write the word count on the front of the report. Max 1500 words or 10 minutes for oral presentations for the introduction, analysis, evaluation and conclusion. In-text referencing and a References list are also not included.

The structure of the report

Heading	Dot-point indicators	Criteria
Introduction	• Relevant biological theory that relates to the investigation. • The purpose of the investigation.	KA1
Problem	• The problem is stated as an Inquiry Question (IQ). • The independent and dependent variables are identifiable.	KA1
Deconstruction of the problem	• Attach a completed 'Deconstruction Template' for the investigation. • Write your name, class and date on the template.	IAE1
Hypothesis	• The hypothesis is derived from the IQ. • Correctly written and links the independent and dependent variable.	IAE1
Procedure	• The procedure is detailed using clear steps. • The way the independent variable is changed is clear. • The way the dependent variable is measured is clear. • There is evidence of individual and collaborative work. • The procedure permits collection of data that is reliable, and accurate.	IAE1
Results	• There is evidence of obtaining primary data. • Secondary data is displayed using a table that includes appropriate column headings, significant figures, SI units and symbols. • At least one hand-drawn graph of the data is drawn that includes an appropriate scale, axes headings and line of best fit. • There is a title for each table and graph that links the independent and dependent variable. • There are mathematical calculations, appropriate equations and sample calculations.	IAE2
Analysis	• The relationship between the independent and dependent variable is clearly discussed.	IAE3
Evaluation	• Sources of uncertainty are identified and discussed. • The impact sources of uncertainty had on the results is discussed.	IAE4
Conclusion	• Evidence and biological understanding is used to formulate logical conclusions with detailed justification. • The limitations of the conclusions are recognised.	IAE3, KA1

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Chapter 1.3

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d) onion cells: https://upload.wikimedia.org/wikipedia/commons/e/ef/Onion_Cells.jpg

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TOPIC 3

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Topic 3 Test

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TOPIC 4

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Chapter 4.1

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Chapter 4.2

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Chapter 4.3

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Chapter 4.4

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Fig 4410 (a) and (b) adapted from ***HBD Kettlewell 1956 Heredity 10: 300***

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Chapter 4.5

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Chapter 4.6

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Fig 4610 b https://commons.wikimedia.org/wiki/File:Boreal_pine_forest_after_fire.JPG

Fig 4610 c,d https://commons.wikimedia.org/wiki/File:Boreal_pine_forest_after_fire.JPG#/media

Fig 4611 https://upload.wikimedia.org/wikipedia/commons/8/8f/Koala%2C_French_Island%2C_Victoria.JPG

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Chapter 4.7

Fig 472a https://cdn.pixabay.com/photo/2013/11/24/10/18/earth-216834_960_720.jpg

Fig 472b http://www.wilderutopia.com/sustainability/midway-atoll-albatross-paradise-plastic-pollution-by-jack-eidt/

Fig 472c http://en.wikipedia.org/wiki/Cane_toad

Fig 472f www.ices.dk/community/groups/Pages/WGMIXFISH.aspx

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Topic 4 Test

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Q18 http://commons.wikimedia.org/wiki/File:Serrated_tussock_(3436999025).jpg?uselang=en-gb

acid rain
rainfall with dissolved gases (e.g. SO_2, NO_2 and CO_2) making it more acidic (lower pH)

acidosis
a condition in which the body fluids become more acidic

activation energy
the amount of energy necessary for a chemical reaction to proceed

activator
a protein that 'switches on' genes by making them more accessible for transcription

active process
any process within the cell that requires an input of energy, usually from ATP

active site
the region on an enzyme's surface where the substrate binds in a complementary fashion

active transport
the process by which materials may be moved across the cell membrane against the concentration gradient, this requires an input of energy, usually from ATP

adaptation
an inherited characteristic (feature) of an organism that increases its chance of survival and reproduction

adaptive radiation
the relatively rapid divergent evolution of a species into many different species with adaptations that permit them to occupy specific niches in ecosystems

adrenal gland
an endocrine gland which is located on top of each kidney and produces a range of hormones including adrenalin (epinephrine)

adrenalin
a hormone secreted from the adrenal glands; it causes an increase in heart rate and blood glucose levels providing energy for muscle contraction

aerobic respiration
a series of cellular biochemical reactions in which glucose, in the presence of oxygen, is chemically changed into carbon dioxide and water to release energy to synthesise ATP; most stages take place in mitochondria

allele frequency
for a specific allele, the relative proportion (%) of each allele of that gene found in a population

allele
alternative forms of a gene for a particular characteristic (e.g. for eye colour) which are always located at the same position (locus) on homologous chromosomes

allopatric speciation
the formation of a new species when two populations are separated by a physical (geographic) barrier that prevents gene flow between them

allosteric site
a site on an enzyme molecule to which an inhibitor may bind. When this occurs, the shape of the active site may be altered and the action of the enzyme inhibited. The inhibitor may be the end-product of a specific biochemical reaction (i.e. end-product inhibition).

alpha (α) helix
a secondary structure of polypeptides with a coiled, helical (spiral) shape

amino acid
a molecule consisting of an amino part and an acid part, which may be joined together by peptide bonds in long chains to form polypeptides and proteins

anaerobic respiration
a series of biochemical reactions in a cell in which glucose is used, in the absence of oxygen to produce ATP. The products may either be alcohol (yeast, plants) or lactic acid (animals, bacteria), also sometimes referred to as fermentation. This process is much less efficient (i.e. less ATP/glucose molecule) than aerobic respiration.

analogous features
features found in various species that are similar because of convergent evolution rather than common ancestry

anaphase
a phase during mitotic cell division, in which chromatids are separated by spindle fibres

aneuploidy
a nucleus where there are not exactly the haploid or diploid number of chromosomes (e.g. Down syndrome)

antibody
a protein molecule made by a plasma cell in the blood as a response to the presence of a specific antigen

anticodon
a three-base sequence on the transfer RNA molecule that is complementary to a mRNA codon

anti-diuretic hormone (ADH)
protein hormone released by the pituitary gland in the brain that increases reabsorption of water by the kidneys leading to a reduced volume of urine

antigen
a 'non-self' molecule, usually protein or carbohydrate, that stimulates production of an antibody

apoptosis
a process that, once initiated, leads to the death of a cell

aquaporin
a type of integral membrane protein that serve as a channel to facilitate the movement of water across a cell membrane

arteriole
a small artery which carries blood between a larger artery and a capillary network

ATP/ADP cycle
the inter-conversion of ATP and ADP to store and release energy for various processes within the cell

auto-immune disease
a disease where the immune system in an organism responds to its own tissues (e.g. rheumatoid arthritis)

autonomic
the part of the nervous system not under voluntary control

autonomic response
a response to a stimulus that is coordinated by the autonomic nervous system (i.e. involuntary)

autotroph
an organism which is able to use simple inorganic compounds to make its own organic compounds, either using light or certain other chemicals

axon
the part of a nerve cell (neuron) that transmits nerve impulses away from the cell body

basal metabolic rate (BMR)
the rate of metabolism required to maintain an animal when it is resting

base deletion
a mutation where a base is removed

base insertion
a mutation where a base is added

base substitution
a mutation where one base is replaced by another

behavioural isolation
courtship and mating behaviours which prevent gene flow between populations

beta (β) pleated sheet
a secondary structure of polypeptides with a folded sheet shape

binary fission
the method of asexual reproduction of prokaryotes, in which one cell divides into two

binomial system
the scientific name of species of organisms using two Latin words; the first is the genus name, followed by the species name e.g. *Eucalyptus leucoxylon*

bio-accumulation
the gradual accumulation of a chemical substance in the body of organisms because it cannot be readily excreted

biodiversity
the variety and diversity that exists in nature at the gene, species or ecosystem level

bioethics
the consideration of whether or not the application of certain biological techniques is good or bad and/or should or should not be used in society

bioinformatics
the study of an organism, a group or organisms or an interaction between organisms using computer software and/or databases of biological data

bio-magnification
the accumulation of a substance, in increasing levels within organisms, at higher levels in a food chain

biomarker
a normal chemical in the body, which, if present in higher or lower amounts can indicate the presence of a disease (e.g. high glucose can indicate diabetes)

biotechnology
an area of science which is concerned with the application of techniques to use other organisms for human purposes, including genetic manipulation

bivalent
the structure formed when two homologous chromosomes, each consisting of two chromatids, pair up during meiosis (prophase 1)

bottleneck effect
genetic drift that is caused when the size of a population is severely reduced e.g. bushfire or human activity

budding
the process of asexual reproduction in simple animals (e.g. hydra) and plants where cells begin to grow and differentiate on the outside of the organism and eventually break away forming a new organism

Calvin cycle
cyclic process in the stroma of the chloroplast where three carbon dioxide molecules are combined in the process of forming glucose; it is not dependent on light

cancer
the general name given to cells or groups of cells which grow uncontrollably and are malignant and will invade and kill other tissues in the body

carcinogen
a chemical substance or physical process which gives rise to cancer in the body

carrier protein
a type of integral protein in the cell membrane which is capable of transporting materials from one side of the membrane to the other, often against a concentration gradient

catalyst
a substance that speeds up chemical reactions

cell
the basic 'building blocks' or structural and functional units of all living organisms. They are microscopic in size and consist of a cell membrane, cytoplasm, DNA and organelles.

cell body
the part of a nerve cell (neuron) which is enlarged and contains the nucleus of the cell

cell cycle
a regulated cycle of events in the life of a cell with periods of growth, DNA replication and division

cell differentiation
the process by which cells become different in structure and function

cell membrane
a very thin layer which encloses the contents of a cell, it consists of phospholipids and proteins arranged in a fluid mosaic

cell theory
the theory that all organisms are made up of cells and the products of cells and that cells can only arise from other cells by cell division

cell wall
a layer outside the cell membrane and made of cellulose (plants), or other substances which helps maintain the shape of plant, fungal or bacterial cell

cellulose
a carbohydrate (polysaccharide) found in plant cell walls

central nervous system
the part of the nervous system that consists of the brain and spinal cord

centriole
an organelle containing micro-tubules that organises the spindle in nuclear division

centromere
a structure holding two sister chromatids together and to which spindle fibres attach during nuclear division

channel protein
a type of integral protein in the cell membrane which facilitates the passage of substances across the membrane, usually by diffusion

checkpoint
a point during the cell cycle where a check takes place that various processes have been completed in order to progress to the next stage

chemical buffer
chemicals in a solution which reduce the pH changes during a chemical reaction

chemical energy
a type of energy which is stored in chemical bonds

chemoreceptor
a sensory receptor that detects a chemical stimulus

chiasmata
(plural chiasma) the point at which non-sister chromatids touch during cell division and at which crossing over of corresponding sections may occur (in Prophase 1)

chlorofluorocarbon (CFC)
chemicals once used in refrigerators that accumulate in the upper atmosphere and can cause ozone depletion and lead to an increase in ultra-violet light reaching the Earth's surface

chlorophyll
a green pigment, mainly found in chloroplasts, that can trap a portion of the suns energy and enable light energy to be converted into chemical energy which is trapped in the chemical bonds of organic molecules (carbohydrates) in photosynthesis

chloroplast
an organelle which is found in the mesophyll cells of plants, it contains a pigment called chlorophyll which is necessary for the process of photosynthesis

cholesterol
a type of lipid which is important in animal cell membranes and is used by cells to make steroid hormones and other lipids

chromatin
the granular material found in the nucleus of a cell during interphase when it is not dividing. It consists of unwound chromosomes and DNA molecules which are not visible with a light microscope.

chromosome
structures which are found in the nuclei of eukaryotic cells and in the cytoplasm of prokaryotic cells. They consist of DNA and proteins and store and carry genetic information from one generation to another.

climate change
changes in climate that are occurring because of the increasing levels of carbon dioxide and other greenhouse gases in the atmosphere

clone
copies of molecules, cells or organisms which are genetically identical. These copies are now able to be formed using modern biological techniques.

co-dominance
both alleles of a gene pair are expressed and can be recognised in the phenotype

codon
a three base sequence on the mRNA ,or DNA, molecule that provides the code for a particular amino acid

co-enzyme
an organic molecule that assists the action of an enzyme; vitamins often act as co-enzymes

co-factor
a chemical substance that is necessary for an enzyme to function e.g. metal ions like sodium (Na^+) and magnesium (Mg^{2+})

common ancestor
an ancestor from which two or more species have evolved over time

comparative genomics
the comparison of the genomes within, or between, different species

competitive inhibitor
an inhibitor whose structure is so similar to the structure of the substrate molecule that it binds to the active site of the enzyme and prevents the substrate from binding

complementary base pairing
takes place between base pairs in DNA and DNA (in replication) or DNA and RNA (in transcription); C pairs with G only; A pairs with T in DNA-DNA pairing and with U in DNA-RNA base pairing

complementary strand
a strand of DNA that is one of the strands of the double helix and complements the coding or template strand

concentration gradient
a measure of how quickly the concentration of a particular solute or substance changes from one region to another

condensation (re chromosomes)
the process by which the very long, thin strands of DNA form coils and super coils to become visible as chromosomes during cell division

contact inhibition
the process by which cells that are dividing and in close contact with each other slow down or stop division; this is not usually the case with cancer cells

convergent evolution
the evolution of similar characteristics among unrelated organisms, due to similar selective pressures

CRISPR
gene editing technology that permits the genes of an organisms to be permanently altered

cristae
folds of the inner membrane of mitochondria. They provide a large surface for the attachment of enzymes that are involved in biochemical reactions in this organelle e.g. ATP synthesis.

crossing over
the exchange of genetic material between sister chromatids, that occurs during the first stage of meiosis when homologous chromosomes are paired together

cyanobacteria
photosynthetic bacteria, generally blue-green in colour and in some species capable of nitrogen fixation; sometimes called blue-green algae

cyclin
a component protein of MPF (maturation promoting factor) involved in the regulation of the cell cycle

cyclin-dependent kinase (Cdk)
an enzyme to which cyclin binds, to form MPF (maturation promoting factor)

cytochrome c
a protein that is involved in the cellular respiration pathway

cytokinesis
the process by which the cytoplasm divides in two at the conclusion of meiotic and mitotic division

cytoplasm
the contents of a eukaryotic cell, excluding the nucleus and other organelles

cytoskeleton
the internal skeleton of a cell consisting of tiny tubules and filaments found in the cytoplasm. It is very important for the structure of the cell and in the movement of organelles within the cell.

cytosol
the fluid part of the cytoplasm of a cell

Darwinian evolution
the process by which changes occur within populations over time, and new species may arise, through the process of natural selection, first described by Charles Darwin in 1859

dendrites
multiple tiny extensions from the cell body of a neuron; they usually receive nerve impulses across a synapse from other neurons

dendron
the part of a neuron that receives impulses, across a synapse(s) from other neurons, often branches into dendrites

diabetes
a disease resulting from the poor regulation of blood glucose, usually associated with low levels of insulin production

diaphragm
a thin sheet of smooth muscle beneath the lungs which enables inhalation when it contracts and exhalation when it relaxes

diffusion
the nett random movement of materials from regions of high to low concentration to become equally distributed in the space available. In living organisms this often involves movement through a cell membrane.

dilation
a small tube becoming wider (e.g. blood vessel or bronchiole)

diploid
cells that contain the full complement of chromosomes i.e. pairs of chromosomes (2n), compared to haploid cells that have only half the complement (n)

divergent evolution
the evolution of species from a common ancestor, due to different selective pressures, and through the process of natural selection

DNA-DNA hybridisation
a method of determining the similarity of DNA from different sources (usually species) according to the degree to which the strands will form complementary base pairs

DNA ligase
the enzyme that can be used to join one fragment of DNA to another (e.g. in a plasmid)

DNA polymerase
the enzyme that catalyses the production of a new DNA strand during replication

DNA primer
a short sequence of DNA bases used to control PCR

DNA profiling
a technique that compares DNA from different sources by cutting it into fragments with restriction enzymes and then separating these fragments into visible bands using the process of gel electrophoresis

DNA repair gene
genes that carry information needed to produce enzymes that can recognise and repair faulty sections of DNA, thereby reducing the number and effects of mutations

DNA replication
the process in which the DNA makes another copy of itself. This occurs prior to cell division during interphase and is said to be 'semi-conservative'.

DNA sequencing
methods used to work out the exact sequence of bases of gene or a section of DNA

DNA
abbreviated name for deoxyribo(se) nucleic acid which carries genetic information.

dominant
a gene (or allele) that will be expressed in the phenotype of an organism, if it is present in the genotype

double helix structure
the spiral structure of the DNA molecule which resembles an imaginary rope ladder wrapped around a large pole

duplication
a type of mutation in which a section of chromosome is doubled, resulting in a chromosomal abnormality

effector
a muscle or a gland which is activated by nerve impulses via a motor neuron, thereby producing a response

electron microscope
a microscope which uses beams of electrons to produce very high magnifications of cells and their contents. They may be scanning (SEM) or transmission (TEM) microscopes.

electron-transport chain
a sequence of biochemical reactions forming the final stages of aerobic respiration in mitochondria

electropherogram
a plot of results from an analysis of DNA fragments done by electrophoresis

endemic
a species that is native to an area; in contrast to a species that has been introduced (exotic)

endocrine gland
a gland in the body which produces a particular hormone and secretes it directly into blood vessels for transport around the body

endocytosis
the process by which materials enter cells through the membrane and are enclosed by vesicles within the cell

endoplasmic reticulum
a network of membranes in the cytoplasm of eukaryotic cells which is concerned with the transport of lipids and proteins

endosymbiosis
the widely accepted theory that mitochondria and chloroplasts originated from 'free-living' prokaryotic cells, engulfed by another cell by endocytosis

end-product inhibition
occurs when the end-product of a biochemical reaction slows down the reaction that is producing it

enzyme
a specific organic catalyst which is able to speed up a biochemical reaction in a cell without being changed itself, most enzymes are proteins

epigenetics
the inheritance of traits caused by modification of gene expression rather than simple transmission of genetic information

erector pili muscles
tiny muscles in the skin that erect hairs, usually in order to reduce heat loss

eukaryotic cells
a type of cell that has its internal structure organised into membrane-bound organelles e.g. nucleus, mitochondria and chloroplasts

evaporative cooling
the cooling effect on the skin and the body, caused by the evaporation of sweat from the skin

exocytosis
the process by which materials are enclosed by vesicles inside the cell and then expelled through the membrane out of the cell

exon
a section of coding DNA which carries sequences of bases which are transcribed and later, in the cytoplasm, translated

exponential growth
occurs when a cell or organism is able to reproduce rapidly and regularly causing a very rapid increase in their number i.e. 1, 2, 4, 8, 16, 32; clearly this is unsustainable for natural populations

exteroceptor
a type of sensory receptor in the body that detects a stimulus from the external environment

facilitated diffusion
passive movement of ions or molecules from high to low concentration across a membrane through membrane channel or transport proteins

feedback
the effect of a response on the original stimulus; usually negative (i.e. the response reduces the stimulus), although it can be can be positive (i.e. the response enhances the stimulus)

fermentation
the chemical conversion of glucose, in the absence of oxygen (anaerobic), into ethanol and carbon dioxide (plants and yeast) or lactic acid (animals and bacteria) to release energy and synthesise ATP

fertilisation
the fusion of male (sperm) and female (ova) gametes to form a zygote and subsequently a new organism

fluid-mosaic model
the '*Singer* and *Nicolson*' model of the cell membrane where proteins can move sideways within a fluid phospholipid bilayer

founder effect
genetic drift that is caused when a few organisms become isolated from the main population and form a new population (e.g. on an island)

frame shift mutation
a type of mutation in which DNA bases are inserted or deleted. This causes the DNA triplets to be read in a different sequence, leading to changes to many amino acids and/or premature termination of the polypeptide chain.

gamete isolation
the process that ensures that gametes from different species are unable to carry out fertilisation

gel electrophoresis
a technique used to separate large molecules using an electric field, based on their size and charge

gene expression
the process that results in information stored in DNA being used to make a gene-product, usually a polypeptide or RNA molecule

gene flow
the exchange of genetic material within or between populations as a result of sexual reproduction

gene pool
the entire collection of alleles (alternative genes) within a breeding population

gene probe
an artificially prepared DNA or RNA sequence made radioactive with carbon-14; used to locate a particular base sequence or gene

gene regulation
the process by which a gene is 'turned off' or 'turned on' to produce a particular gene-product

gene transfer
the deliberate movement of a gene from the DNA of one species to another. This may involve the use of bacterial plasmids, viruses or micro-injection.

gene
a specific section of DNA in a particular chromosome of an organism which carries the information necessary to make a unique protein molecule. It is also referred to as the 'unit of inheritance'.

genetic drift
the gradual change in allelic frequencies within a population; often caused by the 'bottleneck' or 'founder' effects

genetic engineering
the deliberate manipulation of genetic material in order to change some characteristics or produce useful products; e.g. adding the human gene for making insulin to a bacterium

genetic information
information contained in the base sequence of a DNA molecule

genetically modified organism (GMO)
an organism whose genetic material has been altered via genetic engineering

genome
the total genetic material of an organelle, cell or organism

genomics
a biological discipline that investigates and compares the genome sequences of organisms

genotype
the alleles of genes inherited by an individual

genus
a group consisting of very similar species e.g. eucalyptus trees

geographic isolation
the situation when members of a population are separated by a physical (geographic) barrier (e.g. desert) preventing gene flow; this may lead to speciation

germline cell mutation
a mutation in a sperm or ovum cell which may be included in the zygote and therefore in all cells of the resultant organism

germline cell
cells which, either directly or indirectly, give rise to gametes i.e. sperm or ovum (egg) cells

global warming
the observed gradual increase in atmospheric and ocean temperatures caused by an increase in greenhouse gases which are produced as a result of human activities

globular protein
generally large proteins, round in shape and water soluble (hydrophilic) e.g. haemoglobin

glucagon
a hormone which is secreted by the pancreas and increases the level of glucose in the blood, it works in the opposite way to insulin

glycogen
a polysaccharide storage product found in animals, particularly in the liver and muscles, which is formed when many glucose molecules are joined together

glycolipids
lipids with a carbohydrate attached to them

glycolysis
a series of biochemical reactions in which glucose is broken down to produce pyruvate and release energy to synthesise ATP

glycoprotein
proteins which have carbohydrate groups attached to them

Golgi body
an organelle involved in the packaging and secretion of molecules out of the cell

Gondwana
an ancient super-continent, originally a part of Pangea, from which the Australian continent was formed

grana
a collection of stacks of membrane in chloroplasts where the light dependent reactions of photosynthesis take place

greenhouse effect
the observation that the temperature inside a greenhouse (made of glass) is higher than outside; a similar process also happens in the Earth's atmosphere contributing to higher atmospheric temperatures

greenhouse gas
any gas (e.g. CH_4, CO_2) whose presence in the atmosphere causes an increase in the Earth's temperature; thereby contributing to the greenhouse effect

growth factor
a protein, produced outside of a cell that is needed for normal cell division

haploid
a cell which contains only half the normal number of chromosomes

heat (thermal) energy
energy that is due to the rapid movement of the atoms and molecules making up a substance. The higher the temperature, the more rapid the movement and the more heat energy is involved.

herbicide
any chemical that is used to kill plants e.g. glyphosate

heterotroph
any organism that obtains its organic molecules by ingesting another organism, or part of it, most animals are in this category

heterozygous
when an organism has two different alleles of the same gene

histone
small proteins around which DNA is wrapped to form chromosomes in eukaryotic cells

homeostasis
a 'steady-state' condition in blood and tissue fluids which exists within the bodies of organisms, to maintain conditions which are more stable than external conditions e.g. temperature

homologous chromosome
one of a pair of chromosomes which are the same size and shape and have the same genes at the same location (locus)

homologous features
biological features in different species that are similar because of common ancestry, rather than a product of convergent evolution

homozygous
when an organism has two identical alleles of the same gene

hormone
a chemical, released from an endocrine gland and carried in the blood. Hormones (e.g. insulin) bind to surface receptors in the cell membrane and bring about specific functions (e.g. increased uptake of glucose from the blood by cells).

hybrid sterility
a hybrid, produced when different species interbreed, that is incapable of reproduction

hybrid inviability
young are produced but are very weak and do not effectively compete for resources and thus do not reach maturity or reproduce

hybrid
the offspring of closely related organisms that are not the same species (e.g. horse and donkey); it is often infertile and incapable of reproduction (e.g. mule)

hybridise
the process when nucleic acids are mixed and allowed to form complementary binding. DNA hybridisation between different species can be used to indicate the extent of relatedness.

hydrophilic
'water loving' or polar molecules which readily mix with or dissolve in water, often due to the formation of hydrogen bonds

hydrophobic
'water hating' or non-polar molecules which do not mix readily with water (e.g. oil)

hydrothermal vent
an opening in the sea floor through which super-heated water and other material from volcanic activity are discharged into the surrounding seawater

hyperglycaemia
a condition where there is too much glucose in the blood

hyperthermia
a condition where body temperature rises too far above the 'set-point'; this can be life threatening

hypertonic
a solution which contains relatively more dissolved solute, compared to another solution

hypoglycaemia
a condition where there is not enough glucose in the blood

hypothalamus
a part of the brain, linking the endocrine system with the nervous system

hypothermia
a condition where the body temperature drops too far below the 'set-point'; this can be life threatening

hypotonic
a solution which contains relatively less dissolved solute, compared to another solution

independent assortment
the process by which each one of the pair of homologous chromosomes go to opposite poles of a cell in meiosis 1. Each homologous pair is said to separate (assort) independently of the others.

induced-fit model
the model proposed for enzyme action where the substrate induces a fit into the active site of an enzyme

inorganic molecule
the group of chemicals which are not obtained from living cells or organisms, generally they do not contain the element carbon

insecticide
any chemical that is used to kill or prevent the reproduction of insects e.g. DDT

insulin
a hormone produced by the pancreas which decreases the level of glucose in the blood, it works in the opposite way to glucagon

integral protein
a protein that is found within the cell membrane

intercostal muscles
two sets of muscles between the ribs. When one set contract, there is an increase in the chest volume and this enables inspiration, the other set of muscles assist with expiration.

interference RNA
a type of RNA that is used to silence the expression of particular genes

intermediate product
a chemical that is produced by one biochemical reaction as part of a metabolic pathway and is used as a substrate in a further biochemical reaction

interneuron
a type of neuron (nerve cell) that transmits a nerve impulse between a sensory neuron and a motor neuron

interoceptor
a type of sensory receptor in the body that detects a stimulus from the internal environment

interphase
the stage (phase), in the cell cycle between cell divisions

intron
a section of 'non-coding' DNA which carries a non-coding sequence of bases. Transcription may occur but these sections of RNA are removed and 'coding' sequences are spliced together before the mRNA moves out of the nucleus.

inversion
a type of mutation where a section of DNA is reversed (inverted) from its normal orientation in the chromosome, resulting in a chromosomal abnormality

ionising radiation
high energy electromagnetic radiation that can damage cell DNA e.g. UV, X-rays

Islets of Langerhans
small groups of cells in the pancreas that produce the hormones glucagon {alpha (α) cells} and insulin {beta (β) cells}

isotonic
a solution which contains the same amount of dissolved solute compared with another solution

karyotype
an image that shows total number of chromosomes organised into pairs, including the sex chromosomes

kidney tubule
a part of the nephron in the kidney that is responsible for reabsorption of useful materials from the filtrate before it is excreted as urine

kinetic energy
the energy possessed by a moving object

Krebs cycle
the sequence of biochemical reactions by which most living cells use glucose and oxygen to generate energy and ATP during the process of aerobic respiration; it takes place in the mitochondria

limiting factor
a physical or chemical factor which, when in short supply, limits the rate of a biochemical reaction, or the growth of a population

lipid
an organic molecule that is insoluble in water. The main groups of lipids in organisms are fats, oils, steroids and phospholipids.

locus
a specific position on a chromosome where the gene (or allele) for a particular characteristic or gene product is located

lysosome
an organelle found in animal cells that produces enzymes (lysozymes) that are involved in the digestion and destruction of foreign particles or waste materials (e.g. non-functional organelles) from cells

mammal
an organism that has fur or hair, has warm blood and the female suckles its young with milk from mammary glands

marsupial
a group of mammals with a pouch to protect and nurture its young

matrix
the region inside a mitochondrion enclosed by the folded inner membrane

maturation promoting factor (MPF)
a combination of two proteins (cyclin and CdK) that is associated with a cell progressing from interphase to mitosis

mechanical (morphological) isolation
structures (e.g. reproductive organs/features) that make it extremely difficult or impossible for organisms to interbreed

mechanoreceptor
a type of sensory receptor that is able to detect mechanical forces e.g. pressure, sound

meiosis
the division of the nucleus of a cell during meiotic division. Meiosis halves the chromosome number in the daughter cells from diploid to haploid.

meiotic division
a type of cellular division that occurs in gonads (i.e. ovaries and testes) that gives rise to gamete cells (i.e. ova and sperm); it involves both meiosis and cytokinesis

melting point (DNA)
the temperature at which 50% of complementary strands of DNA will come apart; this can be used as a measure of genetic similarity and evolutionary relatedness

messenger RNA (mRNA)
a type of RNA transcribed from DNA in the nucleus, containing information about the sequence of the amino acids in a specific polypeptide that it codes for

metabolic pathway
a series of biochemical reactions occurring in cells, each catalysed by a specific enzyme

metabolism
all of the biochemical reactions occurring within an organism

metaphase
the phase during mitosis in which the chromosomes become aligned in the centre of the cell (metaphase plate or equator), prior to being pulled apart by spindle fibres in anaphase

methylation
the attachment of methyl groups to sections of DNA that may interfere with gene expression; one of several factors involved in epigenetics

microhabitat
a very tiny section of an environment, to which a population of organisms may become adapted

microinjection
a technique that uses a micro-pipette to transfer genes between species

microRNA (miRNA)
a type of RNA that can interfere with the translation of messenger RNA (mRNA)

microtubule
a system of tiny tubules and fibres within the cytoplasm of the cell which are part of the cytoskeleton

missense mutation
a type of mutation in which the change codes for a different amino acid in the polypeptide chain

mitochondrion
an organelle which contain the enzymes necessary, and thus is the site for, aerobic respiration. They are commonly called the 'powerhouse' of the cell.

mitosis
the process by which the cell nucleus divides in two

mitotic division
the type of cell division which gives rise to genetically identical daughter cells, it involves both mitosis and cytokinesis

monotreme
a group of mammals which reproduce by laying eggs

morphological
the structural or anatomical features of an organism

motor neuron
a type of neuron that transmits a nerve impulse to an effector organ, enabling a response

multipotent
a type of stem cell that is able to divide adn produce multiple types of cells

mutagen
any chemical, radiation or other agent which increases the rate of mutation in an organism

mutagenesis
a process giving rise to a mutation

mutation
a random and permanent change in the sequence of bases in DNA which may be expressed as a change in the amino acid sequence of a polypeptide. Many mutations usually occur at the time of DNA replication. Most mutations are harmful but occasionally may improve the chance of survival and reproduction and consequently increase in the population.

myelin sheath
a sheath containing a fatty substance surrounding a neuron, which helps to insulate the conduction of nerve impulses

natural selection
the process that acts on populations where the individuals with favourable inherited characteristics are more likely to survive and reproduce, thereby passing them onto the next generation

negative feedback
a mechanism in organisms which enables the response to reduce the original stimulus and thereby maintain homeostasis

nephron
the structural and functional unit of the kidney consisting of a capsule and a tubule which is surrounded by a rich supply of blood vessels

neurotransmitter
a substance released by the synaptic terminal for the purpose of transmitting nerve impulses from one neuron (pre-synaptic) to another cell (post-synaptic)

niche
the particular role played by an organism in its ecosystem

nociceptor
a type of sensory receptor that is able to detect injury or poisons, usually felt as pain; often called 'pain receptors'

non-competitive inhibitor
a chemical which combines with an enzyme, but not at the active site, and in doing so reduces the activity of the enzyme

non-disjunction
failure to separate of either homologous chromosomes in meiosis I or sister chromatids in meiosis II; it produces gametes which have one chromosome less or more, compared to a normal full set, causing genetic diseases e.g. Down syndrome

nonsense mutation
a type of mutation that results in a STOP codon and premature termination of a polypeptide chain

nucleoid region
the location of the genetic material in a region of a prokaryotic cell

nucleolus
a small, darkly-staining region in the nucleus of a cell

nucleotide
the subunit which makes up nucleic acids, each nucleotide consists of a sugar, phosphate and a nitrogenous (organic) base

nucleus
an organelle in a eukaryotic cell which contains the genetic information necessary for its activity and division. This information is in the form of DNA which forms into chromosomes.

oncogene
a gene which is involved in the regulation of cell division that if changed by mutation; it may cause a cell to divide uncontrollably and cause cancer

organelle
small structures which exist within the cytoplasm of eukaryotic cells; they each have a particular structure and important functions in the cell e.g. nucleus, chloroplast and mitochondrion

organic base
also called a 'nitrogenous' base; part of a nucleotide; DNA has adenine, thymine, cytosine and guanine; RNA has adenine, uracil, cytosine and guanine

organic molecule
substances which are derived from living cells or organisms, generally they are large molecules containing the elements carbon, hydrogen and oxygen

osmoregulation
the control of the balance of solutes and water in the blood, tissue or cytoplasm of a living organism

osmosis
the nett movement of water, through a semi-permeable membrane so as to equalize solute concentrations i.e. from low solute concentration to high

osmotic pressure
the pressure in a cell or tissue due to the movement of water into it by osmosis

over-exploitation
the over use of resources, usually by humans in ways that are clearly not sustainable

Pangaea
the original land mass on planet Earth which has since split into smaller super-continents (e.g. Gondwana) and ultimately continents (e.g. Australia)

passive process
a process by which materials may pass from one region to another, requiring no input of energy e.g. diffusion, osmosis. This includes their passage through a semi-permeable membrane.

peptide bonds
chemical bonds that link amino acids in a polypeptide chain or protein molecule

peptide hormone
a type of hormone consisting of a polypeptide chain

peripheral nervous system
the part of the nervous system that consists of all the nerves connected to the central nervous system (i.e. brain and spinal cord)

peripheral protein
a protein that is only attached to the outside of the cell membrane, and does not extend through to the inside

permeability
the degree to which a membrane allows some materials to move freely through it

phenotype
the appearance of an organism which is determined by its genotype and the effect of the environment

phosphate group
an inorganic ion (PO_4^{3-}) which is an important part of nucleic acids and ATP

phospholipid
organic molecules in which a phosphate group is attached to a lipid molecule

photoreceptor
a type of sensory receptor that is able to detect light as a stimulus

photosynthesis
the process which occurs in the cells of a plant that contain chlorophyll whereby carbon dioxide and water are combined in the presence of light to form glucose and oxygen

phylogenetic tree
a branching diagram showing the evolutionary relationships of a number of different species

phylogenetics
the study of the genetic similarities and evolutionary relationships between different species of organisms

pituitary gland
an endocrine gland which is situated just below the hypothalamus in the brain; often referred to as the endocrine 'master gland'

placental
a mammal in which the young develops within the uterus of the female, is nurtured by a placenta and is born alive

plasmid vector
a small loop of prokaryotic DNA that is used to transfer genes from one species to another

plasmid
a small, circular piece of DNA in bacteria, separate from the main chromosome.

pluripotent
a type of stem cell that is able to divide and produce many different types of cells

point mutation
a type of mutation in which only one base in a gene is changed

polar
the property of molecules that permits them to be soluble in water (hydrophilic) e.g. glucose

polymerase chain reaction (PCR)
the reaction in which millions of copies of the DNA can be made in a short period of time

polypeptide
a long chain of amino acids held together by peptide bonds

polyploidy
the situation (often in plants) where an organism has more than two pairs of homologous chromosomes

population
a group of individuals of the one species, that inhabits the same place at the same time

positive feedback
a mechanism in organisms which enables the response to enhance the stimulus (e.g. breastfeeding)

post-zygotic isolation
a type of reproductive isolation in which a hybrid zygote is successfully formed but then either fails to develop fully, or develops into a sterile adult

pre-capillary sphincter
small circular muscles that can contract and restrict the amount of blood flowing into capillaries in the skin, thereby reducing heat loss

pre-zygotic isolation
a type of reproductive isolation in which organisms of two species never reach the stage of successful mating/fertilsation, and thus no zygote is formed

primary succession
the process by which a simple mix of some species gradually emerges in what was previously a virtually lifeless environment e.g. bare rock

product
the chemical that is produced by a biochemical reaction or a series of biochemical reactions

prokaryotic cell
a type of cell that does not have membrane-bound organelles or very much genetic material. The most common examples are bacteria and blue-green algae.

promoter
a specific base sequence near the start of a gene to which RNA polymerase binds to start transcription

prophase
the first stage of cell division in which the chromosomes become tightly coiled and are visible when viewed with a light microscope

proprioceptor
a type of sensory receptor in the body that is sensitive to movement, pressure or stretching

protein hormone
a type of hormone consisting of chains of amino acids, usually derived from the amino acid tyrosine

protein receptor
a protein which is located in the cell membrane and has a particular shape to which another molecule binds thus causing a message can be sent across the membrane into the cell

proteome
the total set of proteins produced by a cell or organism

protist
the most primitive form of eukaryotic cells and organisms, the most common of these are the protozoa and algae

proto-cell
the first membrane-like structure from which cells are thought to have evolved

protozoa
microscopic non-photosynthetic eukaryotes, usually living in water or moist environments

radiant (light) energy
energy which is visible to the human eye, whether from the sun or some artificial source

reactants
the chemicals which are used in a biochemical reaction to form a product or products

receptor (sensory)
an organ of the body which is able to detect a stimulus and send a message through a sensory neuron to the central nervous system, usually resulting in a response

recessive
a gene (or allele) that may be carried by an organism but is not always expressed in its phenotype

recombinant bacterium
a bacterium which contains DNA or a gene that has been transferred into its DNA from another species

recombinant chromosome
a chromosome consisting of segments of DNA from two different sources e.g. two different species

recombinant DNA
a DNA molecule formed by joining segments of DNA from different species

reflex action
the process by which a stimulus leads to a response automatically and without conscious control or decision

reflex arc
the pathway taken by a nerve impulse to bring about a reflex action

repressor
a protein that 'switches off' genes by making them inaccessible for transcription

reproductive isolation
the situation where members of different populations are unable to interbreed, this is an important step in the process of speciation

reproductively isolated
different populations which are unable to interbreed to produce fertile offspring, although sometimes they can appear to be very similar and live in the same area (see above also)

response
the way that an organism reacts to a particular stimulus

restriction enzyme
an enzyme used to cleave (cut) DNA into different segments. There are over 1,000 known and each one cleaves DNA at a specific 'restriction' site.

ribosomal RNA (rRNA)
RNA that is usually associated with proteins and found in ribosomes

ribosome
an organelle in the cytoplasm which has a vital role in translation

ribozyme
an RNA molecule that can function as an enzyme

RNA
abbreviated name for ribo(se) nucleic acid, there are several types, very important in protein synthesis

RNA polymerase
the enzyme that catalyses the production of mRNA in transcription

RNA splicing
the process in which mRNA bases produced as a result of transcription of introns are removed and the remaining mRNA bases (i.e. transcribed from exons) are joined together

rough endoplasmic reticulum (RER)
an endoplasmic reticulum membrane that has ribosomes attached to it

sclerophyll
species of plants with hardened leaves that contain waxy cuticles to help reduce water loss in hot, dry habitats e.g. species of Eucalyptus

secondary succession
the process by which the mix of species in an ecosystem changes as a result of a natural disaster or a major human activity e.g. bushfire, clearing of vegetation for agriculture

selective pressure
the force of natural selection acting on the population of a species

semi-permeable
the property of the cell membrane which allows some substances to pass in and/or out of the cell whilst not allowing others to do likewise

sensory neuron
a nerve cell which is able to take a message from a receptor to the central nervous system

sensory receptor
a specialised nerve cell that is capable of detecting a stimulus

short tandem repeat (STR)
consists of a unit of two to thirteen nucleotides and repeated hundreds of times in a row on the DNA strand. Their analysis can be very important in DNA profiling.

shunt vessel
a small blood vessel, usually in the skin, that is able to divert blood away from the capillaries and thereby limit heat loss from the skin surface

signal transduction
the cellular mechanism(s) that connects a stimulus to a response

sister chromatids
two identical molecules that are produced as a result of DNA replication. Two chromatids are joined at a centromere as one chromosome before being separated during anaphase.

smooth endoplasmic reticulum (SER)
an endoplasmic reticulum membrane without ribosomes attached to it

solute
a substance that is dissolved in a solvent to form a solution e.g. salt dissolving in water

somatic
normal body cells; in contrast to 'germline' cells that are involved in producing cells for reproduction (i.e. sperm and ova)

somatic cell mutation
a type of mutation which occurs in normal body cells (not sperm or ova); these mutations may sometimes give rise to a cancer

somatic cell
a normal body cell (i.e. not sperm or ovum) , usually 'specialised' and with a diploid number of chromosomes

speciation
the evolutionary process by which new species arise from a common ancestor through natural selection and reproductive isolation

species
a group of organisms that can naturally interbreed with each other to produce fertile offspring; the smallest grouping in the biological classification system

specificity
the unique binding of one molecule to another, e.g. one substrate to one enzyme, or one antibody to one antigen

spinal cord
the part of the central nervous system located inside the backbone containing cell bodies and bundles of nerve fibres; connects the brain to different sensory and motor organs of the body

stem cells
a type of unspecialised cells that is able to divide and produce different types of cells; may be pluripotent or multiipotent

steroid hormone
lipid-based hormones, usually insoluble in water

stimulus
some change in the environment of an organism which is able to be detected by specialised cells called receptors

stimulus-response model
a model to explain how a stimulus is detected by specific receptors that transmit information to effectors which enable a response

stroma
the region inside a chloroplast surrounding the thylakoid membranes (i.e. grana)

stromatolites
a very primitive life form consisting of millions of cyanobacteria which secrete a limy skeleton forming a sedimentary rock; often found in highly saline regions

sub-species
a group of very similar organisms that do not interbreed or only interbreed very occasionally e.g. Australian rosellas

succession
the gradual and orderly process of change in an ecosystem, brought about by changes in biotic and/or abiotic factors

sustainable
whether or not particular practices (usually human) can continue indefinitely without serious consequences; in most cases, present human activities are not sustainable

sweat gland
glands in the skin that are able to produce a dilute watery solution that can then evaporate producing a cooling effect

sympatric speciation
the formation of new species when populations live in the same area and there is no geographic isolation

synapse
the tiny gap between neurons

telophase
the final stage of cell division in which two new nuclei, and subsequently two new cells, are formed

template strand
the coding strand in the DNA helix molecule, it contains the genes that are transcribed into mRNA

temporal isolation
reproductive isolation or low rates of reproduction between individuals as a result of different breeding seasons; may lead to speciation

therapeutic cloning
the technique that uses stem cells to produce specific cell types for medical use

thermoreceptor
a receptor in the hypothalamus of the brain, capable of detecting small changes in temperature

thyroid gland
an endocrine gland located in the neck which produces the hormone thyroxine which stimulates metabolic processes

thyroid stimulating hormone (TSH)
a hormone produced by the pituitary gland that stimulates the thyroid gland to secrete the hormone thyroxine

thyroxine
a hormone which is produced by the thyroid gland and stimulates metabolic processes

tissue
a collection of cells with similar structure and usually a similar function in the body

tolerance limits
limits within which the body is able to function normally for such factors as temperature, pH, blood sugar

transcription factor
a variety of proteins involved in the process of converting, or transcribing, DNA into RNA

transcription
the process which occurs during the first part of protein synthesis in the nucleus of a cell in which DNA makes a 'working copy' of mRNA

transfer RNA (tRNA)
a molecule which carries a specific amino acid into position during the process of translation. They have an anti-codon that binds to the codon on the mRNA molecule.

transgenesis
the process by which genes are taken from DNA of one organism and incorporated into the DNA of another

transgenic organism
an organism which has a transferred gene incorporated into the chromosomes of its cells

translation
the second stage of protein synthesis that occurs at the ribosomes in which the base sequence in mRNA is used to make an amino acid sequence in a polypeptide

translocation
a mutation where a segment of DNA is broken off and becomes incorporated into another chromosome

transmission
communication within the body of messages by nerves, hormones or both working together

tumour suppression gene
a gene that carries information for a cell to produce a protein that stops cell division, thus preventing tumour formation and the onset of cancer

urea
a waste product, containing nitrogen, that is produced in the liver as a result of the metabolic breakdown of proteins

vacuole/vesicle
a membrane-bound structure within the cytoplasm, usually involved in the storage of substances in solution and/or the transport of materials in and out of the cell

variable factor
an aspect of an organism's environment that may affect its changes of survival

vasoconstriction
the constriction of arteries, arterioles and pre-capillary sphincters as a result of the contraction of muscles in their walls which will restrict the flow of blood through capillaries, especially in regions near the skin

vasodilation
the opening or expansion of arteries, arterioles and pre-capillary sphincters as a result of the relaxation of the muscles in the walls which will increase the flow of blood through capillaries, especially near the skin

viral vector
a virus that is used to transfer genes from one species to another

X-ray diffraction
a process in which X-rays are scattered by crystalline structures (e.g. DNA)

zygote
a cell which is formed as a result of the fertilisation of a male and female gamete e.g. sperm and ovum (egg)

Practical Terms

Accurate data
The closer data is to the real value, the more accurate it is. Data from an investigation that was repeated is more accurate because the effect of systematic errors can be minimised.

Analysis
Inspection of the data collected by an investigation to determine if there is a pattern, trend or relationship between changes to the independent variable and measurements of the dependent variable.

Axes headings
The 'x' axis on a hand-drawn graph is labelled with the independent variable and the symbols of the SI unit of measurement e.g. mass (kg). The 'y' axis is labelled with the dependent variable and the symbols of the SI unit of measurement as well.

Collaborative work
Work done, together with other students.

Column heading
The data in a results table is presented in columns that have a heading that includes the quantity the data in the column refers to and the symbols of the SI unit of measurement.

Conclusion
Evidence and biological understanding is used to state whether data supports or refutes the hypothesis and there is detailed justification for this. The limitations of the conclusion include the extent to which it is based on data that is not completely valid e.g. reliable but not accurate.

Controlled factor (variable)
A factor held constant during an investigation.

Deconstruction
The problem is broken down and discussed in order to find the best procedure to find a solution for it.

Dependent variable
The variable that may change as the independent variable is changed and can be measured.

Ethical and safety considerations
How the investigation will be conducted that ensure it is the 'right' thing to do (ethical) and how the procedure ensures it minimises risk of harm (safety).

Evaluation
Discussion of the procedure that includes sources of uncertainty and the effect of them on the results.

Factor held constant
A variable kept constant; often also called a 'controlled' variable.

Factor not controlled
A variable that could not be kept constant.

Fair test
An investigation in which only the effect of the independent variable on the dependent variable is measured. All other factors are deliberately held constant.

Hand-drawn graph
A graph of the data drawn by hand on a piece of graph paper. The independent variable is shown on the 'x' axis and the dependent variable on the 'y' axis.

Hypothesis
States what is expected to happen to the dependent variable as the independent variable is increased or decreased.

Independent variable
The variable that is deliberately changed during an investigation.

Individual work
Work done by students during an investigation, without the assistance of other students.

Introduction
Biological theory relevant to the investigation is outlined and the purpose of the investigation is stated.

Line of best fit
A straight line or curve that is drawn as close as possible to data that has been plotted on a graph.

Materials
All the scientific equipment and materials that are needed to conduct the investigation.

Pattern (or Trend)
This occurs if a continuous change in the independent variable causes a continuos change in the dependent variable.

Precision
How close pieces of data are in a set of data. The smaller the scale of a measuring device, the greater the precision of the data it is able to collect.

Problem
A question that links the independent and dependent variables; also called an Inquiry Question (IQ).

Procedure
The method that is used to carry out the investigation.

Processed data
The product of processing raw data in some way e.g. calculating an average; also called 'secondary' data.

Purpose
The aim of the investigation.

Random error
An error caused by a factor that randomly affects measurement. The effect of random errors on data are minimised by replicating the measurements to increase the sample size.

Raw data
Data collected in an investigation that has not been processed in any way; also called 'primary' data.

Reliable data
Data obtained from an investigation in which measurements were replicated.

Repetition
The entire investigation is repeated using an alternative set of materials to gather another set of data to use to detect the effect of systematic errors on measurements.

Replication
The effect of the independent variable on the dependent variable is measured more than once before the independent variable is changed e.g. the time taken to dissolve sugar is measured three times at 20°C before the temperature is changed to 30°C to determine the dissolving time at that temperature.

Results
Data collected by an investigation; often in the form of measurements that are displayed using a table and/or a graph.

Sample size
The number of measurements taken of the dependent variable.

Scatter in the graph
A measure of how far points on a graph are above and below a line of best fit, probably due to the effect of random errors. The more scatter, the less reliable the data.

Significant figures
The number of single digits in a measurement e.g. 6.23m has three significant figures while 19.82°C has four significant figures.

SI units and symbols
SI (System of International) units are a collection of internationally agreed units of measurement. These include kilogram, metre and second. Each SI unit is represented by a specific symbol e.g. kg for kilogram, m for metre and s for second.

Source of uncertainty
Any aspect of the investigation that contribute to errors of measurement e.g sources of random and systematic errors, and factors that affect the effective control of variables.

Systematic error
An error caused by a measuring instrument being faulty or incorrectly calibrated. The effect of systematic errors on data are minimised by repeating the investigation.

Table
The data collected is displayed in columns, each one of which have a column heading. The independent variable is listed by the left-most column heading and the dependent variable by the right-most column heading.

Uncontrolled factor (variable)
A variable that can not be kept constant in an experiment.

Valid data
Data that is obtained from a fair test of a hypothesis that is reliable and accurate.

Validity
The degree to which an investigation measures what it is designed to measure.

Variable
something that can change, or be changed, in an experiment (e.g. temperature)

Index

R

S

T

U

V

W

X

Z