* CAPE OTWAY LIGHTHOUSE AND 'STAR TRAILS', CAPE OTWAY, VICTORIA, AUSTRALIA. WHEN THE SHUTTER OF A CAMERA IS LEFT OPEN FOR MANY HOURS, THE STARS APPEAR AS CURVED LINES DUE TO THE ROTATION OF THE EARTH ON ITS AXIS.

OXFORD SCIENCE 10

HELEN SILVESTER

VICTORIAN
CURRICULUM

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VICTORIAN CURRICULUM

HELEN SILVESTER

OXFORD UNIVERSITY PRESS
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SCIENCE 10

1 Genetics

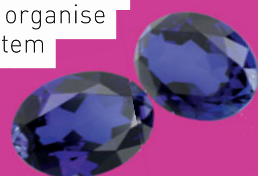
Heritable characteristics are transmitted from one generation to the next in a process that involves genes and DNA.

2 Evolution

The theory of evolution by natural selection explains the diversity of living things on Earth and is supported by a range of scientific evidence. This theory has developed over time.

3 The periodic table

The periodic table is used to classify and organise elements. The atomic structure and properties of elements are used to organise them in the periodic table. This system can be used to make predictions about the properties of elements.



4 Chemical reactions

Different types of chemical reactions are used to produce a range of products and can occur at different rates. Different factors influence the rate of reactions.

5 Global systems

There are interactions and cycles within and between Earth's spheres. Global systems, including the carbon cycle, rely on these interactions involving the biosphere, lithosphere, hydrosphere and atmosphere.

6 The universe

The universe contains features including galaxies, stars and solar systems. The Big Bang theory can be used to explain the origin of the universe. This theory is supported by scientific evidence and has developed over time.

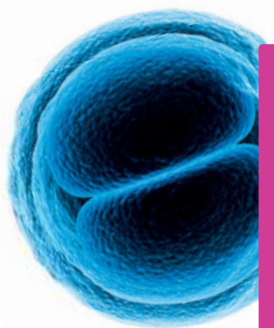
7 Motion

The relationships between force, mass and acceleration can be used to predict changes in the motion of objects.

8 Energy

Energy conservation in a system can be explained by describing energy transfers and transformations.

CONTENTS



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Oxford Science is a series developed to meet the requirements of the Victorian Curriculum: Science across Years 7 to 10. Taking a concept development approach, each double-page spread of Oxford Science represents **one concept** and **one lesson**.

What if?

Student-directed inquiry is encouraged throughout this series using a simple questioning technique. As the series progresses, students discover that their own *What if* questions are actually testable '*if and then*' hypotheses. For example, 'What if *the bubble is touched with a finger*' becomes 'If *the bubble is touched with a finger*, then *it will pop*'.

Concept development

Students are given access to the chapter concepts at the start of every chapter. Each double-page spread of this series represents **one concept**. Students explore concepts one-by-one, encouraging incremental learning and, by the end of the chapter, complete understanding.

Every spread is linked to one or more experiment, challenge or skills task as a practical application of the concept.

The unit heading introduces the concept.

Each unit begins with a short summary of the concept.

Body text elaborates on the concept in clear and accessible language.

Diagrams and photos are used to illustrate the concept and engage students.

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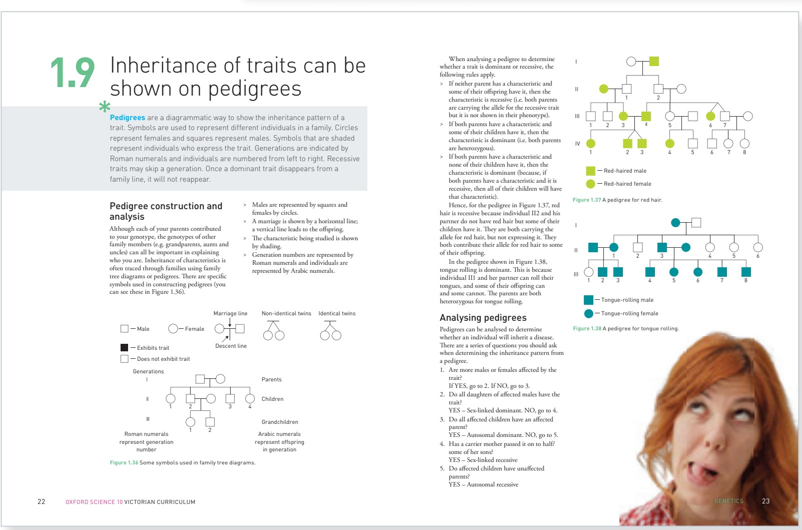

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Oxford Science has been engineered to be accessible to all science students. We believe that science students are served best when they are free to focus on learning the knowledge and skills of science in simple accessible language, crafted into short sentences. Students will be engaged by the inclusion of stunning photography throughout.

Science as a human endeavour

Concepts are linked to real-world applications in the highly engaging **Science as a human endeavour** spreads. The **Extend your understanding** questions on these spreads are designed to be used flexibly as either homework tasks or an extended project.

Experiments

Uniquely, experiments are organised at the end of the book in an extended experiments chapter, rather than being confined to each double-page spread. There is a link on most double-page spreads to an experiment, challenge or inquiry task to ensure that practical activities remain aligned to the content.

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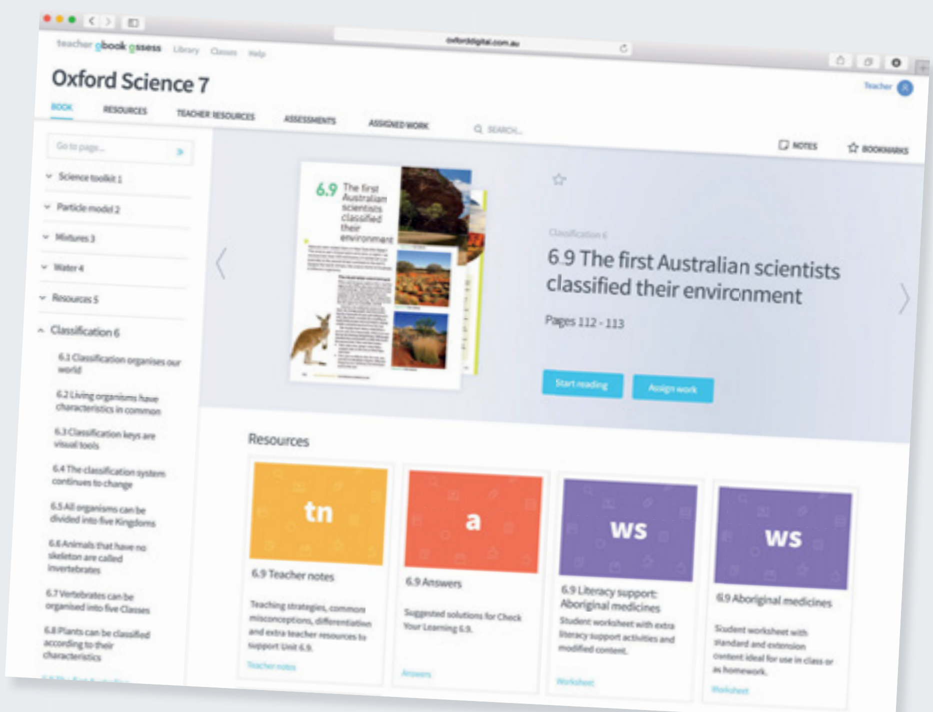
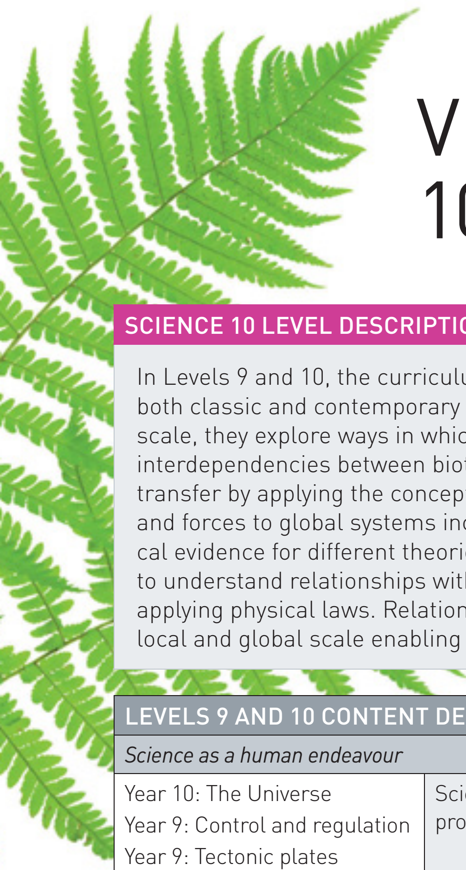
obook assess provides an interactive electronic version of the student book in an easy-to-read format. It features multimedia links, interactive learning objects, videos, note-taking, highlighting and bookmarking tools, and live question blocks. **obook** is compatible with laptops, iPads, tablets and IWBs, and also offers page view (in flipbook format) that can be used offline. **assess** provides 24/7 online assessment designed to support student progression and understanding.



DASHBOARD

Oxford Science is supported by teaching strategies, lesson ideas, planning tips, assessment advice and answers to all activities. **obook assess** allows teachers to manage their classes by assigning work, tracking progress and planning assessment. Teacher Dashboard is your online lesson control centre, which allows you to instantly preview or assign related teacher resources to deliver incredibly engaging digital learning experiences. Students can also toggle from their **obook** to the Dashboard to interact with student resources for each topic.



Victorian Curriculum: Science 10 scope and sequence

SCIENCE 10 LEVEL DESCRIPTION (ABBREVIATED)

In Levels 9 and 10, the curriculum focus is on explaining phenomena involving science and its applications. Students consider both classic and contemporary science contexts to explain the operation of systems at a range of scales. At a microscopic scale, they explore ways in which the human body as a system responds to its external environment, and investigate the interdependencies between biotic and abiotic components of ecosystems. They develop a more sophisticated view of energy transfer by applying the concept of the conservation of matter in a variety of contexts. They apply their understanding of energy and forces to global systems include continental movement. Students explore the biological, chemical, geological and physical evidence for different theories, including the theories of natural selection and the Big Bang theory. Atomic theory is used to understand relationships within the periodic table of elements. Students understand that motion and forces are related by applying physical laws. Relationships between aspects of the living, physical and chemical world are applied to systems on a local and global scale enabling students to predict how changes will affect equilibrium within these systems.

LEVELS 9 AND 10 CONTENT DESCRIPTIONS	
Science as a human endeavour	
Year 10: The Universe Year 9: Control and regulation Year 9: Tectonic plates Year 9: Matter	Scientific understanding, including models and theories, are contestable and are refined over time through a process of review by the scientific community (VCSSU114)
Year 10: Genetics Year 10: The Universe Year 10: Global systems Year 9: Control and regulation Year 9: Tectonic plates Year 9: Electromagnetism	Advances in scientific understanding often rely on developments in technology and technological advances are often linked to scientific discoveries (VCSSU115)
Year 10: Genetics Year 10: Global systems Year 9: Science toolkit Year 9: Chemical reactions	The values and needs of contemporary society can influence the focus of scientific research (VCSSU116)
Biological sciences	
Year 9: Control and regulation	Multicellular organisms rely on coordinated and interdependent internal systems to respond to changes to their environment (VCSSU117)
Year 9: Control and regulation	An animal's response to a stimulus is coordinated by its central nervous system (brain and spinal cord); neurons transmit electrical impulses and are connected by synapses (VCSSU118)
Year 10: Genetics	The transmission of heritable characteristics from one generation to the next involves DNA and genes (VCSSU119)
Year 10: Evolution	The theory of evolution by natural selection explains the diversity of living things and is supported by a range of scientific evidence (VCSSU120)
Year 9: Ecosystems	Ecosystems consist of communities of interdependent organisms and abiotic components of the environment; matter and energy flow through these systems (VCSSU121)
Chemical sciences	
Year 9: Matter	All matter is made of atoms which are composed of protons, neutrons and electrons; natural radioactivity arises from the decay of nuclei in atoms (VCSSU122)
Year 10: Periodic table	The atomic structure and properties of elements are used to organise them in the periodic table (VCSSU123)
Year 9: Chemical reactions	Chemical reactions involve rearranging atoms to form new substances; during a chemical reaction mass is not created or destroyed (VCSSU124)
Year 10: Chemical reactions Year 9: Chemical reactions	Different types of chemical reactions are used to produce a range of products and can occur at different rates; chemical reactions may be represented by balanced chemical equations (VCSSU125)

LEVELS 9 AND 10 CONTENT DESCRIPTIONS	
Year 10: Chemical reactions Year 9: Chemical reactions	Chemical reactions, including combustion and the reactions of acids, are important in both non-living and living systems and involve energy transfer (VCSSU126)
Earth and space sciences	
Year 9: Tectonic plates	The theory of plate tectonics explains global patterns of geological activity and continental movement (VCSSU127)
Year 10: Global systems	Global systems, including the carbon cycle, rely on interactions involving the atmosphere, biosphere, hydrosphere and lithosphere (VCSSU128)
Year 10: The Universe	The Universe contains features including galaxies, stars and solar systems; the Big Bang theory can be used to explain the origin of the Universe (VCSSU129)
Physical sciences	
Year 9: Electricity	Electric circuits can be designed for diverse purposes using different components; the operation of circuits can be explained by the concepts of voltage and current (VCSSU130)
Year 9: Electromagnetism	The interaction of magnets can be explained by a field model; magnets are used in the generation of electricity and the operation of motors (VCSSU131)
Year 10: Energy	Energy flow in Earth's atmosphere can be explained by the processes of heat transfer (VCSSU132)
Year 10: Motion	The description and explanation of the motion of objects involves the interaction of forces and the exchange of energy and can be described and predicted using the laws of physics (VCSSU133)
SCIENCE INQUIRY SKILLS	
Questioning and predicting	
Year 10: Experiments Year 9	Formulate questions or hypotheses that can be investigated scientifically, including identification of independent, dependent and controlled variables (VCSIS134)
Planning and conducting	
Year 10: Experiments Year 9	Independently plan, select and use appropriate investigation types, including fieldwork and laboratory experimentation, to collect reliable data, assess risk and address ethical issues associated with these investigation types (VCSIS135)
Year 10: Experiments Year 9	Select and use appropriate equipment and technologies to systematically collect and record accurate and reliable data, and use repeat trials to improve accuracy, precision and reliability (VCSIS136)
Recording and processing	
Year 10: Experiments Year 9	Construct and use a range of representations, including graphs, keys, models and formulas, to record and summarise data from students' own investigations and secondary sources, to represent qualitative and quantitative patterns or relationships, and distinguish between discrete and continuous data (VCSIS137)
Analysing and evaluating	
Year 10: Experiments Year 9	Analyse patterns and trends in data, including describing relationships between variables, identifying inconsistencies in data and sources of uncertainty, and drawing conclusions that are consistent with evidence (VCSIS138)
Year 10: Experiments Year 9	Use knowledge of scientific concepts to evaluate investigation conclusions, including assessing the approaches used to solve problems, critically analysing the validity of information obtained from primary and secondary sources, suggesting possible alternative explanations and describing specific ways to improve the quality of data (VCSIS139)
Communicating	
All chapters	Communicate scientific ideas and information for a particular purpose, including constructing evidence-based arguments and using appropriate scientific language, conventions and representations (VCSIS140)

YEAR 10 ACHIEVEMENT STANDARD

By the end of Year 10, students analyse how the periodic table organises elements and use it to make predictions about the properties of elements. They explain how chemical reactions are used to produce particular products and how different factors influence the rate of reactions. They explain the concept of energy conservation and represent energy transfer and transformation within systems. They apply relationships between force, mass and acceleration to predict changes in the motion of objects. Students describe and analyse interactions and cycles within and between Earth's spheres. They evaluate the evidence for scientific theories that explain the origin of the universe and the diversity of life on Earth. They explain the processes that underpin heredity and evolution. Students analyse how the models and theories they use have developed over time and discuss the factors that prompted their review. Students develop questions and hypotheses and independently design and improve appropriate methods of investigation, including field work and laboratory experimentation. They explain how they have considered reliability, safety, fairness and ethical actions in their methods and identify where digital technologies can be used to enhance the quality of data. When analysing data, selecting evidence and developing and justifying conclusions, they identify alternative explanations for findings and explain any sources of uncertainty. Students evaluate the validity and reliability of claims made in secondary sources with reference to currently held scientific views, the quality of the methodology and the evidence cited. They construct evidence-based arguments and select appropriate representations and text types to communicate science ideas for specific purposes.

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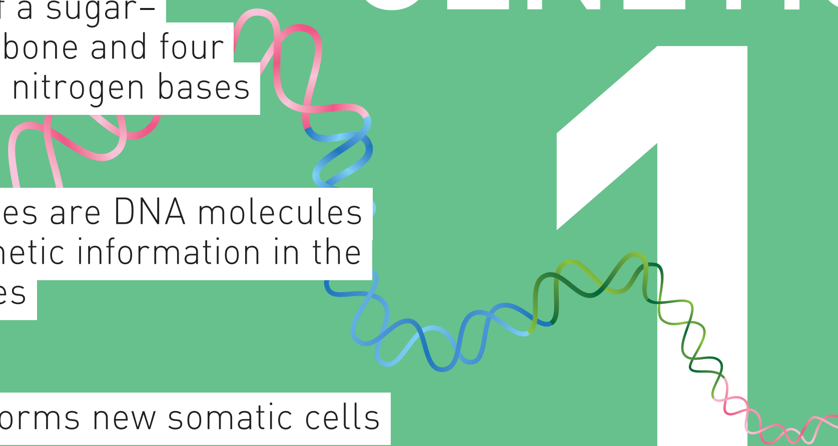
1.1 Scientists review the research of other scientists

1.2 DNA consists of a sugar–phosphate backbone and four complementary nitrogen bases



GENETICS 1

1.3 Chromosomes are DNA molecules carrying genetic information in the form of genes

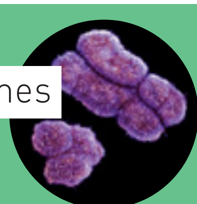
1.4 Mitosis forms new somatic cells

1.5 Meiosis forms gamete cells

1.6 Alleles can produce dominant or recessive traits

1.7 Alleles for blood group traits co-dominate

1.8 Alleles on the sex chromosomes produce sex-linked traits



1.9 Inheritance of traits can be shown on pedigrees

1.10 Mutations are changes in the DNA sequence

1.11 Genes can be tested

1.12 Genes can be manipulated

1.13 Genetic engineering is used in medicine

What if?

What you need:

coin (or plastic counter with 'Heads' written on one side and 'Tails' on the other)

What to do:

1 Toss the coin (or counter) five times and record the results in a table.
2 Predict how many heads or tails will land for the next five tosses.

What if?

» What if heads represented the chance of having a daughter and tails represented the chance of having a son? (Would this change the outcome?)
» What if heads represented the chance of having red hair and tails represented the chance of having black hair?
» What if you had a coin with two heads (for red hair)?

//SCIENCE AS A HUMAN ENDEAVOUR//

1.1 Scientists review the research of other scientists

Scientific understanding is constantly being reviewed, challenged and refined. Sometimes scientists collaborate and sometimes scientific teams 'compete' to make discoveries first. The scientific understanding of genes and DNA is no exception. Gregor Mendel is now known as the 'father of genetics'. He made his discoveries by studying peas. James Watson and Francis Crick used other people's research to develop the double helix model of DNA. Rosalind Franklin was mistaken for a laboratory assistant by a fellow researcher and her research on DNA was shown to competing scientists without her permission.

Figure 1.1 Gregor Johann Mendel, 1822–1884, is known as the father of genetics.

Gregor Mendel

Gregor Mendel was an Austrian monk and scientist who lived in Brno, which is in the modern Czech Republic (Figure 1.1). He was the first person to make accurate conclusions about how genes work. Mendel taught maths, but he loved experimenting with peas – and he did many experiments in his garden. In the mid-1800s, Mendel accurately concluded that genes exist in pairs (one from each parent) and that they can separate and form pairs again in the next generation. Mendel did not use the word 'gene'. Rather, he used the word 'factor' and said that a factor is something in the cell that controls a characteristic.

Before this, it was thought children inherited a group of characteristics 'mixed together' from both their parents, resulting in a mixing pot of looks, in the same way that red paint and yellow paint produces orange paint. Therefore, you can never separate the pure red or yellow forms again.

Mendel's research on pea plants led him to develop two important principles that form the basics of genetics today: the principle of segregation and the principle of independent assortment.

The importance of Mendel's work was not recognised until several decades after his death.

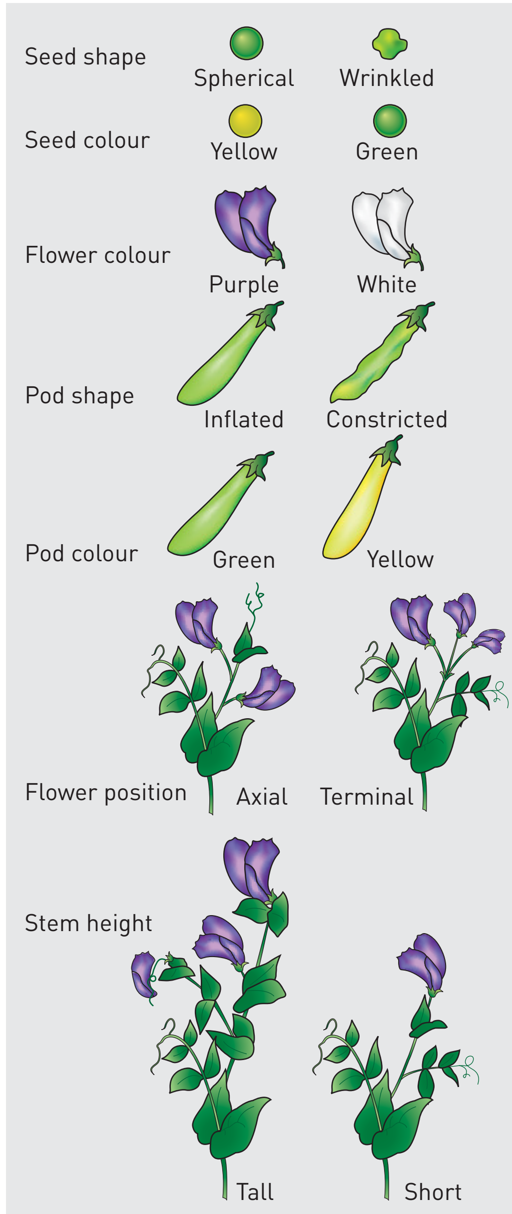


Figure 1.2 The seven traits, or characteristics, of pea plants studied by Mendel.

It wasn't until his experiments were repeated in 1900 that he received credit for his discoveries. All our current knowledge and understanding of genetics began and developed from Mendel's work. Mendel is considered the 'father of genetics'.

EXPERIMENT 1.1: EXTRACTING DNA
GO TO PAGE 192

Principle of segregation

Traits or characteristics of living things exist in pairs of factors. These factors must become separated or segregated before they can be passed on to offspring. Every organism inherits one set of factors from their mother and one set from their father.

Principle of independent assortment

The inheritance of one set of factors from one parent is independent from the inheritance of other factors. So, just because you inherit one factor (for example, blue eyes) from your mother, that does not mean you inherit all other factors from her (for example, her blonde hair and small nose). Factors are inherited independently from each other.

Watson and Crick's double helix discovery

Almost 70 years after Mendel's death, James Watson, a young chemist from the United States, went to the University of Cambridge, in the United Kingdom. There he met Francis Crick, an English physicist (Figure 1.3). They worked as a team to unravel the secret of the structure of **DNA (deoxyribonucleic acid)**, which they identified as a double helix (two-stranded spiral) in 1953. However, they performed no experiments themselves; their talent lay in interpreting the experimental results of others. Many scientists contributed to Watson and Crick's research on DNA, including Linus Pauling, Erwin Chargaff and Rosalind Franklin.

Rosalind Franklin

Rosalind Franklin had wanted to study science since the age of 15. With the reluctant acceptance of her father, Franklin eventually earned her doctorate in physical chemistry at the University of Cambridge in 1945 (Figure 1.4).

In 1951, she began work in John Randall's laboratory at King's College in London. When Franklin started work in Randall's laboratory, Maurice Wilkins (another scientist working on DNA) was away. When Randall gave Franklin responsibility for her part of the DNA project, no one had worked on it for months. When Wilkins returned, he misunderstood her role, treating her as though she were a technical assistant. Both scientists were actually peers. His mistake was not surprising given the situation for women at the university at the time. Only males were allowed in the university dining rooms, and after hours Franklin's colleagues went to men-only pubs.

Between 1951 and 1953, Franklin came very close to solving the DNA structure. She was beaten to publication by Crick and Watson in part because of the friction between Wilkins and herself. At one point, Wilkins showed Watson one of Franklin's crystallographic images of DNA (Figure 1.5). When Watson saw the picture, the solution became clear to him, and the results were published in the journal *Nature* almost immediately. Franklin's work appeared as a supporting article in the same issue of the journal.

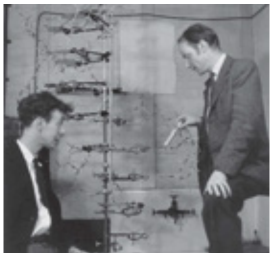


Figure 1.3 James Watson and Francis Crick with their DNA model. They interpreted other scientists' research.

Figure 1.4 Rosalind Franklin, 1920–1958. Her contribution to solving the structure of DNA was not acknowledged at the time.

Figure 1.5 X-ray crystallography image of DNA taken by Rosalind Franklin.

Extend your understanding 1.1

1. According to Mendel, how many factors for a characteristic are present in the cells of each organism? Where do these factors come from?
2. Why did Mendel have such an influence on genetics?
3. Search the Internet to research the work of either Linus Pauling or Erwin Chargaff and explain their contribution to Watson and Crick's work.
4. Rosalind Franklin died from cancer at the age of 37. Watson and Crick received a Nobel Prize in 1962 for their work on the structure of DNA. The Nobel Prize cannot be awarded posthumously (after death). If Franklin had been alive, should she have been awarded the Nobel Prize with Watson and Crick? Provide arguments to support your answer.
5. Wilkins showed Franklin's results to Watson and Crick without her knowledge. If she had been given a choice, should she have shared her results with other scientists? Should all scientists share their results with each other? Provide reasons why or why not.

1.2 DNA consists of a sugar–phosphate backbone and four complementary nitrogen bases

Genes are made of a chemical called deoxyribonucleic acid (DNA). DNA is the genetic material that is passed from one generation to another. It is found in the nucleus of almost every cell in your body. The DNA molecule consists of two long, thin strands of complementary nucleotides that are held together by hydrogen bonds. The double-helix shape of DNA is often compared to a twisted ladder.

Your DNA blueprint

DNA is like a blueprint for every structure and function in an organism. It contains a code unique to the individual that can be passed to offspring, generation after generation, with little or no change. Each cell (except red blood cells) within a single organism contains DNA molecules with the same general structure. Each species has its own unique DNA that defines the species. However, individuals within a species have fine variations in the structure of their DNA and therefore in the code that it carries. An understanding of the structure of DNA enables us to explain the similarities and differences that exist between and within species.

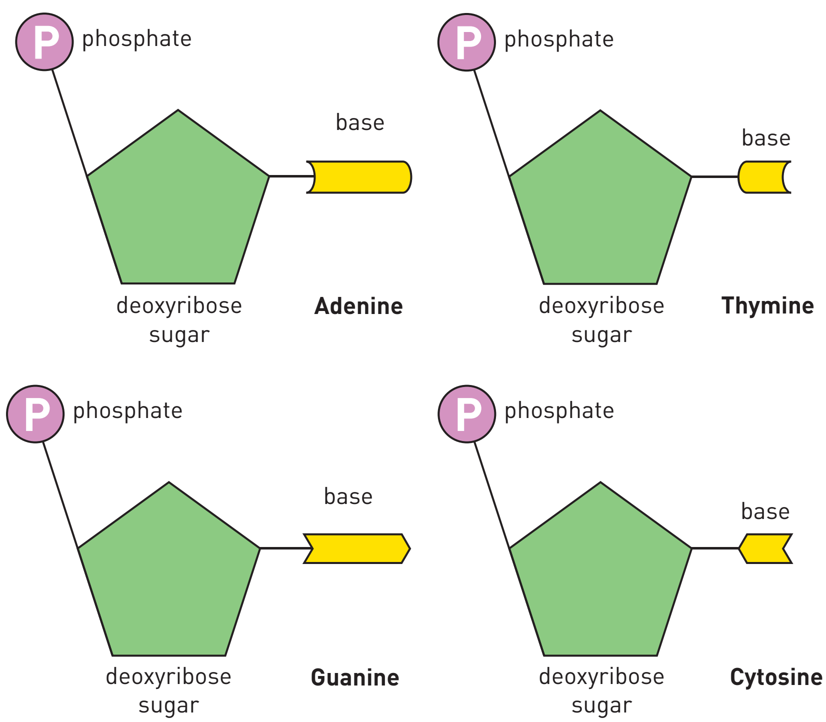


Figure 1.6 Nucleotides: the building blocks or subunits of DNA.

Structure of a nucleotide

Each DNA strand is like a necklace of beads. The individual 'beads' are called **nucleotides**. These are the subunits or building blocks of DNA (Figure 1.6).

A nucleotide is a complex molecule composed of three smaller molecules:

> a nitrogen base (sometimes just called a 'base')
> a sugar molecule (deoxyribose)
> a phosphate molecule.

In DNA there are four different types of nitrogen bases: **adenine** (A), **guanine** (G), **cytosine** (C) and **thymine** (T).

Structure of a polynucleotide chain

When nucleotides join together, they form a long polynucleotide chain called a nucleic acid. DNA is a nucleic acid.

CHALLENGE 1.2: MODELLING THE STRUCTURE OF DNA
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Nucleotides are joined together by their sugar and phosphate groups. The sugar of one nucleotide is joined to the phosphate of the next nucleotide. This forms a sugar–phosphate backbone like the sides in a ladder (Figure 1.7).

Double helix

Two polynucleotide chains, or strands, are attached together by **hydrogen bonds** (relatively weak bonds) between the nitrogen bases. A large base (adenine or guanine) is always bonded to a small base (thymine or cytosine) because this gives the correct amount of space between the strands.

The four different types of nitrogen bases link in a specific way: adenine (A) always pairs with thymine (T) and cytosine (C) always pairs with guanine (G). These base pairs are called **complementary bases** or complementary base pairs. The two polynucleotides then wind into a double helix – the twisted ladder (Figure 1.8).

DNA molecules have two vital properties.

> DNA can make copies of itself: If two strands unwind, each strand can be used to make a new DNA molecule.

> DNA can carry information: The order of bases along a strand is a code for making proteins.

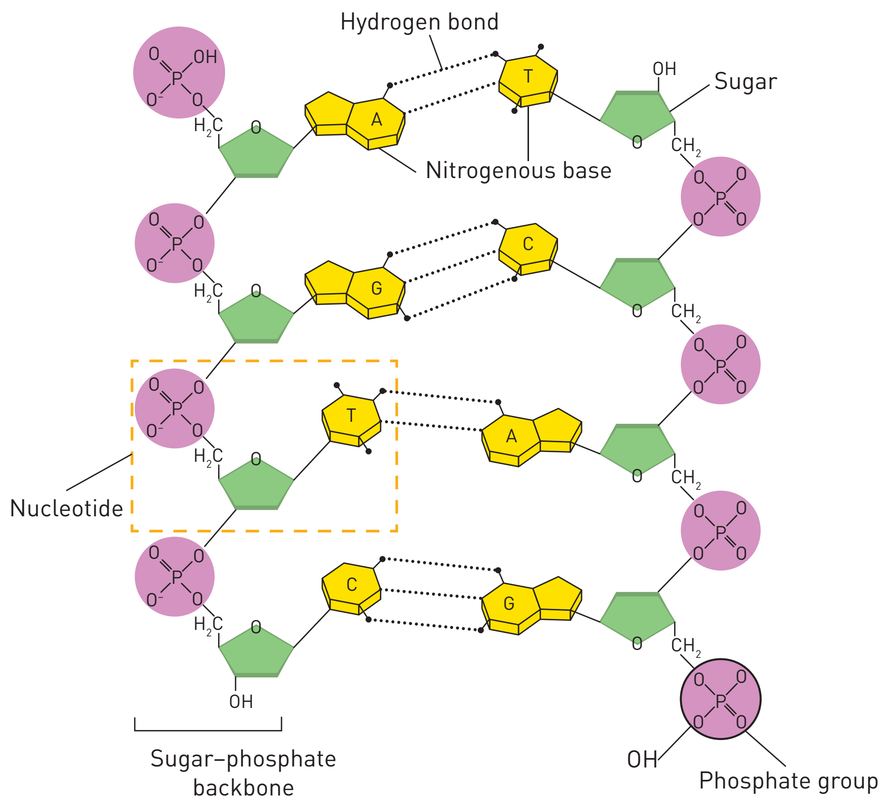

Figure 1.7 Nucleic acids such as DNA are made of a chain of nucleotides joined together through a sugar–phosphate backbone.

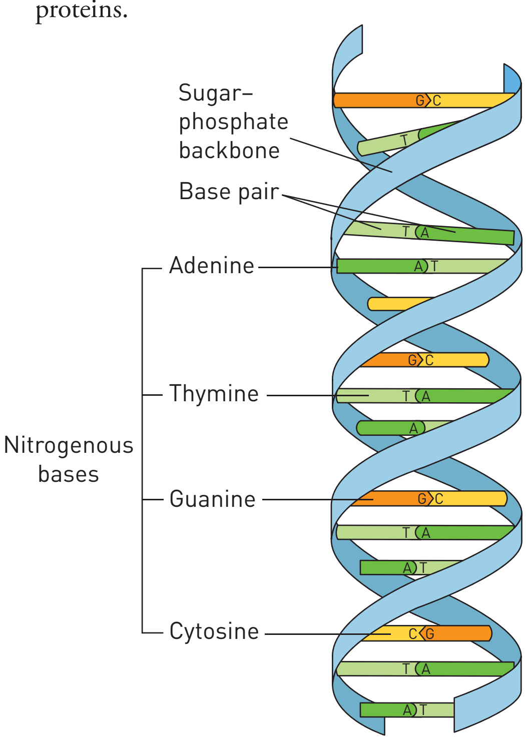

Figure 1.8 The DNA double helix. If you picture the DNA molecule as a twisted ladder, the sides are sugar and phosphate molecules and the rungs are pairs of nitrogen bases.

Check your learning 1.2

Remember and understand

1 What is a nucleotide?
2 Explain how nucleotides join together to form polynucleotides.

Apply and analyse

3 Explain how two polynucleotides can twist helically around each other to form a double helix of DNA.
4 What part of the DNA molecule varies? What part remains constant?
5 How does the order of the bases on one polynucleotide chain determine the order of the bases on the other chain?
6 What is the complementary DNA sequence of GTTAGCCAGT?

1.3 Chromosomes are DNA molecules carrying genetic information in the form of genes

Each cell in your body (except red blood cells) contains 46 chromosomes. These chromosomes are made up of DNA molecules tightly wound around proteins. Along the DNA strand are the sections called genes. When a protein needs to be made, the DNA in the gene unwinds to make a complementary copy of **ribonucleic acid (RNA)**. The RNA can leave the nucleus to make a protein in the cell's cytoplasm.

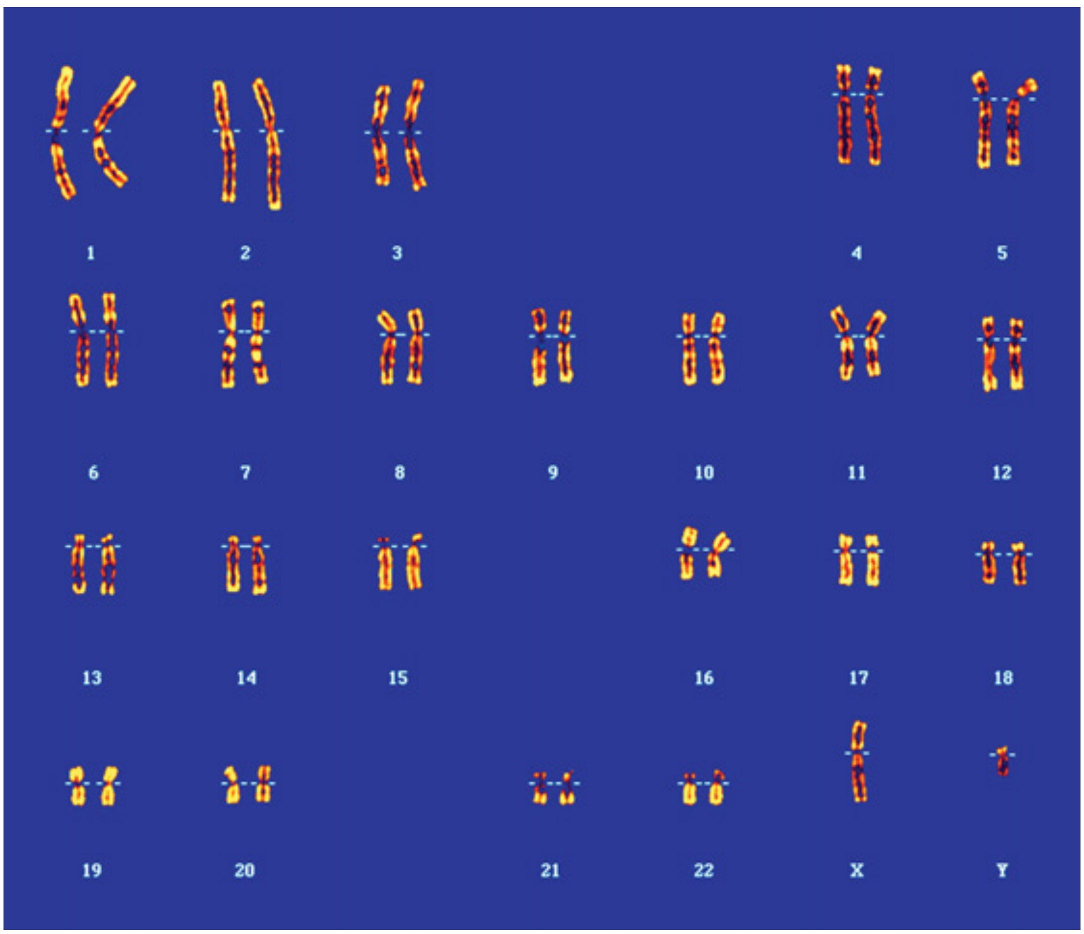

Figure 1.9 Pairs of chromosomes are often referred to by numbers according to their size – the largest pair is number 1. The last two chromosomes determine the sex of an individual. Human females have two X chromosomes and males have one X and one Y chromosome. This karyotype is from a male (XY).

SKILLS LAB 1.3: MAKING PROTEIN
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Relationship between DNA, chromosomes and genes

Inside the nucleus of a cell are the chromosomes. There are 46 chromosomes in a human nucleus: 23 of them come from the mother and 23 come from the father. Along the length of each chromosome, in specific positions, are the genes.

Chromosomes can be organised into pairs according to length and banding patterns. Pairs of matching chromosomes are called homologous. A picture of all the homologous chromosomes in a cell, arranged from largest to smallest, is called a **karyotype** (Figure 1.9).

How we relate chromosomes to DNA

DNA is found inside a cell's nucleus, looking a little like a pile of wool. By the time a cell is ready to divide, the DNA has copied itself and the chromosomes can clearly be seen under a microscope.

A simple equation to understand the relationship between DNA and chromosomes is:

A single chromosome = a molecule of DNA (a DNA helix)

Chromosomes may be single or bivalent. The **bivalent chromosome** is the 'X' that you are familiar with. The two strands of a bivalent chromosome are identical to each other. Bivalent chromosomes are formed during DNA replication so that two identical copies are produced. Each strand of a bivalent chromosome is called a **chromatid**. The two chromatids are joined at the centromere (Figure 1.11).

If the DNA in a single chromosome were unwound, it would be 5 cm long. With 46 chromosomes in the average human cell, this means all the unravelled DNA in a single cell would be approximately 2 m long! The DNA fits inside the cell because the DNA molecules are tightly wound around small proteins called histones. These histones stack tightly together and only unwind when the instructions they carry are needed by the cell.

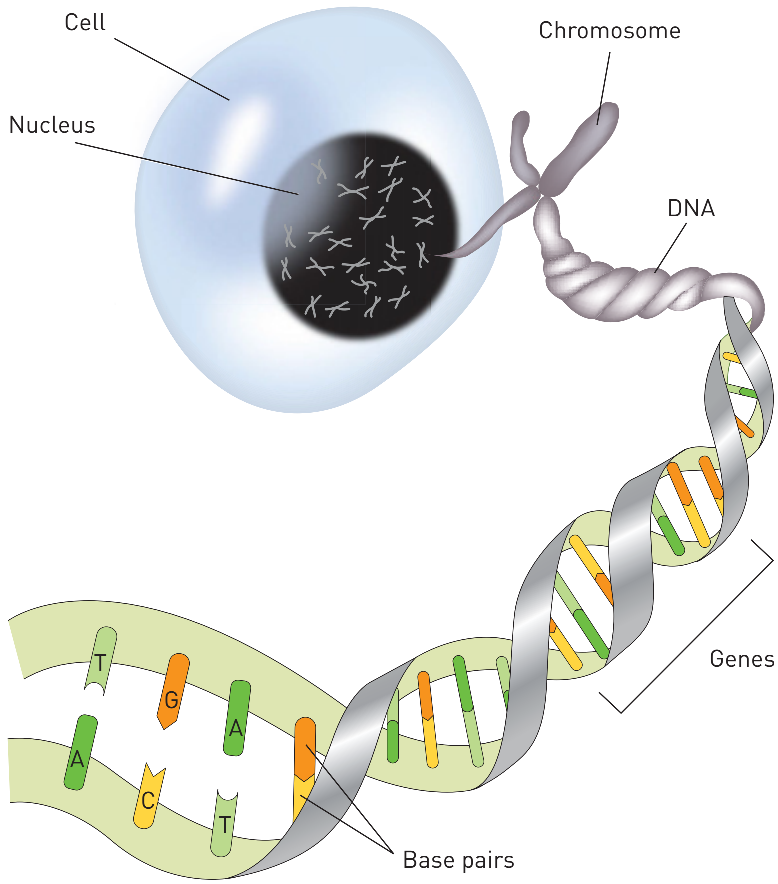


Figure 1.10 The relationship between DNA and chromosomes.

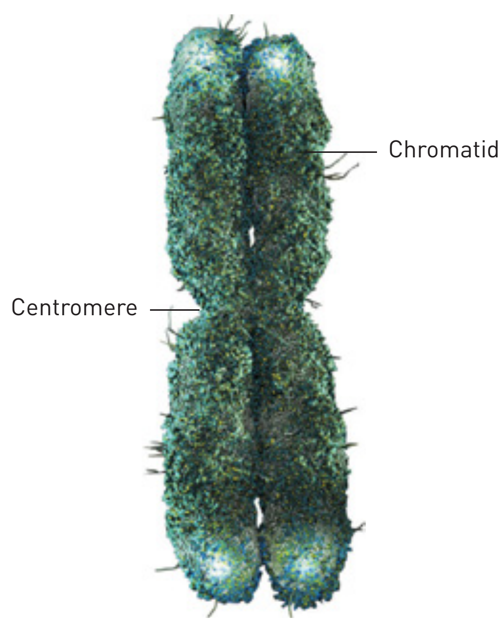


Figure 1.11 A bivalent chromosome is made up of two sister chromatids joined at the centromere.

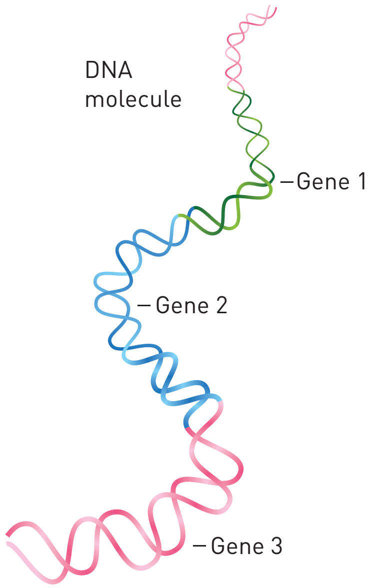


Figure 1.12 The relationship between DNA and genes.

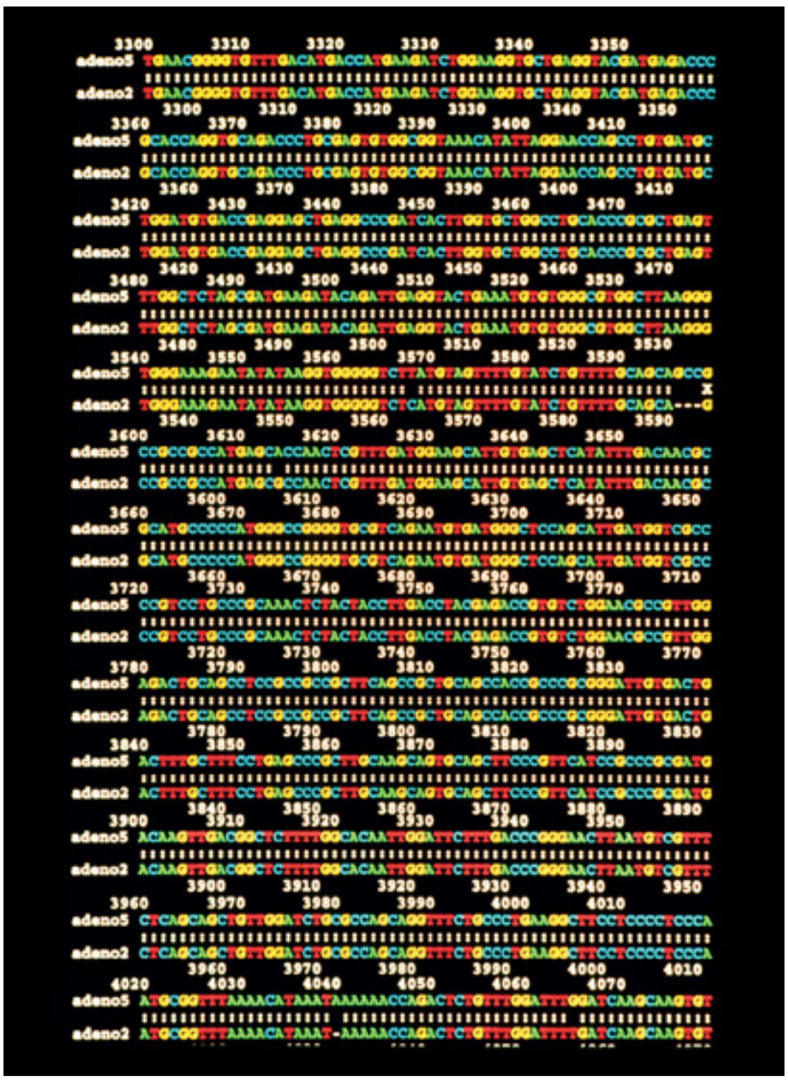


Figure 1.13 The sequence of bases on DNA is the coding system for life. The sequence of bases here comes from the DNA in adenovirus types 5 and 2. These viruses cause a range of illnesses including colds, sore throats and diarrhoea.

How we relate genes to DNA

DNA in chromosomes consists of sections that are genes (Figure 1.12). The order of nitrogen bases in each gene contains information for one characteristic or trait. For example, a gene may have information for making the pigment melanin, which gives our skin colour. Another gene may have the information for making keratin for hair and nails. So a chromosome, which contains many genes, is like a recipe book with a lot of recipes.

Genetic code

One major feature of DNA is its ability to replicate; the other is that it carries a genetic coding system for making proteins. The order of nitrogen bases on the DNA strands is the **genetic code** for an organism.

The genetic code specifies the structure of proteins (Figure 1.14). Some proteins (such as collagen) provide support for cells in the body. Other proteins are enzymes that help us digest food and speed up the chemical reactions of our metabolism.

How genes make protein

To synthesise protein, first the DNA double helix unwinds and one strand acts as a pattern or template to form a molecule of RNA (Figure 1.15).

RNA

RNA contains a ribose sugar, unlike DNA that has a deoxygenated ribose sugar. The nitrogen bases of RNA are adenine, cytosine, guanine and **uracil**. RNA plays a key role in protein synthesis. RNA acts like a photocopy of the original DNA blueprint. This process of making an RNA copy from a DNA strand is called **transcription**.

Unlike DNA, RNA can leave the nucleus and attach to a ribosome in the cytoplasm. The RNA now 'tells' the ribosome the order in which to connect the amino acids that will make up a protein. The nitrogen bases on the RNA are read in groups of three, called codons. Each codon corresponds to a single amino acid. Eventually all the amino acids line up like beads on a necklace and form the finished protein. This process of forming a protein from RNA is called **translation**.

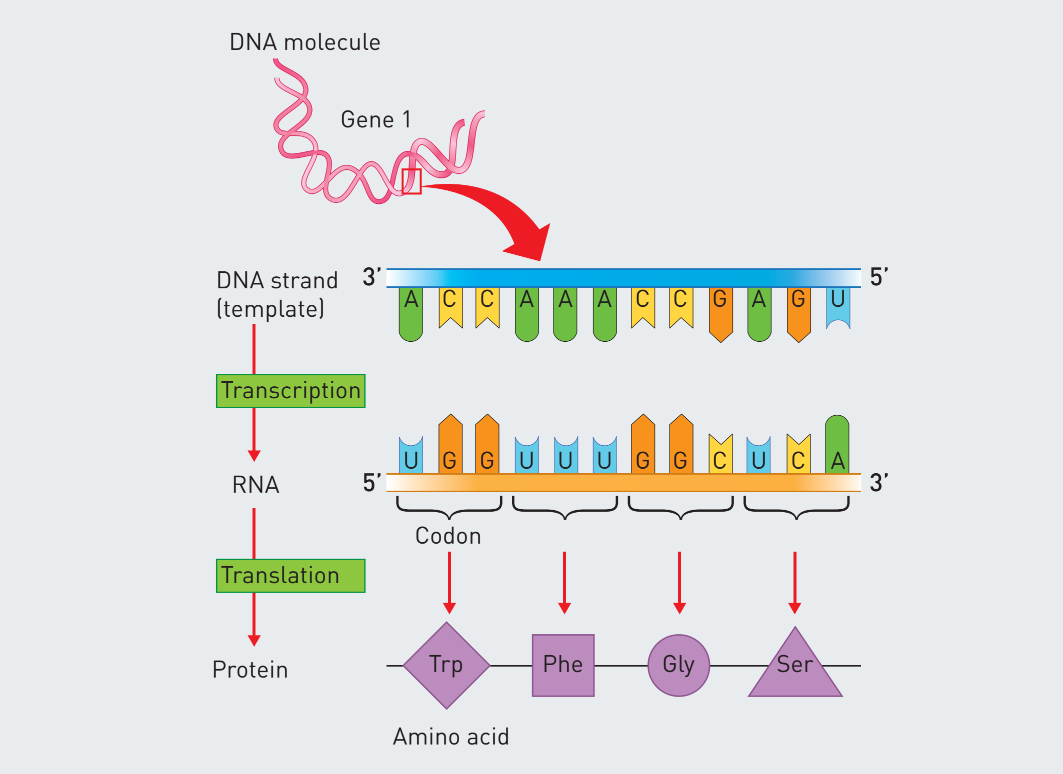


Figure 1.14 Protein synthesis.

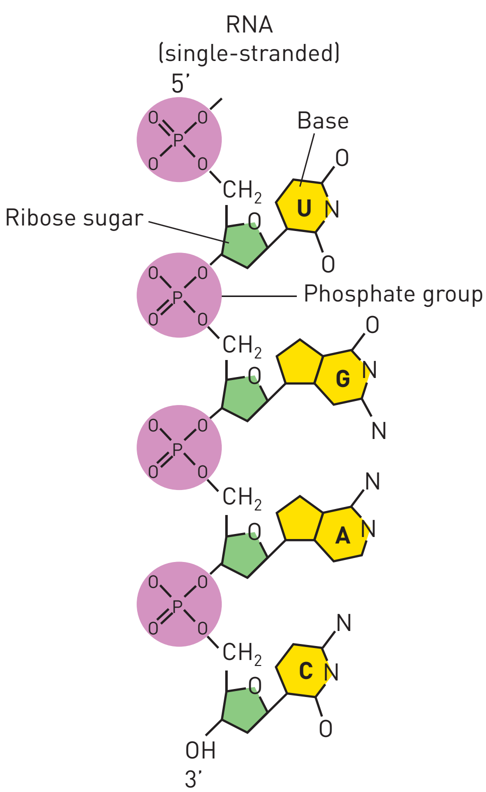


Figure 1.15 The structure of RNA.

Check your learning 1.3

Remember and understand

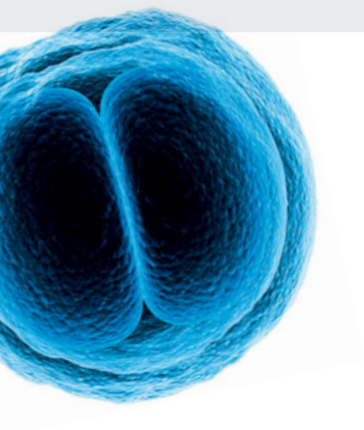
1. How many chromosomes are in each of your cells?
2. What is karyotyping?
3. What role does RNA play in the conversion of DNA information into protein?
4. How is a protein like a string of beads?

Apply and analyse

5. If part of a base sequence of one polynucleotide strand on DNA reads ACTGGCATTCAG, what is the base sequence of the corresponding part of the other polynucleotide strand? What is the base sequence of the RNA for which this strand acts as a template?
6. What is the difference between transcription and translation?
7. What would be the RNA sequence for the template DNA sequence GTTAGCCAGT? (Remember to pair uracil with adenine.)

1.4 Mitosis forms new somatic cells

Most of the cells in your body are somatic cells (all except sperm and egg cells). Somatic cells are **diploid**, which means they carry two sets of genetic material – one from the mother and one from the father. **Mitosis** is the division of the genetic material to produce two identical nuclei. The cell then divides in two in a process called **cytokinesis**. Together, these processes produce two new, genetically identical daughter cells.



Mitosis is cell division that does not change the number of chromosomes

Every organism needs to grow and repair damage throughout its lifetime. This means cells need to reproduce. Somatic cells are all the cells in the body except for the egg and sperm cells (which are called gametes). When somatic cells reproduce, they undergo a process called mitosis.

Mitosis is a type of cell division where one parent cell divides to form two genetically identical daughter cells. In humans, this means the parent cells have 46 chromosomes and the daughter cells each have 46 chromosomes.

Mitosis is essential for an organism to grow or to repair damage. In humans, intestine cells replace themselves every 4 days, skin cells every 3 weeks and bones every 7–10 years. This means the body is constantly undergoing mitosis and cytokinesis.

Most of the time, cells that are not dividing are in the phase called interphase (Figure 1.16), in which they do everyday processes such as making proteins. Cells will only start mitosis when new cells are needed.

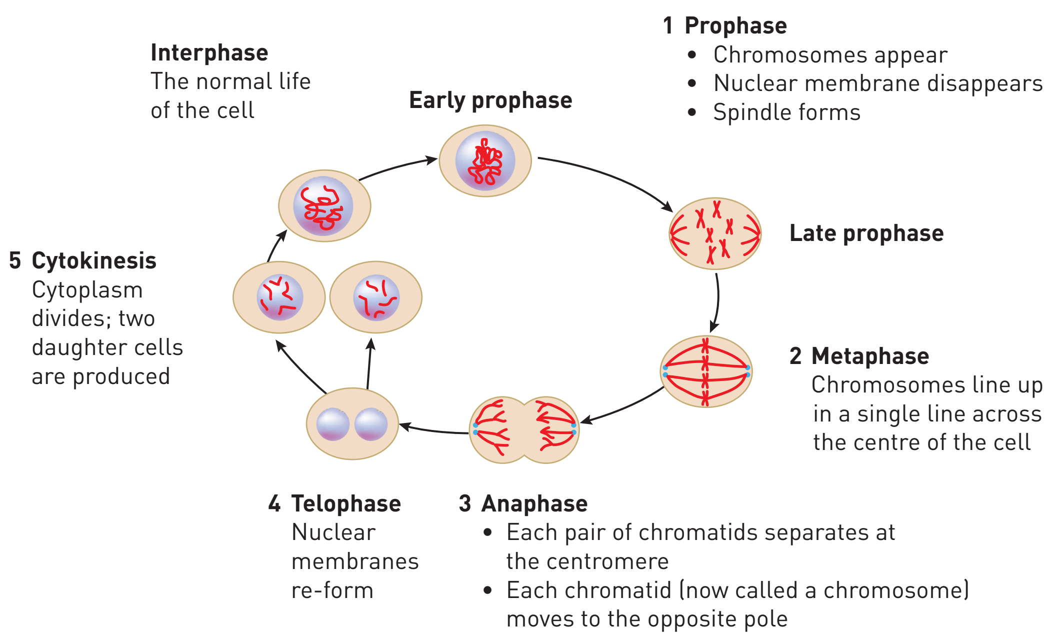


Figure 1.16 Interphase and the phases of mitosis.

SKILLS LAB 1.4: CELL DIVISION IN ACTION
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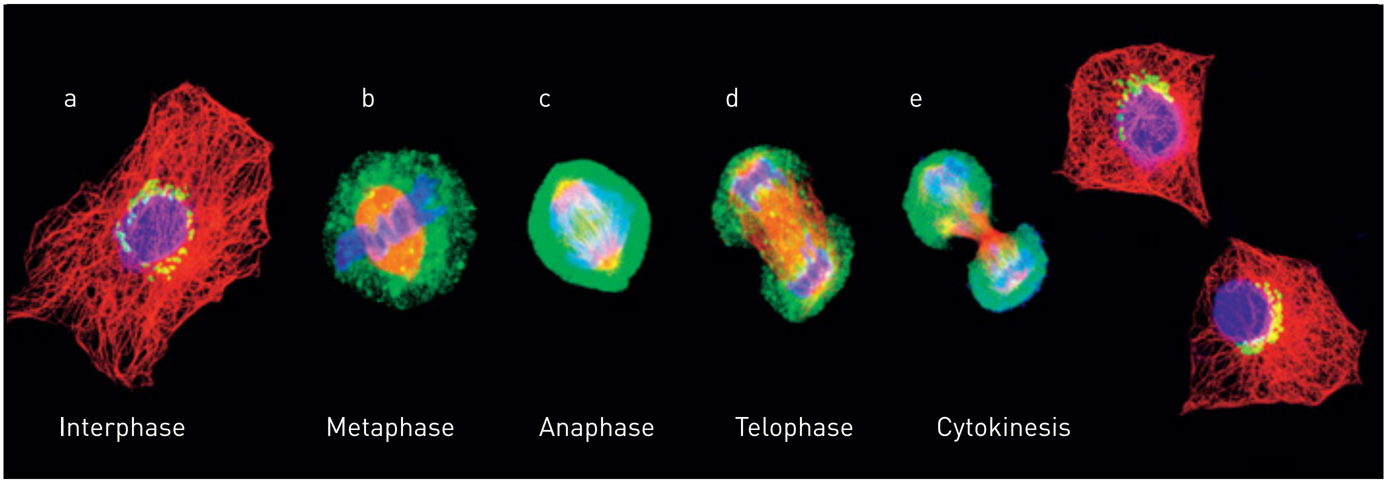


Figure 1.17 These mitotic cells have been stained with a fluorescent stain to show the separation of DNA. (a) The cell is at the end of interphase – the DNA has been replicated. During prophase, the nuclear membrane breaks down and the red spindle fibres bind to the centromere. (b) The (blue) chromosomes line up along the middle of the cell during metaphase. (c) Anaphase occurs when the spindles contract, separating the two chromatids at the centromere and pulling them to the end of the cell. (d) During telophase, the nuclear membrane reforms around the two sets of DNA. (e) Cytokinesis occurs when the cell membrane divides in two.

Cancer: mitosis out of control

The rate of mitosis in a cell needs to be carefully controlled. Cells do not survive indefinitely in an organism. The death of a cell is carefully programmed into a cell's DNA. All cells are constantly checking to make sure that everything is running normally. If any errors occur, then the cell will undergo programmed cell death, called **apoptosis**. This checking of errors is especially important during mitosis. Before the cell enters prophase or telophase, the DNA is carefully checked to make sure there are two complete sets of unaltered chromosomes.

Sometimes the DNA of a cell can become damaged. This may be due to radiation, viruses or chemicals called mutagens. If this damage is not detected, then the cell may start undergoing continual cycles of mitosis without apoptosis. This is one of the key characteristics of cancer cells.

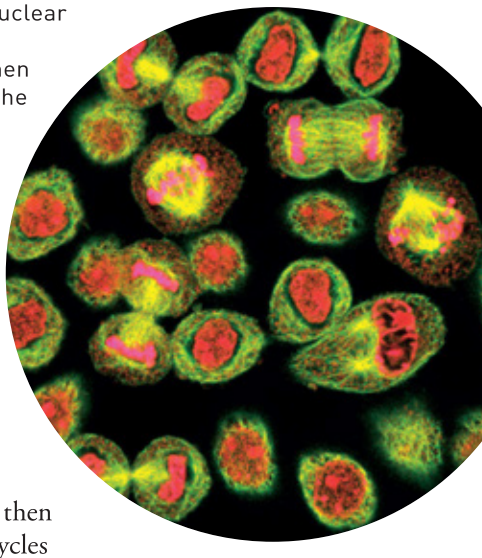


Figure 1.18 Stages of mitosis.

Check your learning 1.4

Remember and understand

1 What is the difference between mitosis and cytokinesis?
2 Why do cells undergo mitosis?
3 In which phase do most cells spend most of their time?
4 Describe what happens in each phase of mitosis.

Apply and analyse

5 A cell that is about to undergo mitosis must double its amount of DNA. Suggest why this needs to occur.

Evaluate and create

6 Identify each of the stages of mitosis that are happening in Figure 1.18.
7 Write a story of a chromosome as it undergoes mitotic division. Describe how it replicates, remains attached at the centromere until anaphase, and the final goodbye during cytokinesis.

1.5 Meiosis forms gamete cells

A gamete is a sex cell (egg and sperm) that has half the genetic material of the parent cell. Gametes are **haploid**. **Meiosis** is the process of cell division that produces haploid gametes. Two haploid gametes combine to produce the first diploid cell of a new organism.

Meiosis is cell division in which the number of chromosomes is halved

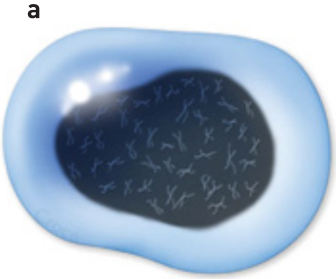
Half of the genetic material in each of your cells comes from your mother, and the other half comes from your father. Have you ever wondered how the genetic material in one of your parent's cells divided in half?

A gamete is a sex cell. In animals, the male gamete is a sperm and the female gamete is an ovum. In flowering plants, the male gamete is contained in a pollen grain and the female gamete is located in the flower's ovary. The male and female gametes of a species join to form the first cell of the offspring.

Gametes differ from all other body cells because they contain half the number of chromosomes of somatic cells – they are haploid. Most somatic cells in your body contain 46 chromosomes arranged in pairs (two sets of 23 chromosomes, or $2n$). They are diploid. Gametes (egg and sperm) in humans have 23 chromosomes (n) (Figure 1.20). When the egg and sperm combine at fertilisation, a diploid somatic cell is produced – one set of 23 chromosomes comes from the mother and one set of 23 chromosomes comes from the father. In this way, all children are similar, but not identical, to their parents.

Meiosis is a special type of cell division in which the number of chromosomes is halved. Meiosis occurs only when gametes are being made. It is sometimes called reduction division and occurs in two stages, known as meiosis I and meiosis II (Figure 1.22).

a



46 chromosomes in a diploid body cell

b

23 chromosomes in a haploid gamete

Figure 1.19 (a) A diploid body cell and (b) a haploid gamete.

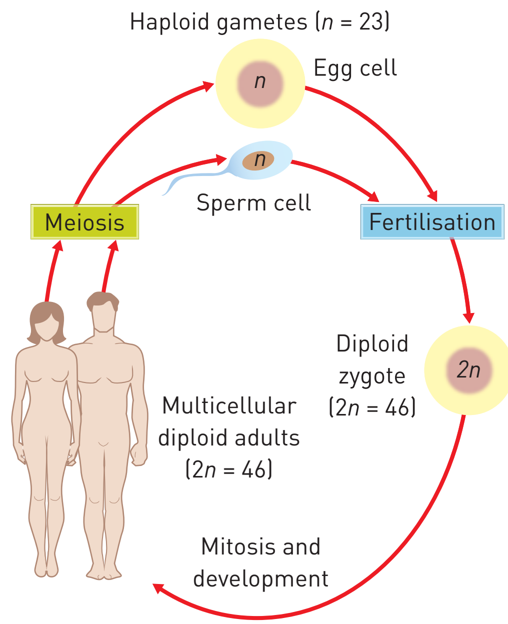


Figure 1.20 The human life cycle, involving mitosis and meiosis.

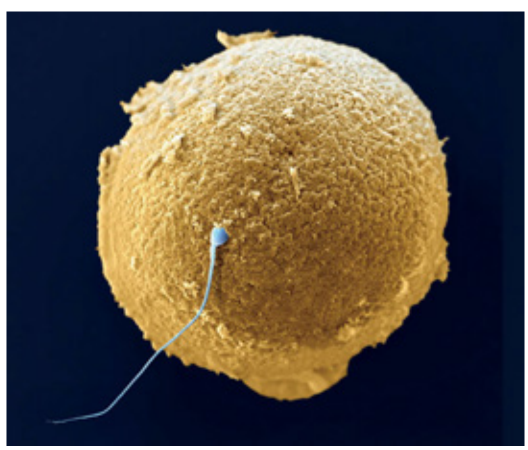


Figure 1.21 When a haploid sperm cell (n) fertilises a haploid egg cell (n), a diploid somatic cell ($2n$) is formed.

CHALLENGE 1.5: MODELLING MEIOSIS
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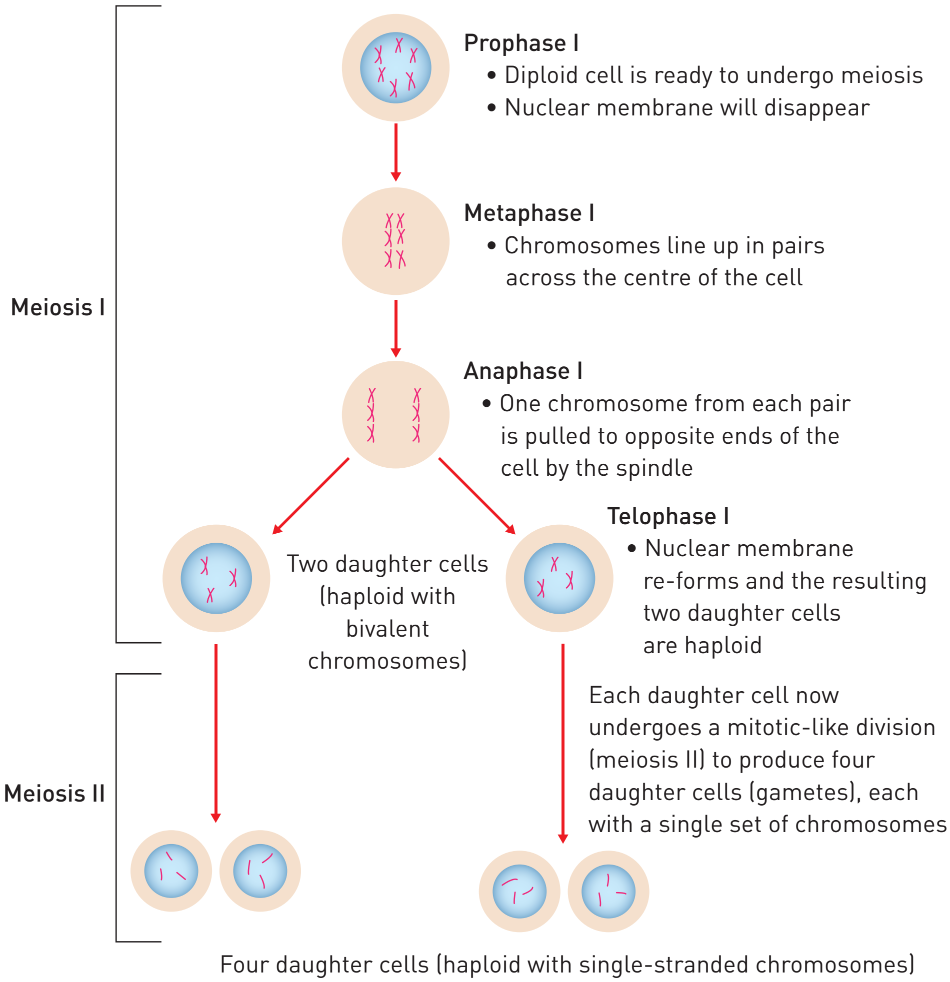

Figure 1.22 Meiosis consists of two rounds of each phase: prophase, metaphase, anaphase and telophase. If a gamete is fertilised, the chromosomes of the zygote will become diploid again so that the zygote can grow (by mitosis) into an embryo.

Check your learning 1.5

Remember and understand

1 What is the difference between a haploid cell and a diploid cell? Give an example of each.

2 Prepare a table showing the similarities and differences between mitosis and meiosis.

Apply and analyse

3 We all started from a single cell, a zygote, which then grew into an embryo. What type of cell division is involved in the growth of a zygote into an embryo? Explain your answer.

4 Are the offspring of sexually reproducing organisms identical to their parents?

5 Interphase is the 'normal' life stage of the cell – the stage between one mitotic division and the next. Interphase also occurs before meiotic divisions. What important process involving DNA occurs during interphase and why does it occur?

6 Why is it essential that the number of chromosomes is halved during meiosis?

7 The chromosomes in Figure 1.23 are separating at the centromere. What phase of meiosis is the cell undergoing?

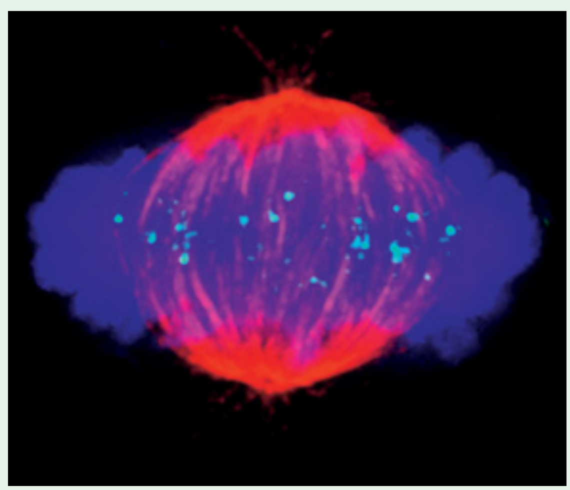

Figure 1.23

1.6 Alleles can produce dominant or recessive traits

Genes can have different versions (alleles) on the same location of a chromosome. The unique combination of alleles for a gene inherited from parents is called the **genotype** of the organism. **Homozygous** individuals have two identical alleles. **Heterozygous** individuals have two different alleles. Only a single allele for a trait needs to be present for a dominant trait to appear in the **phenotype**. Recessive traits need two copies of the allele before it can be expressed in the phenotype. A person who is heterozygous for a recessive trait is said to be a carrier for the trait. Phenotypes can be influenced by the environment.

Alleles

Have you ever wondered why some people look so much like their mother or father? Each cell in your body contains two sets of chromosomes – one from your mother and one from your father. If your mother has blue eyes, then you may inherit the gene for blue eyes from her. If your father has brown eyes, then you may inherit the gene for brown eyes from him. Both genes are for eye colour. Each version of the same gene (for eye colour) at the same position (or loci) of a chromosome is called an **allele**.

If a person has two identical alleles for a trait or characteristic, they are said to be homozygous for that trait. If a person has two different alleles for the same trait (for example, a blue eye allele and a brown eye allele), they are heterozygous for the trait.

If someone is heterozygous for eye colour, then the colour of their eyes is determined by which version is dominant. **Dominant traits** only need one copy of the allele to be visible in the appearance of the individual. Dominant traits are usually represented by capital letters. For example, brown eyes is a dominant trait and is often given the symbol 'B'.

Other traits are called **recessive traits**. These traits can only be seen if there are two copies of the allele present. The alleles for recessive traits are represented by lower-case letters. For example, blue eyes is a recessive trait and is often given the symbol 'b'.

Therefore, a person with blue eyes must have two alleles for blue eyes (bb). In contrast, a person with brown eyes could be homozygous (BB) or heterozygous (Bb) for the trait. A brown-eyed individual who is heterozygous for the trait is sometimes called a **carrier** for the blue eye trait. They have the allele for blue eyes, but the trait cannot be seen in their appearance.

The combination of allelic symbols that a person has for a trait (i.e. BB, Bb or bb) is called their genotype.

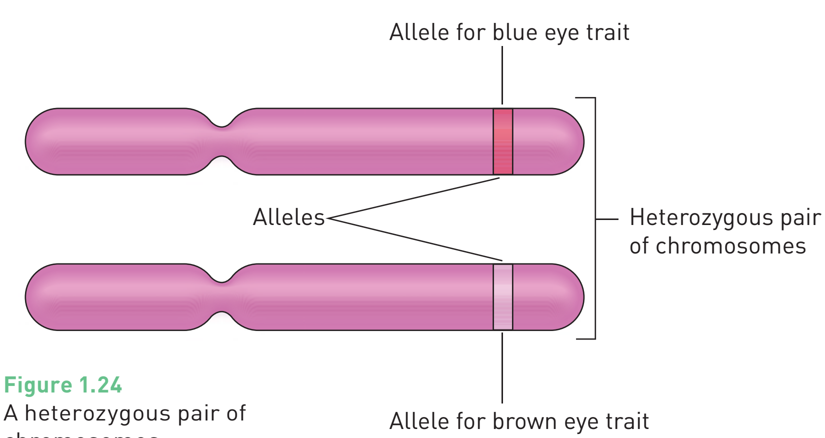

Figure 1.24
A heterozygous pair of chromosomes.

EXPERIMENT 1.6: ZAZZLE GENETICS
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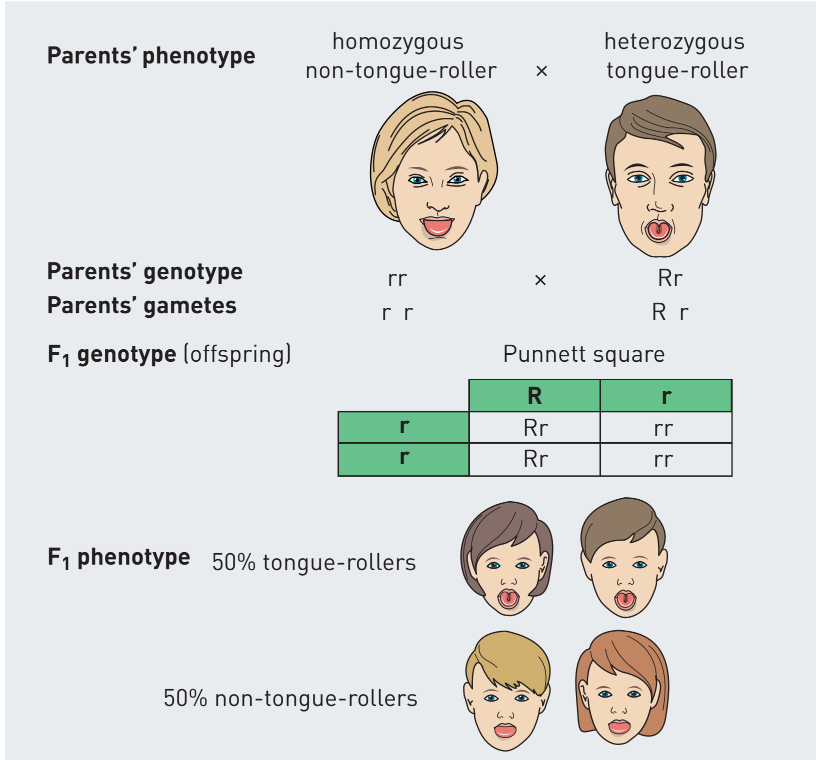
Figure 1.25 Genetically identical hydrangeas produce different coloured flowers depending on the environment.

Nature versus nurture

For over a century, scientists have puzzled over whether the genetic material you inherit (nature) or the environment in which you are raised (nurture) is more important in determining your characteristics. For example, genetically identical hydrangeas (Figure 1.25) that produce pink flowers in alkaline soil and blue flowers in acidic soil suggest that nurture is more important. However, the growth of the stem, flowers and leaves is a result of the genes in the plant.

Phenotype is the physical expression of a trait or characteristic that results from the genetic make-up of the organism and is influenced by the environment. An example is also how tall you will grow. You inherit a series of genes from your parents that will determine your growth potential, but if you don't get enough food when you are growing, then you will not reach your full height.



	R	r
r	Rr	rr
r	Rr	rr

Figure 1.26 The ability to roll your tongue is inherited.

Monohybrid cross

Some traits, such as the ability to roll your tongue, are controlled by only one gene. This single gene has two alleles: one for rolling your tongue (the dominant trait, R) and one for non-tongue rolling (the recessive trait, r). We can examine how this single trait is passed on by using a **Punnett square** (Figure 1.26). In a Punnett square, the parents' genes are listed across the top and down the side. The remaining boxes are filled by combining the letters of each parent.

Check your learning 1.6

Remember and understand

1. Dimples (D) is dominant to no dimples. Write the genotypes for individuals who:
   a. are homozygous for dimples
   b. are heterozygous for dimples
   c. have no dimples.
2. What is a carrier?

Apply and analyse

3. If the children of a right-handed man and a left-handed woman are all left-handed, does this mean that left-handedness is dominant? Provide evidence to support your view.
4. The trait for blue eyes is recessive to the trait for brown eyes. What are the chances of two blue-eyed parents having a brown-eyed child? What are the chances of two brown-eyed parents having a blue-eyed child?
5. Wavy hair in humans is dominant to straight hair. A wavy-haired man and a straight-haired woman have two children. The first child has wavy hair and the second child has straight hair. State the genotype of all four individuals and use suitable symbols to show your working.

Evaluate and create

6. A student wants to check if her grey cat is heterozygous or homozygous for coat colour. Assuming breeding was ethical and time efficient, what cross should she carry out? What results would she obtain if the cat is:
   a. homozygous?
   b. heterozygous?

1.7 Alleles for blood group traits co-dominate

Some traits do not dominate other traits. Red blood cells can display special molecule markers on their surface. These markers can be 'A' sugars or 'B' sugars. People with blood group A or blood group B display the sugar markers 'A' or 'B' respectively. Individuals with blood group O do not have either marker on their red blood cells. People with blood group AB display both markers on the surface of their red blood cells. This is an example of both traits being expressed equally. They are **co-dominant**.

Blood types

Some genotypes are more complex and involve more alleles. This is the case when determining your blood group. When stating your blood group, two components are usually referred to – a letter grouping (ABO) and whether you are Rhesus positive or negative. Rhesus markers are present on the surface of the red blood cells of 80% of people. These people are said to be Rhesus positive. If the Rhesus marker is not present these people are, said to be Rhesus negative. People belong to one of four other main blood groupings.
Table 1.1 shows the proportion of Australians who fall into each of these four groups.

Table 1.1 Blood groupings in Australia

BLOOD GROUP (PHENOTYPE)	FREQUENCY IN AUSTRALIAN POPULATION (%)	FREQUENCY IN AUSTRALIAN POPULATION OF RHESUS POSITIVE (%)	FREQUENCY IN AUSTRALIAN POPULATION OF RHESUS NEGATIVE (%)
O	49	40	9
A	38	31	7
B	10	8	2
AB	3	2	1

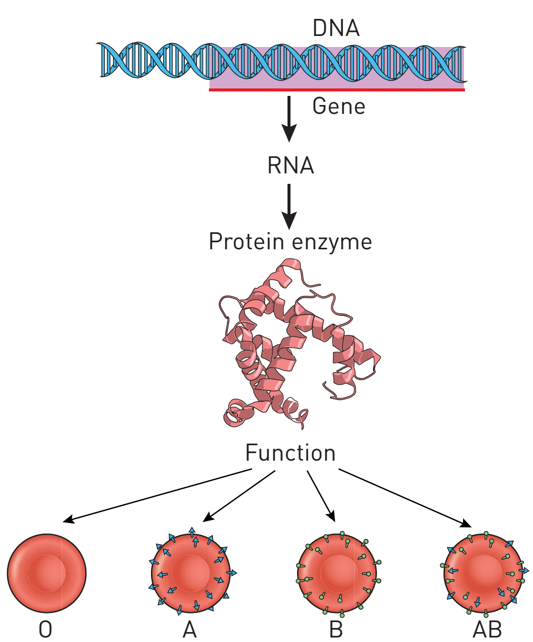


Figure 1.27 Genes for blood type produce an enzyme that makes a sugar (A or B) on the surface of a red blood cell.

People who have blood group A have red blood cells that display a special sugar marker A on the surface of their red blood cells. People who are blood group B display sugar marker B on their red blood cells. Group AB people display both markers A and B, and people in blood group O have neither marker. The gene for each of these traits produces an enzyme (a protein) that makes the specific red blood cell sugar marker (Figure 1.27).

It is important to know your blood group because mixing different types of blood can cause clots to form that block blood vessels. A person who is transfused with the wrong type of blood can die.

EXPERIMENT 1.7: BLOOD TYPING EXPERIMENT
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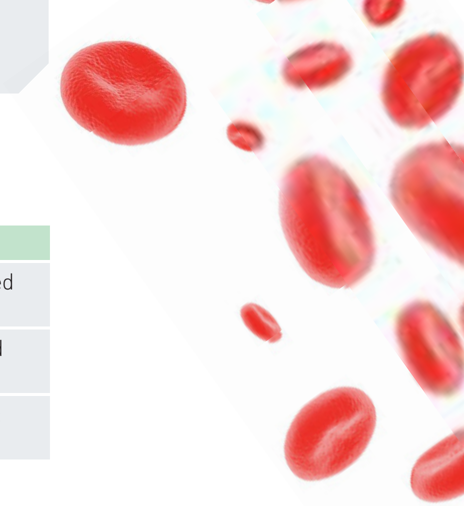

Table 1.2 Blood group alleles

TRAIT	ALLELE SYMBOL	FUNCTION
Dominant trait	I^A	Produces an enzyme that forms an A sugar on red blood cells.
Dominant trait	I^B	Produces an enzyme that forms a B sugar on red blood cells.
Recessive trait	i	Results in a non-functioning enzyme. No specific sugar on the surface of red blood cells.

ABO blood grouping is determined by a different gene from Rhesus grouping, so the inheritance of each component must be investigated separately. Three alleles determine the ABO blood group (Table 1.2). Depending on which of these three alleles you inherit from your parents, your blood group may be different from that of your parents or your siblings.

The I^A and I^B alleles are described as co-dominant. In other words, they are expressed equally together, rather than one being dominant over the other. However, either of these alleles is completely dominant over the recessive trait (i).

Consider a couple – Greg, who is blood group A, and Ellie, who is blood group B. Both Greg's mother and Ellie's mother were blood group O. What are the possibilities for their child in terms of their blood group? To answer this question, we first need to consider the phenotype and then the genotype of each parent (Figure 1.28).

We know that Greg's blood group is A. This means there are two possibilities for his genotype: I^AI^A or I^Ai. We know that Greg's mother was blood group O, which means that Greg could have only inherited the alleles for the recessive trait (i) from his mother and so he must be heterozygous (I^Ai). By applying the same process to Ellie, you can determine that she is I^Bi.

In the process of meiosis, Greg can pass on only one of his two chromosomes and, hence, either the I^A or i allele. Likewise, Ellie can only pass on the I^B or i allele. The chance of either allele being inherited is equal (i.e. 50% or ½). This information can be used to construct a Punnet square, as shown in Figure 1.28.

	Greg		Ellie
Parents' phenotype	blood type A	x	blood type B
Parents' genotype	I^Ai	x	I^Bi
Parents' gametes	I^A i		I^B i
F_1 genotype (offspring)	Punnett square		

	I^B	i
I^A	I^AI^B	I^Ai
i	I^Bi	ii

Figure 1.28 Determining blood types of offspring.

Thus, the four possibilities for Greg and Ellie's child with respect to ABO blood groups are:

Genotypic ratio: ¼ I^AI^B : ¼ I^Ai : ¼ I^Bi : ¼ ii

Phenotypic ratio: ¼ AB: ¼ A: ¼ B: ¼ O

Check your learning 1.7

Remember and understand

1 Why is it important to know your blood group?

2 From Table 1.1, in Australia what blood group is the:

a most common?

b least common?

3 Complete the following table to record the possible genotypes that combine to produce each blood group phenotype and the sugars displayed.

BLOOD GROUP (PHENOTYPE)	POSSIBLE GENOTYPES	SUGARS DISPLAYED ON A RED BLOOD CELL
O		
A		
B		
AB		

Apply and analyse

4 Consider two parents who are both blood group O. What blood groups could their children have?

5 Vinda is homozygous for blood group A. Julie is heterozygous for blood group B. Use a Punnett square to determine the possible genotype(s) and blood group(s) for a child of Vinda and Julie.

6 If Vinda and Julie have a second child, will the blood group of the first child affect that of the second? Explain your reasoning.

1.8 Alleles on the sex chromosomes produce sex-linked traits

Sex chromosomes are chromosomes that determine the sex of an organism. Human females have two X chromosomes and human males have an X and a Y chromosome. **Sex chromosomes** contain genes that are inherited in a unique way. Fathers pass their X chromosome to all their daughters and their Y chromosome to all their sons. Mothers will pass one X chromosome to each of their children. **Autosomes** are non-sex chromosomes.

Sex chromosomes

Humans have 22 pairs of chromosomes that are not sex chromosomes, called autosomes. The 23rd pair of chromosomes are the sex chromosomes. The genotype for the sex chromosomes in a female is XX and the genotype for a male is XY. These chromosomes contain the genes with information for sexual traits.

The X chromosome is larger than the Y chromosome (Figure 1.29). In addition to carrying genes for sexual characteristics, it contains information for non-sexual characteristics, such as blood clotting and red–green colour vision. Traits (and the genes that determine them) that are carried on a sex chromosome are said to be sex linked. Males show deficiencies in these genes more commonly than females because they only have one X chromosome.

In general, when investigating the pattern of inheritance for a particular trait (characteristic), it is useful to consider each trait as one of the following four types:

- autosomal dominant
- autosomal recessive
- X-linked dominant
- X-linked recessive.

Figure 1.29 The X chromosome (left) is much larger than the Y chromosome (right) and carries more genetic information.

Figure 1.30 Most sex-linked genes are situated on the X chromosome. There are only a few Y-linked genes, such as hairy ears. So only males have hairy ears.

EXPERIMENT 1.8: COLOUR-BLINDNESS INHERITANCE
GO TO PAGE 198

Figure 1.31 A male gets his X chromosome from his mother and his Y chromosome from his father. A female gets one of her X chromosomes from her mother and the other from her father.

Table 1.3 The four patterns of inheritance

	DOMINANT	RECESSIVE
Autosomal	• Males and females are affected equally over a large sample size. • Affected offspring have at least one affected parent (i.e. does not skip a generation).	• Males and females are affected equally over a large sample size. • Affected offspring may have unaffected parents (i.e. parents may be carriers).
X-linked	• Generally, more females than males are affected. • Affected offspring have at least one affected parent (i.e. does not skip a generation). • An affected father will pass the trait to all daughters, but not to any sons. • An affected mother has a 50% chance of passing the trait to any son or daughter.	• Generally, more males than females are affected; females are carriers. • Affected offspring may have unaffected parents (men cannot be carriers, but women may be). • A carrier mother has a 50% chance of passing the trait on to each son. • Daughters of an affected father will all be carriers.

Sex-linked conditions

Two conditions that are caused by defective sex-linked genes are red–green colour blindness and haemophilia.

Red–green colour blindness is an X-linked recessive trait. This means the red–green colour-blindness allele is found on the X chromosome and the trait only appears if no 'normal' alleles for this gene are present. The colour receptors in the retina of the eye are controlled by a gene on the X chromosome. When the gene is defective, the colour receptors do not function properly and the person cannot distinguish red from green (Figure 1.32). Approximately 8% of males and less than 1% of females have red–green colour blindness. It is very rare for a female to have two defective genes, but not so rare for them to be 'carriers' (heterozygous) of the defective gene.

Figure 1.32 A person with colour blindness will have a very different view of the world. (a) A person with normal vision can see all the colours of these parrots. (b) A person with colour blindness would not be able to see the red and green feathers.

Figure 1.33 Queen Victoria's granddaughter Alexandra, her husband Nicholas II (the last Tsar of Russia) and their son Alexei, who suffered from haemophilia.

Haemophilia is a disease that prevents the blood from clotting. This occurs when the X-linked gene that controls one of the clotting factors is defective. Even a small injury to a person with haemophilia can result in prolonged bleeding. It is possible to treat this disease today because the clotting factors can be produced from donated blood or made in the laboratory. These clotting factors are given by injection.

In the past, there was no treatment for haemophilia. Queen Victoria, Queen of the United Kingdom, appears to have had a spontaneous mutation in the gene on the X chromosome for making a blood clotting factor. She passed this defective gene on to some members of her family. When her male descendants inherited the X chromosome with the 'defective' allele, they often died prematurely.

Queen Victoria's granddaughter Alexandra was a carrier of the haemophilia gene. She married the last Tsar of Russia, Nicholas II, with whom she had four unaffected daughters and a son, Alexei, with haemophilia (Figure 1.33). Alexei's disease caused great stress to the family. Alexandra even consulted the monk Rasputin to pray over him, but there was no reliable treatment for haemophilia in the early 20th century.

Communicating sex-linkage

When writing genotypes for sex-linked crosses, it is important to show the allele as being attached to either the X or the Y chromosome because the gender of the offspring is important in determining phenotype.

For example, in colour blindness, using X for normal and X^c for colour blindness, the genotype for a colour-blind female is X^cX^c, the genotype of a carrier female is XX^c and the genotype for a colour-blind male is X^cY. For haemophilia, we can use X^H and X^h to represent the normal allele and the allele for haemophilia, respectively (see Figure 1.34).

Key: H = normal allele and h = allele for haemophilia

Queen Victoria X^HX^h × X^HY Albert

↓

Carrier daughter X^HX^h × X^HY Her husband

↓

Alexandra X^HX^h × X^HY Nicholas II
(carrier granddaughter) (last Tsar of Russia)

↓

Alexei X^hY
(haemophiliac son)

Figure 1.34 Genotypes in the family tree of Queen Victoria leading to Alexei.

Check your learning 1.8

For the following questions, assume that the sex-linked gene is X-linked and recessive.

Remember and understand

1 Why does a defect in a sex-linked gene affect males more than females?

Apply and analyse

2 A man and a woman, both of whom had normal sight, had three children: two boys and a girl. One of the boys had normal sight and the other was red–green colour blind. The girl had normal sight. Write the genotypes for this family.

3 The girl from the family in question 2 married a normal-sighted man and had a son who was colour blind. Write the genotypes for this family.

4 The colour-blind son from the family in question 3 married a normal-sighted woman and had a son with normal sight and a colour-blind daughter. Write their genotypes.

5 What is the probability that the four girls in the family of the last Russian Tsar were carriers of the allele for haemophilia?

6 Who will be affected by a Y-linked gene? Explain your answer.

7 If a man has a mutated gene on his Y chromosome, which grandparent did he inherit it from?

Evaluate and create

8 Tortoiseshell cats have fur coats that are a combination of orange and black. The gene for hair colour is found on the X chromosome.

a Explain why all tortoiseshell cats are female. Use diagrams to explain your answer.

b What colour would the offspring of a tortoiseshell and a black cat be?

Figure 1.35 Tortoiseshell cat

1.9 Inheritance of traits can be shown on pedigrees

Pedigrees are a diagrammatic way to show the inheritance pattern of a trait. Symbols are used to represent different individuals in a family. Circles represent females and squares represent males. Symbols that are shaded represent individuals who express the trait. Generations are indicated by Roman numerals and individuals are numbered from left to right. Recessive traits may skip a generation. Once a dominant trait disappears from a family line, it will not reappear.

Pedigree construction and analysis

Although each of your parents contributed to your genotype, the genotypes of other family members (e.g. grandparents, aunts and uncles) can all be important in explaining who you are. Inheritance of characteristics is often traced through families using family tree diagrams or pedigrees. There are specific symbols used in constructing pedigrees (you can see these in Figure 1.36).

- Males are represented by squares and females by circles.
- A marriage is shown by a horizontal line; a vertical line leads to the offspring.
- The characteristic being studied is shown by shading.
- Generation numbers are represented by Roman numerals and individuals are represented by Arabic numerals.

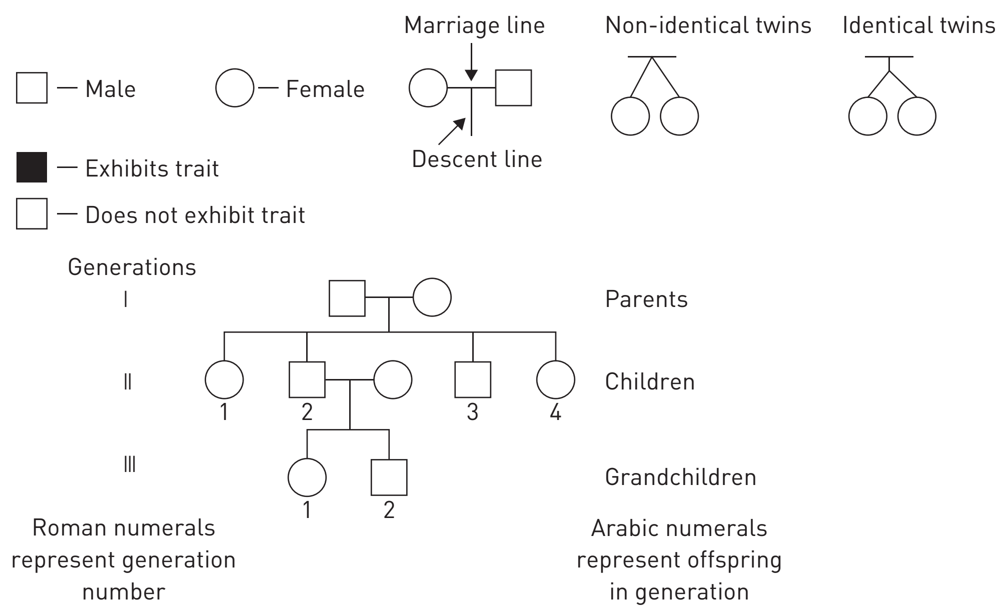

Figure 1.36 Some symbols used in family tree diagrams.

When analysing a pedigree to determine whether a trait is dominant or recessive, the following rules apply.

> If neither parent has a characteristic and some of their offspring have it, then the characteristic is recessive (i.e. both parents are carrying the allele for the recessive trait but it is not shown in their phenotype).
> If both parents have a characteristic and some of their children have it, then the characteristic is dominant (i.e. both parents are heterozygous).
> If both parents have a characteristic and none of their children have it, then the characteristic is dominant (because, if both parents have a characteristic and it is recessive, then all of their children will have that characteristic).

Hence, for the pedigree in Figure 1.37, red hair is recessive because individual II2 and his partner do not have red hair but some of their children have it. They are both carrying the allele for red hair, but not expressing it. They both contribute their allele for red hair to some of their offspring.

In the pedigree shown in Figure 1.38, tongue rolling is dominant. This is because individual II1 and her partner can roll their tongues, and some of their offspring can and some cannot. The parents are both heterozygous for tongue rolling.

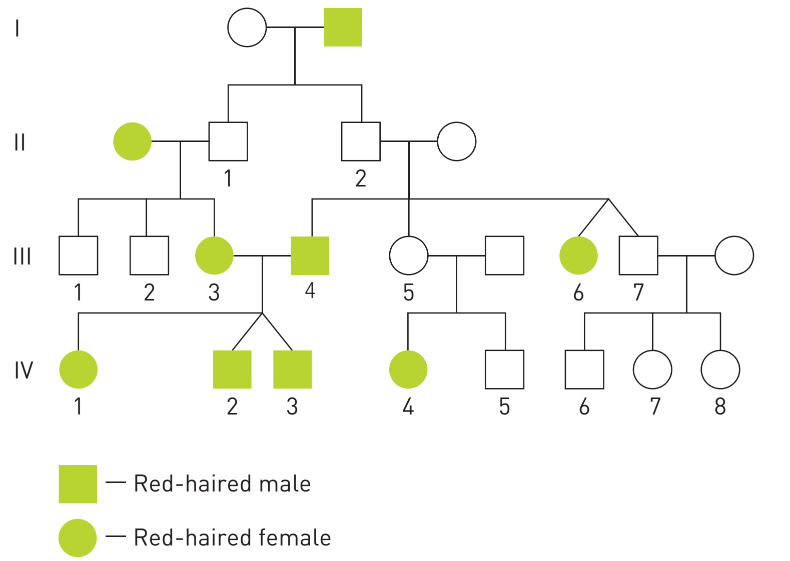

Figure 1.37 A pedigree for red hair.

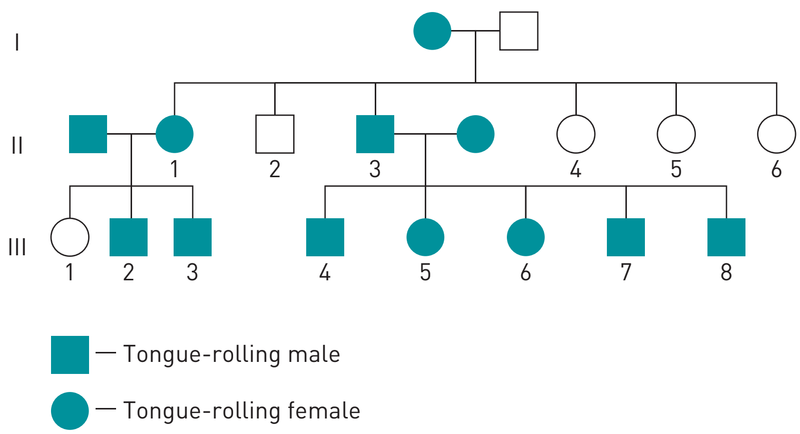

Figure 1.38 A pedigree for tongue rolling.

Analysing pedigrees

Pedigrees can be analysed to determine whether an individual will inherit a disease. There are a series of questions you should ask when determining the inheritance pattern from a pedigree.

1. Are more males or females affected by the trait?
   If YES, go to 2. If NO, go to 3.
2. Do all daughters of affected males have the trait?
   YES – Sex-linked dominant. NO, go to 4.
3. Do all affected children have an affected parent?
   YES – Autosomal dominant. NO, go to 5.
4. Has a carrier mother passed it on to half/some of her sons?
   YES – Sex-linked recessive
5. Do affected children have unaffected parents?
   YES – Autosomal recessive

Figure 1.39 Achondroplasia is the most common form of dwarfism.

Dwarfism

Achondroplasia is the most common form of dwarfism and is inherited as an autosomal dominant trait (although spontaneous mutations can also arise with no prior family history) (Figure 1.39). The gene is located on chromosome 4 and it controls the production of a growth factor receptor. Therefore, individuals with an affected allele will have dwarf stature. Most people with achondroplasia have normal intelligence and lead independent and productive lives, although they often have medical problems.

Because the trait is dominant, people affected by achondroplasia have at least one affected parent. If one parent is affected, there is a 50% chance of the children being affected (Figure 1.40).

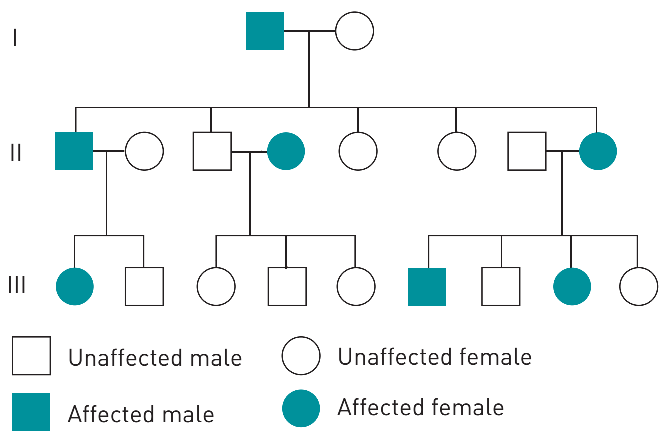

Figure 1.40 The pedigree chart of a family affected by achondroplasia. Some of the children are unaffected.

Check your learning 1.9

Apply and analyse

1 Some people have ear lobes that hang free and some people's are attached. Natalie has attached ear lobes but both Natalie's parents and her brother, Daniel, have free-hanging ear lobes as shown in the pedigree (Figure 1.41).

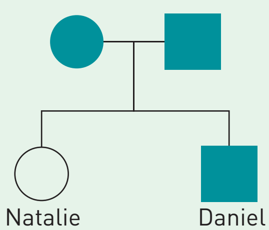

Figure 1.41

a Is the characteristic of free-hanging ear lobes a dominant trait or a recessive trait? Explain your choice.

b Use suitable symbols to represent the alleles for the ear lobe gene, then write the genotypes of:

i Natalie

ii Natalie's parents.

c What are the possible genotypes for Daniel?

2 A particular X-linked disease causes weakening of the muscles and loss of coordination. This often leads to death in childhood. A pedigree for this disease is shown in Figure 1.42.

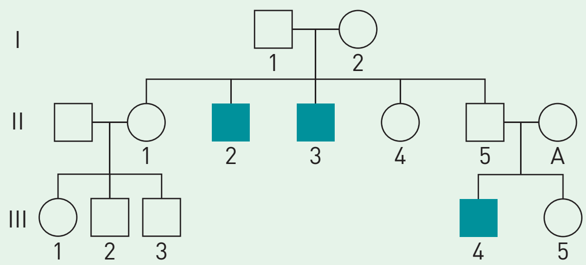

Figure 1.42

a Use this pedigree and suitable symbols to show the genotype of individuals I1, I2 and II5. What must be the genotype of individual A?

b What is a carrier? Identify one carrier in the pedigree shown in Figure 1.42.

3 Look at Figure 1.43.

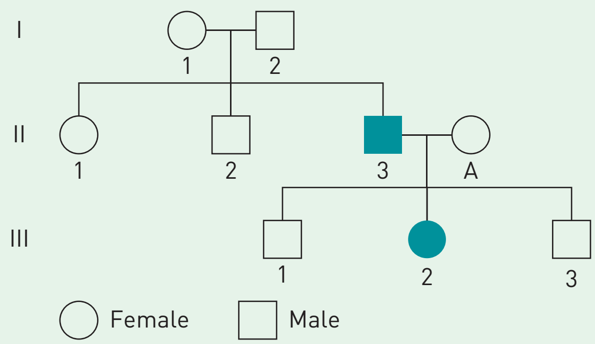

Figure 1.43

a In this family pedigree, is the characteristic indicated by shading dominant or recessive? Explain.

b If R represents the allele for the dominant trait and r represents the allele for the recessive trait, write the genotypes for I1, I2 and person A.

c If A and her partner had another child, what is the chance of the child having the characteristic indicated by shading? Show your working.

4 The pedigrees in Figure 1.44 show the inheritance of two genetic disorders (vision and limb defects) in the same family.

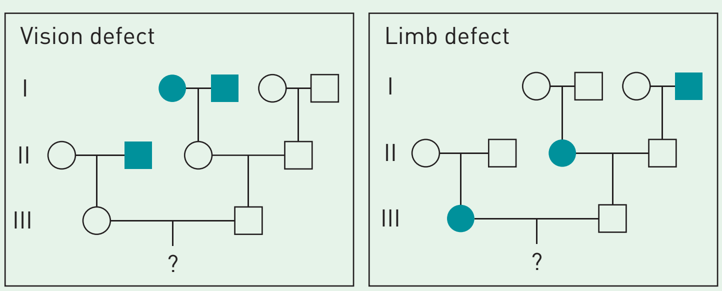

Figure 1.44

a Is the allele responsible for the vision defect dominant or recessive? Explain your choice.

b Is the allele responsible for the limb defect dominant or recessive? Explain your choice.

1.10 Mutations are changes in the DNA sequence

Mutagens such as chemicals, UV light and cigarette smoke can cause permanent changes in the sequence of nucleotides that make up DNA. These changes are called **genetic mutations**. They can involve substituting one nucleotide for another, or deleting or adding a nucleotide. Chromosomal mutations result from the centromere failing to separate (non-disjunction) during meiosis. The resulting daughter cells have too many or too few chromosomes. This causes a variety of changes in the organism, called a syndrome.

Mutations and mutagens

A mutation is a heritable change in the structure or amount of the genetic material (DNA). Therefore, a mutation is a permanent change in the DNA and it may be in one gene or in a number of genes (part or all of a chromosome). 'Heritable' refers to the change being 'inherited'.

If the change is in a single gene, then it is called a genic or genetic mutation; if it affects most of a chromosome, it is called a chromosomal mutation.

Because DNA replication (and other similar genetic events) is a copying process involving huge numbers of base pairs, mistakes occasionally happen – these are natural mutations. The base sequence (order of nucleotide nitrogen bases) in DNA is critical – a tiny change in the sequence changes the order of amino acids in the protein being made, which, in turn, may affect how the protein functions. Although the aim of genetic copying is to preserve that order, occasional errors can occur. On many occasions, these changes can be corrected by the cell or they do not cause a change in an important part of the protein that is produced by the gene.

It was a single mutation many thousands of years ago that prevented the production of brown pigment in eyes. As a result, blue eyes developed in humans. The mutation gave humans a new allele. However, some mutations are deadly, and our body works hard to correct them.

Natural mutations occur at a continuous low rate. However, environmental factors called mutagens can increase the frequency of mutations. Mutagens include chemicals, radiation and ultraviolet (UV) light (Figure 1.45).

Radiation

- Ionises biochemical compounds in cells, forming free radicals
- The free radicals cause damage to DNA and proteins (e.g. breakages in chromosomes)

Chemicals

- Some chemicals insert into DNA instead of bases (i.e. they substitute for bases)
- Other chemicals insert between bases, causing problems when the DNA replicates

UV light

- Causes thymines that are close together on a DNA polynucleotide chain to bind together, forming 'thymine dimers'. This causes problems during DNA replication

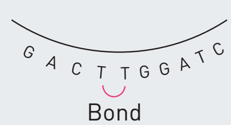

Figure 1.45 The effect of mutagens.

SKILLS LAB 1.10: IDENTIFYING MUTATIONS
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Genetic mutations

There are two types of genetic mutation:

> point or substitution mutations
> frameshift mutations.

A point mutation occurs when one base substitutes for another. As the genetic code is read in groups of three (called triplets), this may or may not have an effect on the final protein. This is best shown using the sentence:

THE CAT ATE THE RAT AND RAN FAR

If there was a point mutation in this sentence, it might read:

THE CA**R** ATE THE RAT AND RAN FAR

In this case, the sixth letter, T, was substituted by R. In DNA it might be a G substituted for A. This small change will be passed on to the RNA, but may not affect the order of amino acids in a protein.

Sickle cell anaemia is an example of a point substitution that does affect the final protein. The gene that makes part of the haemoglobin molecule, which carries oxygen around the body, has substituted an adenine (A) for a thymine (T). So the code in the DNA sequence reads CAC instead of CTC. As a result, the codon on the RNA reads GUG instead of GAG. This makes the matching amino acid valine rather than glutamic acid. This means a slightly deformed haemoglobin is produced, which doesn't carry oxygen as effectively (Figure 1.46).

However, a deletion or an addition can have a large impact on how the genetic code is read.

A deletion of the sixth letter (T) in the example sentence would result in the triplet code becoming:

THE CAA TET HER ATA NDR ANF AR

An addition of an extra R would result in the triplet code becoming:

THE CAR TAT ETH ERA TAN DRA NFA R

These are called **frameshift** mutations because the group-of-three reading frame has been shifted along the DNA strand.

Frameshift mutations have more damaging effects than point mutations because they change the entire reading frame of the DNA and RNA, producing quite a different protein. If the RNA sequence reads UAC after the mutation, then this is a 'stop codon' and the protein synthesis will stop at that location, resulting in a shorter molecule that is unable to be useful.

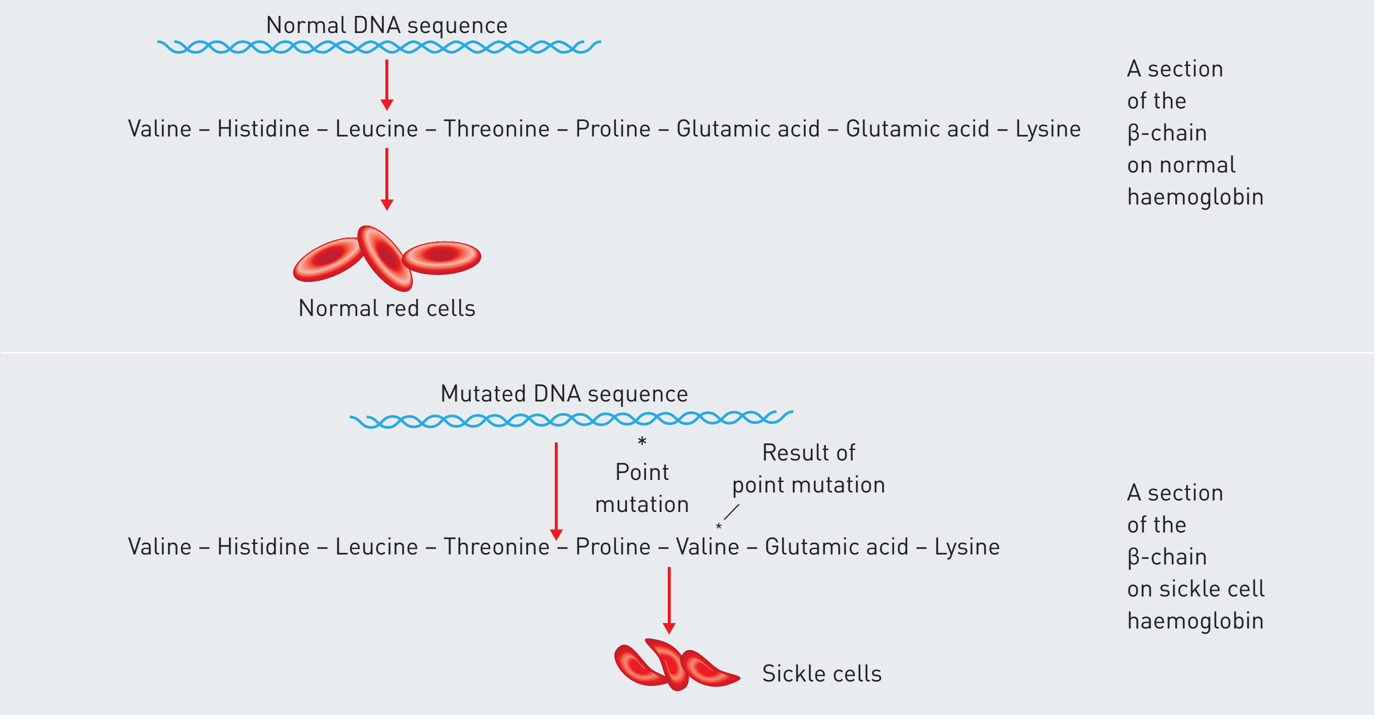


Figure 1.46 Haemoglobin and sickle cell anaemia – an example of the effects of a point mutation.

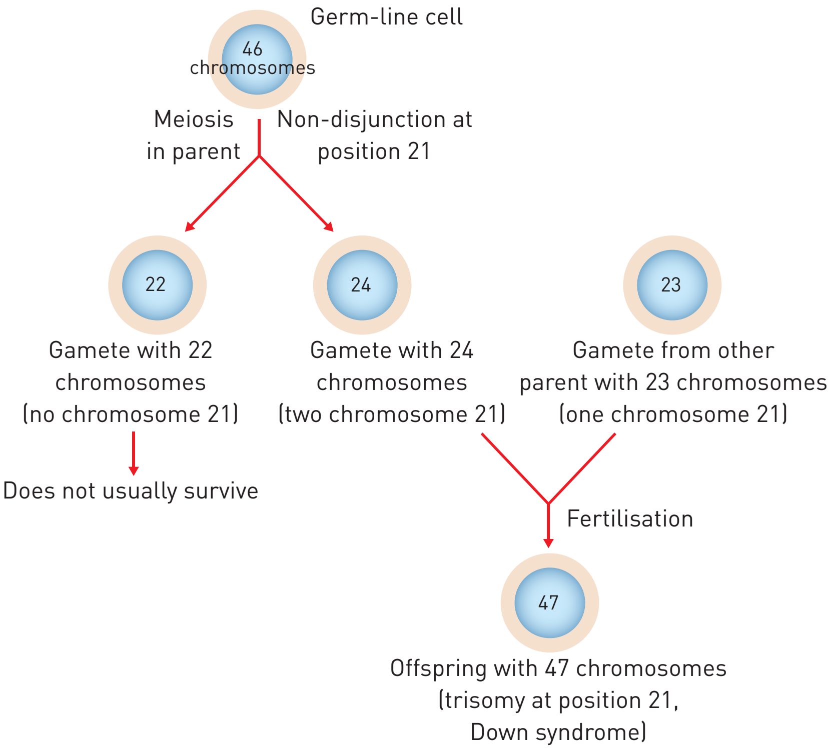


Figure 1.47 Changes in chromosome numbers due to non-disjunction.

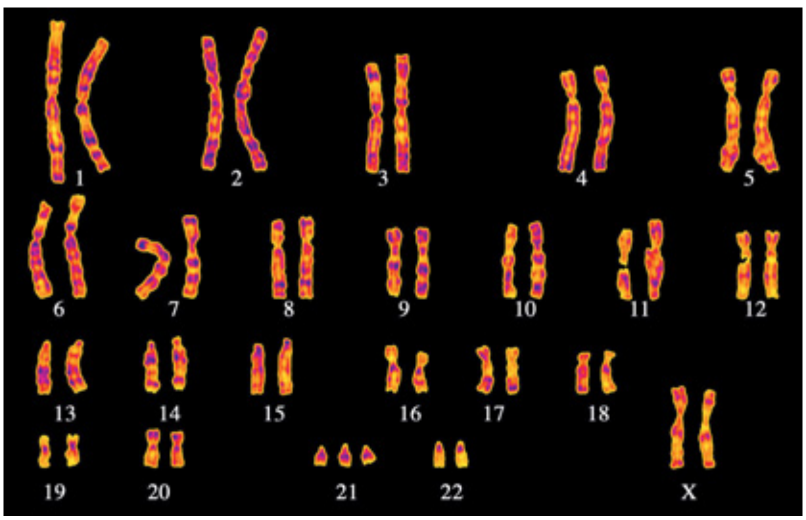


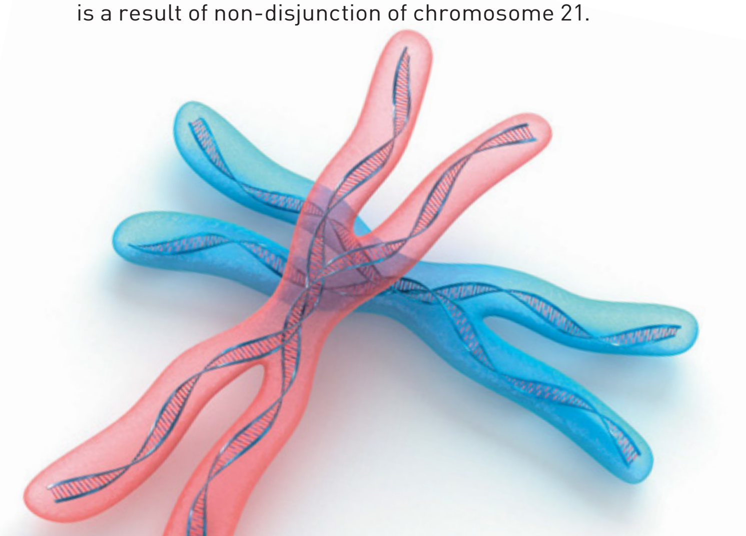
Figure 1.48 Individuals with Down syndrome have three copies of chromosome 21.

Mutations involving chromosome number

This type of mutation is usually the result of **non-disjunction** – the failure of a chromosome pair to separate at the centromere in meiosis. In such cases, one of the daughter cells (gametes) will have too many chromosomes and the other will have too few chromosomes (Figure 1.47). If an abnormal gamete is fertilised, the offspring will have either too many or too few chromosomes.

Down syndrome is the result of non-disjunction in chromosome pair 21 during the formation of the gametes in one parent. A person with Down syndrome has three copies (trisomy) of chromosome 21 (Figure 1.48).

Figure 1.49 This girl has Down syndrome, which is a result of non-disjunction of chromosome 21.



Non-disjunction in sex chromosomes

Non-disjunction can also occur with the sex chromosomes X and Y. This can result in a variety of syndromes.

Females with Turner syndrome have only one X chromosome (Figure 1.50). Turner syndrome can manifest in many different ways and it is not always apparent from the person's physical appearance. Symptoms can include shorter than average height, infertility, extra webbing on the neck, swollen hands and feet, diabetes and many other difficulties. Turner syndrome does not normally affect intellectual ability.

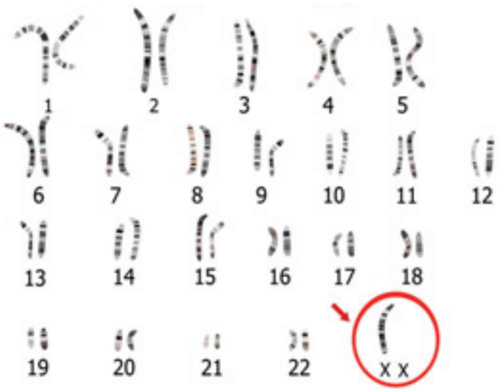


Figure 1.50 Turner syndrome is a result of non-disjunction of the X chromosome.

Males with Klinefelter syndrome have an extra X chromosome, giving them a total of 47 chromosomes (Figure 1.51). This can affect their fertility, muscle development and intellectual abilities. Many of these individuals will be undiagnosed. Approximately 1 in 660 males are affected.

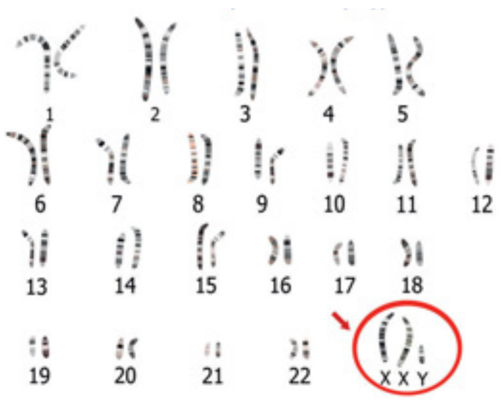


Figure 1.51 Males with Klinefelter syndrome have an extra X chromosome.

Cri du chat syndrome

This series of symptoms is caused by missing portions of chromosome 5 (Figure 1.52). Both males and females can be affected. Symptoms include having a high-pitched cry (similar to that of a cat) as a baby. People with Cri du chat syndrome are slow to grow, and often have a small head and intellectual difficulties. Their fingers or toes can sometimes be fused together.

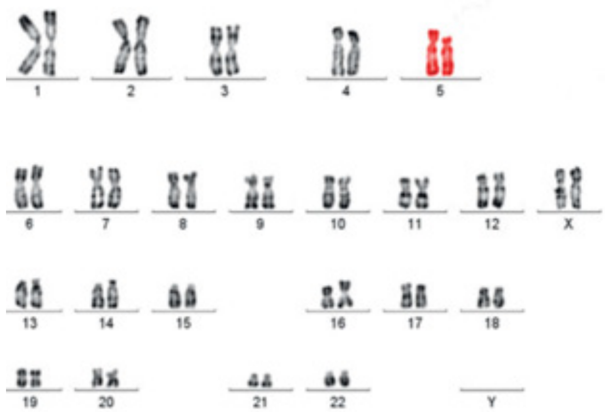


Figure 1.52 Cri du chat syndrome occurs when part of chromosome 5 is missing.

Check your learning 1.10

Remember and understand

1. Define 'mutation'.
2. What is a mutagen? Give some examples of mutagens and how they act to cause mutations.
3. What is a trisomy? Give an example of a trisomy in humans.
4. What is a frameshift mutation?

Evaluate and create

5. Can mutations ever be advantageous? Provide evidence to support your answer.
6. Draw a series of diagrams that show non-disjunction occurring in meiosis.
7. How would you test if a male had Klinefelter syndrome?

//SCIENCE AS
A HUMAN ENDEAVOUR//

1.11 Genes can be tested

Unique probes (short sections of complementary nucleotides) can be used to bind to the specific alleles of individuals at risk of genetic diseases. These probes can be used to identify if an individual has inherited the alleles for a disease or if they are at increased risk of developing a disease such as breast cancer, cardiovascular disease or Alzheimer's disease. While this has advantages in the treatment of the disease, there are many social and ethical issues that must be considered.

Genetic screening and testing

Genetic testing is carried out on people who are known to be at risk of a particular genetic disease or condition. This is usually evident from an individual's family history. The genetic material of a person at risk is obtained through a blood sample. DNA from the white blood cells (red blood cells do not have a nucleus) is isolated and replicated. Special probes act like a stain that sticks to specific genes in the chromosomes, identifying the particular allele that is present in people at risk of the trait.

Genetic screening refers to testing that is readily available to a cross-section of people within the community regardless of a previous family history of genetic disease.

Figure 1.53 A blood sample is being collected from a newborn infant to screen for phenylketonuria – a disease that affects the way the body breaks down proteins.

Genetic screening and testing services currently available in Australia include:

- **maternal serum screening (MSS)** – offered to all pregnant women for the detection of Down syndrome and neural tube defects
- **newborn screening** – the screening of all newborn babies for genetic diseases, including phenylketonuria (PKU), hypothyroidism and cystic fibrosis
- **early detection and predictive testing for adults** – the screening of adults to detect existing disease, a predisposition to disease or carriers with a reproductive genetic risk.

Genetic screening can increase the early diagnosis of and subsequent intervention in genetic diseases. Potentially, this will minimise the frequency of such diseases in subsequent generations; however, it sometimes involves some very difficult decisions. For example, parents who are carriers of genetic mutations must decide whether to have children, who may suffer from the disease. Genetic screening also raises the following questions. What are the risks of the tests and are people prepared to take them? Who should be screened, and for what? What is the impact of false positives? What options are available if it's not good news?

Genetic counsellors can help clarify the situation, but they cannot make the decision for the people involved.

The collection, storage and potential uses of genetic information raise many ethical questions, including who should access the information and the possible misuse of such information.

Sex, Down Syndrome Tests

The Weekend West November 7 – 8, 2015, p.17

by Cathy O' Leary, Medical Editor

A growing number of pregnant women in WA are having a simple blood test that can pick up signs of Down syndrome and the baby's sex as early as 10 weeks.

Doctors say demand has gone 'crazy' in WA for non-invasive prenatal testing (NIPT), which costs more than $400 but is more accurate than the blood test used in traditional prenatal screening. Women found to be at low risk of Down syndrome by the test could avoid having invasive procedures such as amniocentesis, which increases the risk of miscarriage.

Instead of testing cells from the foetus or the placenta, NIPT picks up traces of foetal DNA circulating in the mother's blood. Because there is an option to screen for sex-linked chromosomes, it can also show the gender of the foetus.

Some ethics experts are worried that detecting the gender early on could make it easier for couples who want a child of a particular sex to terminate the pregnancy.

Prenatal screening is usually aimed at women at higher risk of Down syndrome, such as those aged over 35, but even low-risk women are having the newer test, despite it not having any Medicare or private health insurance rebate. It cost $1400 when it became available in Australia three years ago but it is now as low as $420. While it is not a diagnostic test, it is 99 per cent accurate and has a very low false positive rate. A WA survey of high-risk pregnant women presented at the Royal Australian and New Zealand College of Radiologists scientific meeting in Adelaide yesterday showed most preferred it.

Obstetric radiologist Emmeline Lee, from Western Ultrasound for Women, said there had been a huge uptake in WA. 'The market has gone crazy,' she said. 'Even though we were cautious about offering it only to high-risk women, we're seeing low-risk women wanting it as an extra layer of security.'

Professor Peter O'Leary from Curtin University's Faculty of Health Sciences, said there was a push to have test publicly funded but he believed it should be limited to 20 per cent of women at higher risk.

What is NIPT?

- Non-invasive prenatal testing is a new way to screen for genetic abnormalities.
- Unlike invasive tests such as amnioncentesis and chorionic villus sampling (CVS) that collect cells from the foetus or the placenta, NIPT uses traces of foetal DNA in the mother's blood.
- It can be done from 10 weeks and is 99 per cent accurate at detecting Down syndrome.
- Costs between $420 and $900.
- Samples have to be sent to the Eastern states, with results usually within a week.
- A 12-week ultrasound should still be done to check for structural abnormalities.
- It is not a diagnostic test, so women who test positive need to have it confirmed by amniocentesis or CVS.

Extend your understanding 1.11

1. Research one of the diseases mentioned in the text. What are the symptoms of the disorder? How can the disorder be treated? What is the life expectancy of a person suffering from the disorder?
2. List two advantages and disadvantages of pre-natal testing.
3. Prepare a debate on the topic 'Public funding for pre-natal testing should only be made available to high-risk pregnant women'.

//SCIENCE AS
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1.12 Genes can be manipulated

The ability to insert genes from one organism into another relies on the universal nature of DNA. This means that the DNA in every organism is made out of the same four nucleotides (A, T, C and G). The DNA is transcribed into RNA. Each codon (group of three nucleotides) in the RNA must code for the same amino acid. A genetically modified organism is an organism that has had its DNA changed in some way. A transgenic organism is an organism with DNA from a different species inserted into its genome.

Genetically modified organisms

One of the most controversial developments in modern food production is the proliferation of genetically modified organisms, or GMOs. Genetically modified (GM) plants have been modified in the laboratory to enhance certain desired traits, such as increased resistance to herbicides or improved nutritional content. Traditionally, the enhancement of desired traits has been achieved through selectively breeding or mating two organisms that have the trait. Genetic engineering can create plants with the exact desired trait very rapidly and with great accuracy. For example, geneticists can isolate a gene for drought tolerance and insert that gene into a different plant. The new GM plant will display a tolerance to drought. Not only can genes from one plant be transferred into another plant, but genes from non-plant organisms can also be used. Transgenic organisms are those that contain a foreign gene inserted from another organism, usually a different species.

Agriculture has been significantly affected by the introduction of transgenic animals and genetically modified crops and foods (GM foods), including plants that are resistant to herbicides and pesticides. There are also 'pharm' plants and animals that produce pharmaceutical proteins required by humans.

Crops that have been engineered to resist disease mean that farmers use lower amounts of pesticides and herbicides when growing these crops. This reduces production costs. Reducing the amount of pesticides and herbicides also reduces environmental pollution.

Examples of plants that have been genetically engineered include those shown in Figures 1.54–1.56. Figure 1.57 shows the process of introducing a gene from a daffodil into corn.

Figure 1.54 Transgenic variety of cotton that is pest resistant. Genes (specifying a protein toxic to many serious insect pests) from the bacterium *Bacillus thuringiensis* have been introduced into the chromosomes of this plant. The protein is called Bt (*Bacillus thuringiensis*) toxin and the plants are Bt plants. The toxin only becomes active in the alkaline environment of the insect gut, whereas in vertebrate animals it is destroyed by the acid in the stomach.

Figure 1.55 Transgenic papaya plants in Hawaii are resistant to the ring spot virus. Genetically engineering papaya has saved the industry. The technology has also been exported to other countries where ring spot virus is damaging papaya plants.

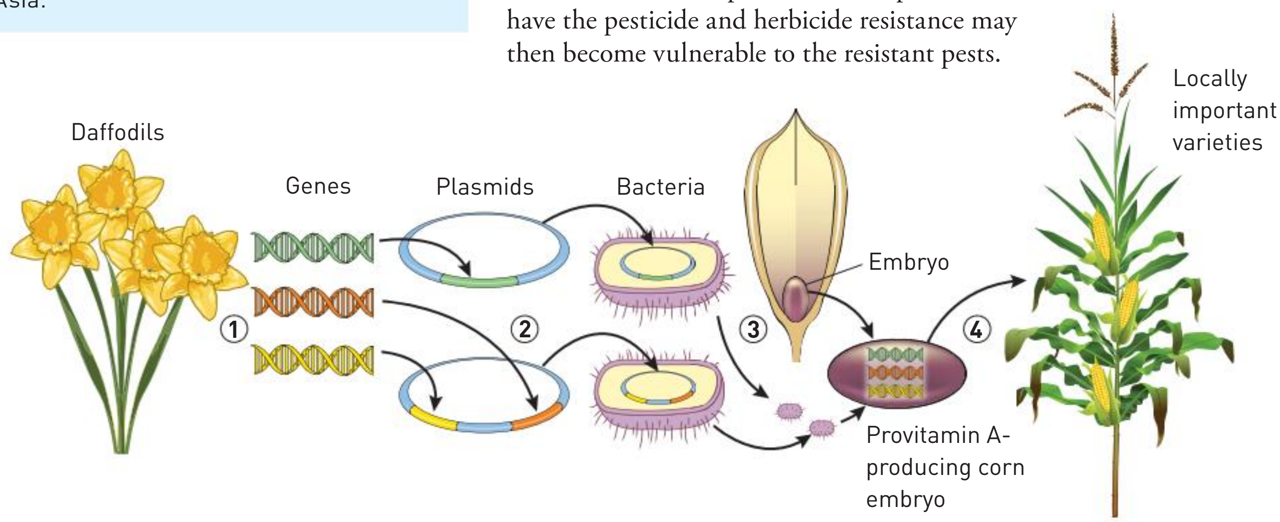
Figure 1.56 Golden rice has had genes inserted from daffodils. These genes control the production of a chemical that is converted into vitamin A, making this rice much richer in vitamin A than non-transgenic rice. Without adequate amounts of vitamin A, people's eyesight can be severely impaired, even leading to blindness. Many people in South-East Asia, a large rice-consuming area of the world, are blind or have severe sight problems due to vitamin A deficiency. Therefore, this high-nutrition rice is most valuable in parts of Asia.

GMO issues

GM crops pose a threat to biodiversity because they replace a number of natural varieties of plants with one variety: the genetically engineered plant. The significant increase in GM plants has only occurred in the past decade or so.

The organic food movement is completely against the principle of GM foods, and public debate into the benefits and dangers of such foods is likely to continue well into the future. Some people believe that GM foods pose health risks, although there is no clear evidence for or against this.

A criticism of GM foods is the potential for accidental gene transfer to other species. GM plants may also contaminate non-GM plants of the same species; for example, when wind blows the pollen from one farm to another nearby. Another problem is that increased pesticide and herbicide resistance may develop in insects and other pests. The GM plants that have the pesticide and herbicide resistance may then become vulnerable to the resistant pests.



1 The gene that produces vitamin A is isolated from a daffodil.

2 This gene is added into a plasmid, a small loop of DNA that acts as a vector, transporting the gene into a bacterial cell.

3 The bacterial cells containing the plasmid are added to the embryonic corn plant.

4 The transgenic corn plant grows. The introduced genes produce high levels of vitamin A.

Figure 1.57 Scientists can grow transgenic corn that produces high levels of vitamin A.

Extend your understanding 1.12

1. Give an example of an organism that has been genetically engineered for use in agriculture. How has it been useful?
2. Briefly describe a method that is used to insert 'new' genes into plant cells.
3. What are some reasons for genetically engineering plants?
4. As a consumer, do you think that food containing GMOs should be labelled?
5. What factors would influence your decision to purchase or not to purchase food containing GMOs?

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1.13 Genetic engineering is used in medicine

Genetic engineering is the process of changing the genetic code of an organism. **Gene cloning** uses this process to produce multiple copies of a particular gene. This can be done to mass produce proteins such as insulin. **Gene therapy** involves the insertion of a healthy version of a gene into the chromosomes of an individual with a defective gene. Current Australian laws prevent any changes to the germ-line cells of an individual.

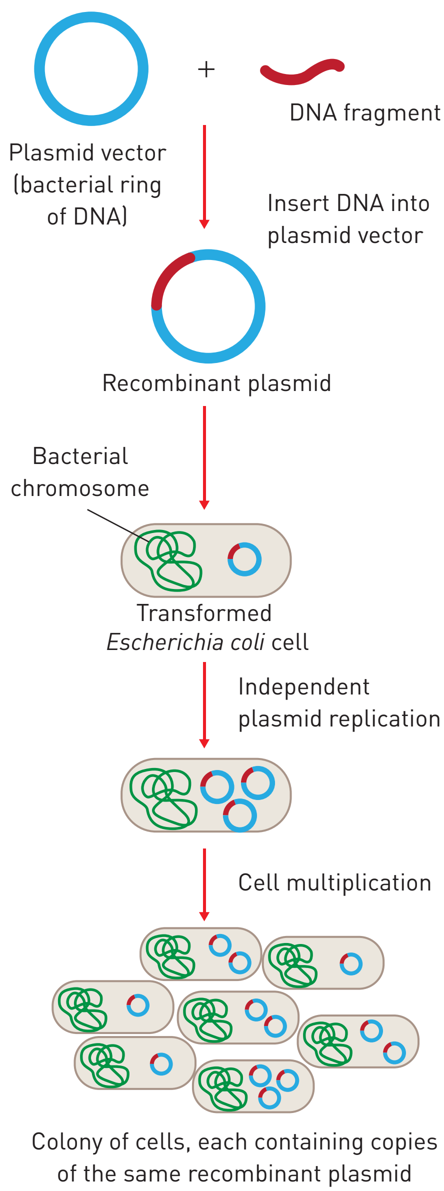


Figure 1.58 Gene cloning

Gene cloning

Another application of genetic engineering is gene cloning: to insert a gene, for example a human gene, into bacteria so that the bacteria now produce a human protein that can be purified and used to treat a human disease (Figure 1.58). This method avoids the rejection issues faced by using similar products from animals, such as pigs or sheep. An example is the production of human insulin by bacteria. People with diabetes need to inject insulin to help control their blood sugar levels.

Gene therapy

Gene therapy involves inserting a healthy gene into the chromosomes of an individual with a defective gene. Gene therapy that involves the body cells (somatic cells) can be therapeutic only. This means that the new gene cannot be passed on to the next generation. At present, gene therapy targeting germ-line cells (cells destined to become gametes) is not legal in Australia.

Gene therapy has been quite successful in the treatment of cystic fibrosis (CF). Patients with CF have a deficiency in a gene that controls the production of a protein that regulates the movement of chloride ions across cell membranes. A major symptom of CF is the accumulation of a thick mucus that can damage lung tissue. This reduces the life span of patients significantly. Medical scientists have been able to clone the healthy gene in bacteria. The purified gene is then attached to a carrier molecule called a vector. The vector in this case is a harmless virus and it is added via a spray through the nose of patients. The virus enters many of the lung cells and inserts the healthy gene into the DNA in the nucleus. When the lung cells divide, the new cells contain the healthy gene (Figure 1.59).

Apart from the success with CF and the great potential of gene therapy, there has been limited progress since the first clinical trials in 1990. Several people died as a consequence of the technique. The ethics of treating patients with a technique that involves significant risks to life have to be considered carefully.

Stem cells and ethics

Stem cells are undifferentiated cells that can differentiate (mature) into many different types of specialised cells, such as muscle, nerve, liver and blood cells. There are two types of stem cells. Pluripotent embryonic stem cells (obtained from embryos) can develop into most cell types in the body, whereas multipotent adult stem cells can only develop into certain cell types in the body.

There are many ethical issues associated with the use of embryonic stem cells. The establishment of a stem cell line involves the artificial creation of an embryo solely for the purpose of collecting stem cells. This process results in the destruction of the embryo. At present, such procedures are illegal in Australia. The only embryos that are used for research are those classed as 'excess embryos', having been originally created for use in *in vitro* fertilisation (IVF). However, some people consider the use of these excess embryos to be unethical. They regard the embryos as potential life and their use in research as depriving life to these embryos.

Most recently, scientists have been able to reverse the differentiation process and turn multipotent adult stems cells back into pluripotent stem cells. These cells are called induced pluripotent cells. In the future, induced pluripotent stem cells may be used to treat a variety of diseases, including cancer, multiple sclerosis (MS), Parkinson's disease, motor neurone disease and spinal cord injuries.

Some potential parents also want to choose certain embryos over others. For example, they may want a male or a female child. They may want a child with blue eyes and fair hair. They may choose a healthy embryo over one with, say, cystic fibrosis. This situation has ethical implications. What will parents do with embryos that don't have the desired characteristics?

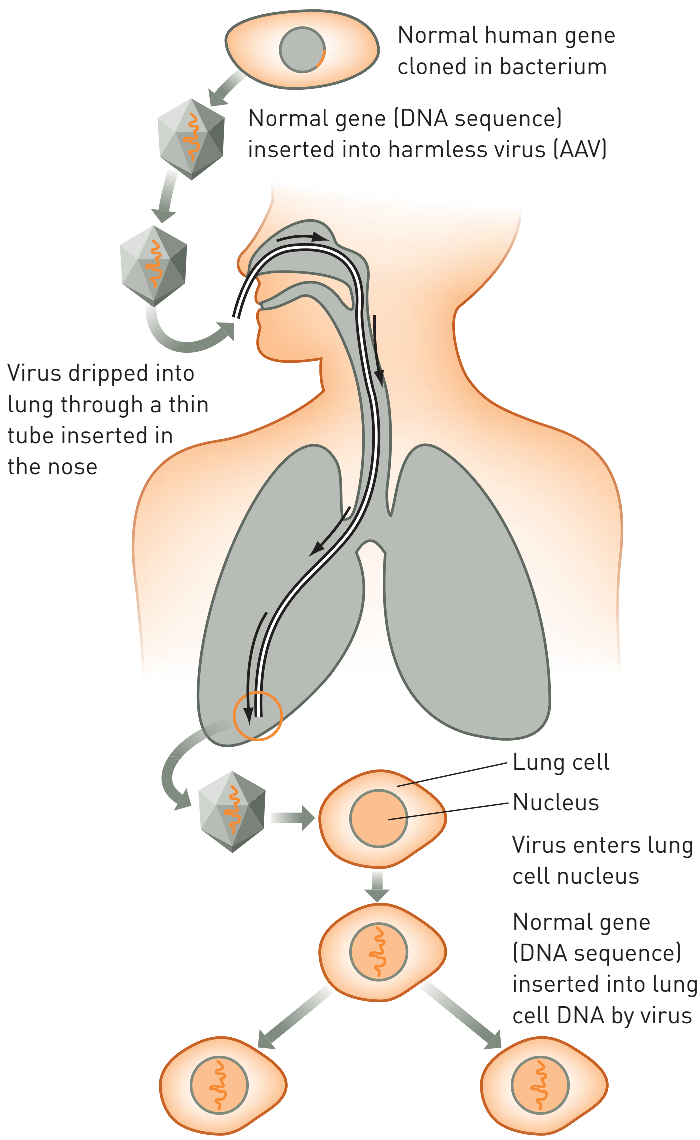


Figure 1.59 Gene therapy.

Extend your understanding 1.13

1. What is the aim of gene cloning?
2. Describe the process used to produce human insulin by gene cloning.
3. Why do scientists choose bacteria to clone human genes?
4. Give an example of a successful gene therapy treatment for a disease.
5. Why is the use of induced pluripotent cells more acceptable to some people than embryonic stem cells?

Remember and understand

1 Name the four nitrogen bases found in DNA.

2 Use the terms 'gametes' and 'fertilisation' to explain how DNA is transferred from one generation to the next.

3 Relate a chromosome to a molecule of DNA and explain how the replication of DNA is important for both mitosis and meiosis.

4 Describe three differences between the structure or function of DNA and RNA.

5 Use words and/or diagrams to explain the differences between:
   a a nitrogen base and a codon
   b diploid and haploid.

6 What is a monohybrid cross?

7 What were Mendel's conclusions from his work on breeding peas?

8 What is the difference between the following pairs of terms?
   a Autosome and sex chromosome
   b Gene and allele
   c Heterozygous and homozygous

9 Explain what is meant by the following formula:

   Phenotype = genotype + environment

10 Define:
   a GMO
   b transgenic organism.

11 Explain the process of:
   a gene cloning
   b gene therapy.

Apply and analyse

12 If a gene contains 600 nitrogenous bases, how many amino acids would be incorporated into the resulting protein?

13 Which of the following is not a function of mitosis?
   A Replenishing the epithelial cells of the small intestine that are shed daily
   B Forming new red blood cells to replace those that are worn out
   C Forming cells for sexual reproduction
   D Repairing cuts and abrasions of the skin

14 What sort of information can be determined from the pedigree shown in Figure 1.60? List as many points as possible.

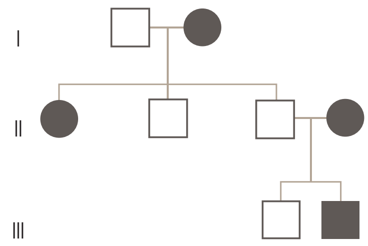


Figure 1.60

15 Can large-scale genetic screening programs reduce the prevalence of genetic diseases? Explain your answer.

16 Gene therapy has been proposed as a treatment for a young boy suffering from Duchenne muscular dystrophy, a degenerative disorder of the muscles. Describe three factors that should be considered by the boy's health team prior to treatment.

Evaluate and create

17 Does a chromosome or a gene provide the most information about the make-up of an individual? Explain the reasons why.

18 A newborn baby shows distinct facial abnormalities. A karyotype (Figure 1.61) was prepared to determine whether there were any chromosomal abnormalities.

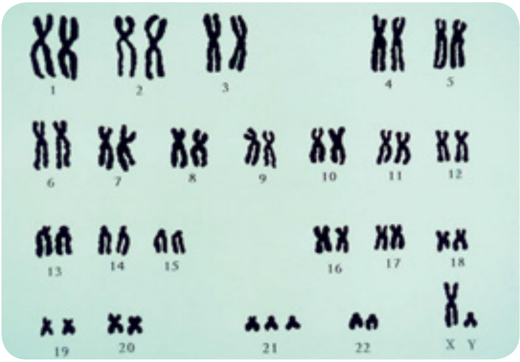


Figure 1.61

   a What is the total number of chromosomes shown?
   b Is the child male or female? How do you know?
   c As the geneticist, what could you tell the parents about their baby?

19 If both parents have achondroplasia, what are the chances of their children being unaffected?

20 Phenylketonuria is an autosomal recessive genetic disorder. It results in the lack of production of an enzyme that is needed to metabolise the amino acid phenylalanine to the amino acid tyrosine. A diet low in phenylalanine and high in tyrosine is prescribed to people with phenylketonuria to avoid problems with brain development. Every child born in Australia is now screened for phenylketonuria within weeks of birth. What is the benefit of such genetic screening?

21 Create a teaching resource that could be used to teach a Year 7 student about the process of cell division.

22 Select a genetic disease and create a pamphlet for display in the reception area of a doctor's surgery. The pamphlet should outline information about the cause of the disease (gene or chromosomal abnormality), pattern(s) of inheritance, the frequency of the disease in the population, diagnosis, symptoms and treatment.

23 Produce a brochure that promotes the benefits of purchasing organic and non-GM foods. Alternatively, produce a brochure promoting the benefits of GM foods.

Ethical understanding

24 The debate around embryonic stem cells is heated. What are the reasons for and against using embryonic stem cells? How have governments intervened in this area? Based on your findings, do you think that using embryonic stem cells could provide benefits to humans?

Research

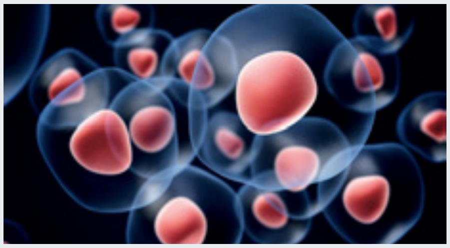
25 Choose one of the following topics for a research project. Some questions have been included to help you begin your research. Present your report in a format of your own choosing.

> **Breast cancer**
> To what extent does a family history affect an individual's chances of developing breast cancer? How is breast cancer detected and treated?

> **A shrinking Y chromosome**
> The Y chromosome has been losing genes over the course of time so that it is now only a fraction of the size of the X chromosome. How has this happened? Will it disappear altogether? What is the future of the Y chromosome? What effect could this have on humans?

> **Cloning**
> What other sorts of animals have been cloned since Dolly the sheep in 1997? What are some of the arguments for and against cloning?

> **Stem cell survival technique**
> Australian scientists have found a way to keep muscle stem cells alive so they can regenerate damaged tissue around them. Why is this technique a breakthrough? What does the technique involve? What are the immediate uses of this technique?



KEY WORDS

1

adenine
a nitrogen base of DNA or RNA; complementary to thymine in DNA and uracil in RNA

allele
a version of a gene. Each person inherits one allele from each parent

autosome
a chromosome that does not determine the sex of an organism

carrier
a person who has the allele for a recessive trait that does not show in their phenotype

complementary base
a nucleotide base that pairs with its partner nucleotide on the alternative DNA strand. Adenine pairs with thymine, cytosine pairs with guanine

cytosine
a nitrogen base of DNA or RNA; complementary to guanine

deoxyribonucleic acid (DNA)
a molecule that contains all the instructions for every job performed by the cell; this information can be passed from one generation to the next

diploid
a nucleus that contains two complete sets of chromosomes

dominant trait
a characteristic that needs only one copy of an allele to appear in the physical appearance of an organism

frameshift
the process of moving the reading frame of codons through the addition or deletion of a nucleotide; usually results in a deformed protein

genetic code
the sequence of nucleotides found in DNA that is inherited from parents

genetic mutation
a permanent change in the sequence of nucleotides in DNA

genotype
the combination of alleles for a particular trait

guanine
a nitrogen base of DNA or RNA; complementary to cytosine

haploid
a nucleus that contains one complete set of chromosomes; usually found in a gamete

heterozygous
having two different alleles for a particular trait; a carrier for the recessive trait

homozygous
having two identical alleles for a particular trait

karyotype
the arrangement of a complete set of chromosomes in pairs of decreasing size

meiosis
the process that results in the formation of gametes with half the genetic material of the parent cell

mitosis
process of cell division to provide growth or repair: results in genetically identical daughter cells

mutagen
a chemical or physical agent that causes a change in genetic material such as DNA

non-disjunction
the failure of one or more chromosomes to separate and move to the end of the cell during meiosis; it can result in an abnormal number of chromosomes in the daughter cells

nucleotide
a subunit of a DNA molecule

phenotype
the physical characteristics that result from an interaction between the genotype and the environment

Punnett square
a diagram that is used to predict the outcome of breeding organisms

recessive trait
a characteristic that results from the inheritance of two identical alleles

ribonucleic acid (RNA)
ribonucleic acid; a complementary copy of DNA that is able to carry the genetic message from the nucleus to the cytoplasm

sex chromosome
a chromosome that determines the sex of an organism

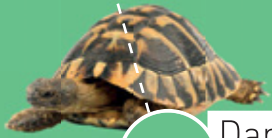
stem cell
a cell that can produce a number of different types of cells. Adult stem cells can produce a limited number of cell types (e.g. skin stem cells), whereas embryonic stem cells can produce multiple types of cells

thymine
a nitrogen base of DNA; complementary to adenine

transcription
the formation of complementary RNA from DNA

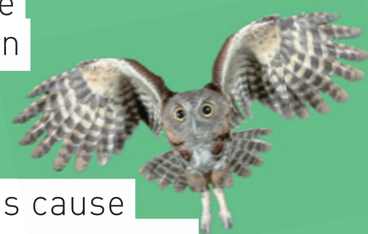
translation
the formation of a protein from RNA; occurs on a ribosome

EVOLUTION 2



2.1 Darwin and Wallace were co-conspirators

2.2 Natural selection is the mechanism of evolution



2.3 Different selection pressures cause divergence. Similar selection pressures cause convergence

2.4 Fossils provide evidence of evolution

2.5 Multiple forms of evidence support evolution

2.6 DNA and proteins provide chemical evidence for evolution

2.7 Humans artificially select traits

2.8 Natural selection affects the frequency of alleles

What if?

What you need:

range of eating utensils (e.g. spoons, forks, chopsticks or straws), lollies

Make sure you check for food allergies and avoid using lollies that present a risk of anaphylaxis.

What to do:

1 This is a whole-class activity. Each group of students has a different type of eating utensil, such as spoons, forks, straws and chopsticks. Each group has the same mix of lollies.

2 Using only the tool provided, try and collect as many of the lollies as possible into a bowl.

What if?

» What if there were more spoons? (Would some lollies disappear quicker/slower?)

» What if only hard-boiled lollies were available? (Which utensil would collect the most lollies?)

» What if straws were the only utensil available? (What type of lolly could they be used for?)

//SCIENCE AS A HUMAN ENDEAVOUR//

2.1 Darwin and Wallace were co-conspirators

Scientific theories are explanations of the natural world that are based on well-substantiated evidence. These theories are contested and refined over time through a process of review by the scientific community. The statement 'organisms change in response to environmental pressures' is an observation. Natural selection as the mechanism of **evolution**, as proposed by Charles Darwin and Alfred Wallace, is a scientific theory that has 200 years of reproducible experimental evidence supporting it.

Figure 2.1 These layers of rock are an indication of different time periods. Pale layers can sometime represent volcanic ash released during an eruption.

Before evolutionary theory

The generally accepted belief for many thousands of years was that life was 'created' by gods. Even events such as volcanoes and earthquakes were considered to be the consequences of the emotions of the gods. Societies could have one or more gods, which could be human or animal-like in appearance.

There was little thought given to whether organisms changed over time. The idea of extinction was not proposed until the 1790s, when William Smith uncovered fossils while analysing the geology of a mine in England. Fossils were already known to be the remains of living organisms, but Smith identified organisms that had never been seen before and was able to 'date' them by the layer of rock in which they were found. This later became known as relative dating.

Georges Cuvier, a French zoologist, collected and examined many fossils. He concluded that many of the animals represented were remains of species now extinct.

Early evolutionary theory

Evolutionary theories were all proposed without any knowledge or understanding of DNA and genetic inheritance – making the following accounts even more remarkable.

Lamarckian theory

One of the first documented theories of evolution was by Jean-Baptiste de Lamarck, a French naturalist. Lamarck believed in evolutionary change – that organisms change over time due to changing environmental conditions. He is best known for his hypothesis of inheritance of acquired characteristics, which was first presented in 1801. In this hypothesis, Lamarck proposed that if an organism changes during its lifetime in order to adapt to its environment, those changes are passed on to its offspring. This is how he explained the long necks of giraffes (Figure 2.2).

There are many problems with Lamarck's hypothesis. For example, Lamarck's hypothesis implied that the children of a man who had lost his arm would also have weak or deformed arms as a result. This was obviously not the case. August Weismann finally provided scientific evidence when he cut the tails off 22 generations of mice, continually allowing them to breed with each other. Unsurprisingly, all their offspring were born with tails.

Figure 2.2 Lamarck believed that giraffes stretched their necks to reach food and that their offspring, and later generations, inherited the resulting stretched long necks.

Charles Darwin

Charles Darwin (Figure 2.3) was well educated and had been exposed to the sciences from an early age through his father and grandfather, who were both physicians. Darwin had also read the works of Lamarck. In 1832, the young 23-year-old set sail on a 5-year world cruise as the unpaid naturalist on the HMS *Beagle*.

During the final stages of the voyage, the ship visited the Galapagos Islands, about 1000 km off the coast of South America. Here, Darwin made his most significant observations.

Darwin and his helpers collected specimens, seeking to obtain at least one of each species. Among the specimens collected were 13 finches, all of which resembled one another in terms of the structure of their beaks, the form of their bodies and their plumage. Yet each specimen represented a new species and most had been found on different islands.

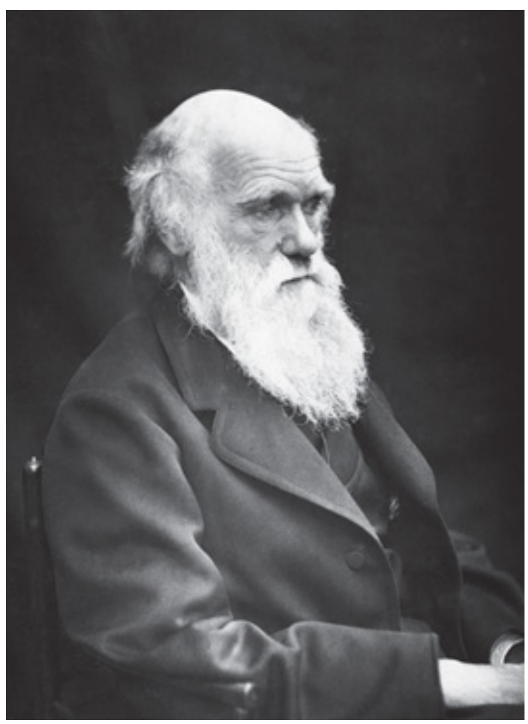


Figure 2.3 Charles Darwin's theory of evolution was a departure from the traditional view of Creation and attracted much public interest and criticism.

Figure 2.4 On the Galapagos Islands, tortoises' shells vary in shape according to habitat.

In his journal, Darwin noted that these birds were strikingly similar to those found on the mainland of South America. He wondered why the different populations looked so similar, if new and different beings had been placed on the islands at the time of Creation.

The dry, volcanic Galapagos Islands archipelago is also home to different species of tortoise. Darwin noted that the different types of tortoise had different-shaped shells (Figure 2.4). Tortoises that live on dry islands, such as Hood Island, have shells that are raised at the front so they can reach up for vegetation. In contrast, tortoises that live on islands with dense vegetation have domed shells to help them push through the shrubbery.

Darwin was also aware that humans have selectively bred pigeons and racehorses for more than 10 000 years by choosing breeding partners for animals and other organisms in an effort to 'select' for certain traits in their offspring. Over many generations, the 'wild' traits are often lost and the species is considered 'domesticated'.

Figure 2.5 Was the plague simply nature's way of keeping the human population in check?

Darwin then wondered how 'selection' occurred in nature. Thomas Malthus's paper *An Essay on the Principle of Population* gave Darwin the insight he needed. Malthus argued in his paper that the human race would completely overrun the Earth if it were not held in check by war, famine and disease such as the plague, or 'Black Death', in the 14th century (Figure 2.5). Darwin concluded from this that, under changing circumstances, favourable variations would tend to be preserved and unfavourable ones would be destroyed.

At last Darwin had a hypothesis to test. But it would take another 20 years of painstaking hard work before he was convinced that his hypothesis had enough support to be developed into a theory.

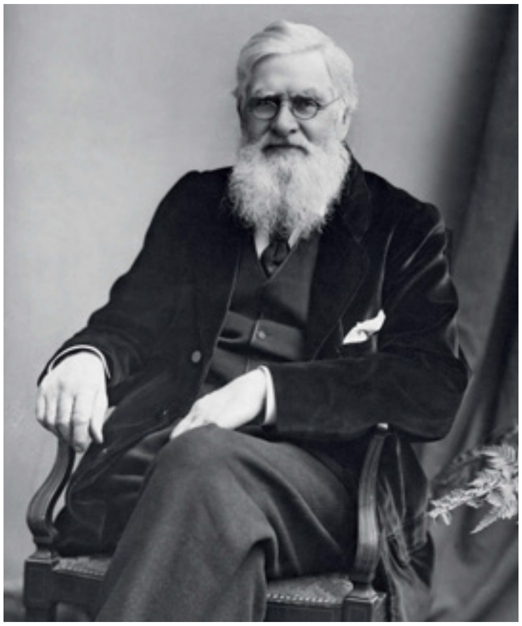


Figure 2.6 Alfred Russel Wallace formed the same theory as Darwin and at the same time. Wallace's work was conducted in Asia, whereas most of Darwin's observations were made in Africa. Darwin had the advantage of a wealthy family that could assist him in being published. Perhaps this is why Darwin receives all the credit.

Alfred Russel Wallace

Alfred Russel Wallace (1823–1913) (Figure 2.6) was a naturalist working at the same time as Darwin. Wallace collected specimens from tropical regions, particularly the Malay Archipelago, which is now Malaysia and Indonesia. Wallace collected thousands of insects, shells and bird skins, as well as mammal and reptile specimens, many of which were new species to science at the time. One of his best-known discoveries was Wallace's golden birdwing butterfly.

During his time in the Malay Archipelago, Wallace proposed the theory of natural selection as the mechanism of evolution. In 1858, he wrote a series of letters to Darwin outlining his idea. Darwin and his friends were worried about who should get the credit for the two theories that were essentially identical. They decided to read Wallace's letter and Darwin's paper one after the other at the Royal Linnaean Society of London. We now associate Darwin with the theory of evolution because, in 1859, Darwin published his book *On the Origin of Species by Means of Natural Selection.*

Extend your understanding 2.1

1. One of the biggest questions asked by humans is 'Where did we come from?' How have different people answered this question?
2. Charles Darwin wasn't the first person to propose the idea of evolution. What was Lamarck's hypothesis about the way evolution worked?
3. What was it about the tortoises of the Galapagos Islands that helped Darwin develop his ideas about evolution and natural selection?
4. What features of the finches showed similarity in form?
5. Why do you think Darwin waited so long between arriving at his hypothesis and publishing his theory on evolution?
6. Draw a timeline of ideas before and after the theory of evolution.
7. Do you think it is fair that Darwin receives all of the credit for the theory of evolution? Justify your answer.
8. Discuss why, for various reasons, the theory of evolution has been controversial for some people.

2.2 Natural selection is the mechanism of evolution

Evolution is the permanent change in the frequency of alleles in a population due to natural selection. Mutations introduce new alleles into the gene pool, increasing the diversity of a population. **Selection pressures** cause some of these new variations to survive and others to die. If an organism is suited to its environment, then it is able to mate and produce offspring. The offspring will have the same survival characteristics (and the corresponding alleles) as their parent. This gradually changes the frequency of alleles in the gene pool.

Observations and inferences

Although scientists knew that living organisms change over time, how the change occurred was first described by Charles Darwin and Alfred Wallace. They did this through a series of observations.

1 Members of a species are often different from each other.
2 There are always more children than parents.
3 The size of a population does not change.
4 Some offspring do not survive (survival of the fittest).
5 Offspring look like their parents.

These five observations led Darwin to make two key inferences.

1 In the struggle to survive, those individuals that are most suited to their environment survive.
2 Those individuals that survive pass their traits on to their children.

Variations in populations

Natural selection depends on the variation of traits within a population, but where does this variation come from?

Much of the variation between individuals is due to genetic differences that can be inherited – something that Darwin and his contemporaries observed but did not understand.

Individuals of the same population generally have the same number and types of genes, but different alleles (variations of the genes). For example, all humans will have the gene for eye colour, but the alleles they have for this gene may be blue, brown or even hazel. New alleles arise because of small changes in the DNA sequence. Some mutations are not evident in the appearance of an organism. Other mutations cause variations in the physical appearance (phenotype) of the individual. For example, it was a single mutation about 6000–10 000 years ago that resulted in one of our ancestors having blue eyes.

Figure 2.7 These Siberian huskies have different versions, or alleles, of the gene for eye colour.

EXPERIMENT 2.2: WHAT IF THE HABITAT OF BEAN PREY WAS CHANGED?
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All the different types of genes in the entire population can be thought of as a **gene pool** – a pool of genetic information. The gene pool includes all the alleles for all the genes in the population. New alleles arise through changes (or mutations) in the DNA that makes up the genes.

A mutation may give an individual an advantage, making them better able to survive than others of their population. This means they have a greater chance of mating and passing their genetic advantage on to their offspring.

Allele frequencies

Populations are always evolving. The frequency of an allele is how common that allele is within a population. The allele frequency is affected by environmental conditions. If the environmental conditions are favourable, then more of that allele is passed on to the next generation.

Mutating moths

In the 1950s, scientists in England documented changes in the colour of the moth species *Biston betularia*. These moths range in colour from light grey to nearly black (Figure 2.9). During the day, the moths rest motionless on tree trunks. In unpolluted areas, tree trunks are covered with light-grey lichens, against which the light-grey moths are well camouflaged. In areas with severe air pollution, lichens cannot survive, so the tree trunks are lichen-free and dark, exposing lighter moths to predation from birds.

It seemed to researchers that, as areas became more polluted, dark moths increased in frequency. This is often described as the selection pressure. The darker – coloured bark allowed the dark moths to survive (be selected for), and the lighter moths to be eaten (be selected against). Natural selection seemed to be increasing the frequency of the allele for dark colour in the population. This was selection pressure in favour of the 'dark' allele.

In 1952, strict pollution controls were introduced in England, the lichens returned, and the tree trunks became mostly free of soot. As may have been predicted, selection pressures started to operate in the reverse direction. In areas where pollution levels declined, light moths were selected for, and dark moths selected against. The frequency of dark moths declined.

Other examples of directional selection include the evolution of pesticide-resistant insects and antibiotic-resistant bacteria. In these cases, our use of chemicals (i.e. pesticides or antibiotics) has selected for variants that are resistant to the chemicals.

Figure 2.9 Dark-coloured moths of the species *Biston betularia* increased in numbers when air pollution killed lichen on trees. Lighter coloured moths were then more visible to predators and were selected against.

Figure 2.8 Syndactyly is webbing between the fingers and toes. It is quite common because a foetus has webbing that undergoes 'programmed cell death', or apoptosis, to remove it prior to the baby being born. Syndactyly is biologically neutral, because the webbing is usually neither an advantage or a disadvantage. However, there are certainly situations in which it may be beneficial. Imagine a career as an Olympic swimmer!

Check your learning 2.2

Remember and understand

1 Variation in individuals can occur in different ways, but there is only one way in which new alleles can arise. What is this process called?

2 Darwin made a series of inferences based on observations he made over 20 years. Link each of Darwin's observations with the appropriate inference he made.

3 Describe the selection pressures that caused the allelic frequency of light-grey moths to decrease in England in the 1950s.

4 In your own words, describe the mechanism by which natural selection can influence the frequency of alleles in a population.

Apply and analyse

5 Natural selection cannot increase or decrease the frequency of some mutations in a population. Why is this?

2.3 Different selection pressures cause divergence. Similar selection pressures cause convergence

When two populations become separated, the gene flow between the species is stopped. If the two species experience different selection pressures, then they gradually become more different from each other. Eventually they may become reproductively isolated and are said to have **diverged**. The two new species may retain homologous structures in common. If two very different species are exposed to the same selection pressures, they may develop analogous structures. Their structures will appear to converge.

Speciation

When a variation within a species is favoured by the environmental conditions, it is referred to as an **adaptation**. Variations within a species provide 'options' for the species when environmental conditions change. Although individual organisms may be wiped out, some members of the population with the favourable adaptation survive and continue the species' gene pool.

Along the way, entire species may become extinct and new species increasing the biodiversity of organisms in the environment will emerge.

Under normal conditions, genes in a given population are exchanged through breeding. This means the genes will flow from one generation to the next as different families or groups in the population choose partners and mate. This is called **gene flow**. But the gene flow is interrupted if the population becomes divided into two groups – **isolation**. If there is no exchange of genes between the two groups, then they may begin to look and behave differently from each other. Over time, different selection pressures occur in the two groups. Different characteristics are selected for. Given enough time for evolution to occur, the two populations may become so different that they are incapable of interbreeding should they ever come together again. The two populations become reproductively isolated and therefore are different species – **speciation**. The two species have diverged.

Allopatric speciation is one of the most common ways species become different or diverge.

Even though populations diverge and become different species, they retain some characteristics in common. These characteristics, such as forelimbs, may be used for different purposes because the selection pressures have changed. Common structures that are found in different species often have a similar pattern but a different function. These structures are known as **homologous structures**. The most commonly discussed homologous structure is the pentadactyl limb – the pattern of limb bones in all groups of tetrapods (i.e. four-legged vertebrates) that ends in five digits (Figure 2.10). This structure is found in the fins of certain fossil fishes from which the first amphibians are thought to have evolved. Throughout the tetrapods, the basic structure of the pentadactyl limbs is the same.

EXPERIMENT 2.3: DIVERGENT AND CONVERGENT EVOLUTION OF BIG BEAKS AND SMALL BEAKS
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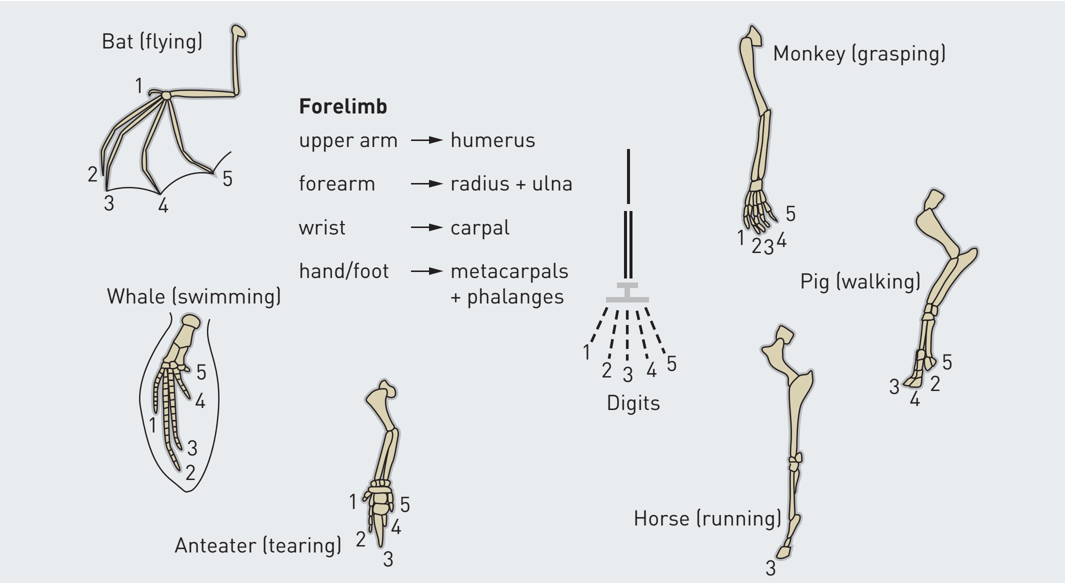

Figure 2.10 The homologous forelimbs of different mammals show the same basic structure, with a single upper bone, two lower limb bones, small wrist or ankle bones and five digits that are adapted to different uses.

This indicates that these organisms originated from a common ancestor. But, during the course of evolution, these structures have become modified and are used for different purposes as a result of different selection pressures.

Analogous structures are structures in organisms that perform the same function but are structurally different (suggesting no recent common ancestor). For example, a dolphin (mammal) and a shark (fish) have the same environmental selection pressures. Although these species do not share a recent common ancestor, they both need to move through water fast enough to catch fish and escape predators. As a result they both have a streamlined body with fins and tails. This is an example of **convergent evolution**. The wings of birds and butterflies are also analogous structures (Figure 2.11).

Figure 2.11 The wings of a bird and the wings of a butterfly are analogous structures: they perform the same function, but have significantly different structures.

Check your learning 2.3

Remember and understand

1 Give an example of how physical isolation could create a new species.
2 How does gene flow influence the process of speciation?
3 Define the term 'homologous structures'.
4 Give an example of an analogous structure.

Apply and analyse

5 Describe how the land ancestors of dolphins evolved to become the streamlined mammals we see now.

2.4 Fossils provide evidence of evolution

The existence of fossils is one form of evidence supporting evolution. **Fossils** are remains or traces of an organism that once existed. The fossilisation process requires the dead organism to be buried without oxygen. **Transitional fossils** are intermediary fossils that have traits of both the ancestral organism and the more recent organism. Relative dating determines the relative order the fossilised remains were buried. Older fossils are found in deeper layers than more recent fossils. **Absolute dating** uses the amount of radioactivity remaining in the rock surrounding the fossil to determine its age.

Evolution

Support for any theory, including evolution, requires evidence from a range of sources that all point towards the same explanation. Early evidence for evolution came from the discovery of fossils that identified extinct species. Evidence of large-scale extinctions reinforced the fact that life forms change with changing environmental pressures – even if that simply means that many die and only few survive.

What are fossils?

Fossils are the remains or traces (e.g. footprints, imprints or coprolite/fossilised faeces) of organisms from a past geological age embedded in rocks or other substances by natural processes.

Fossilisation requires the organism, or its traces, to be buried quickly so that weathering and total decomposition do not occur. Skeletal structures or other hard parts of the organisms that resist weathering are slower to decompose.

Figure 2.12 This fossil of *Triceratops horridus* is 65 million years old.

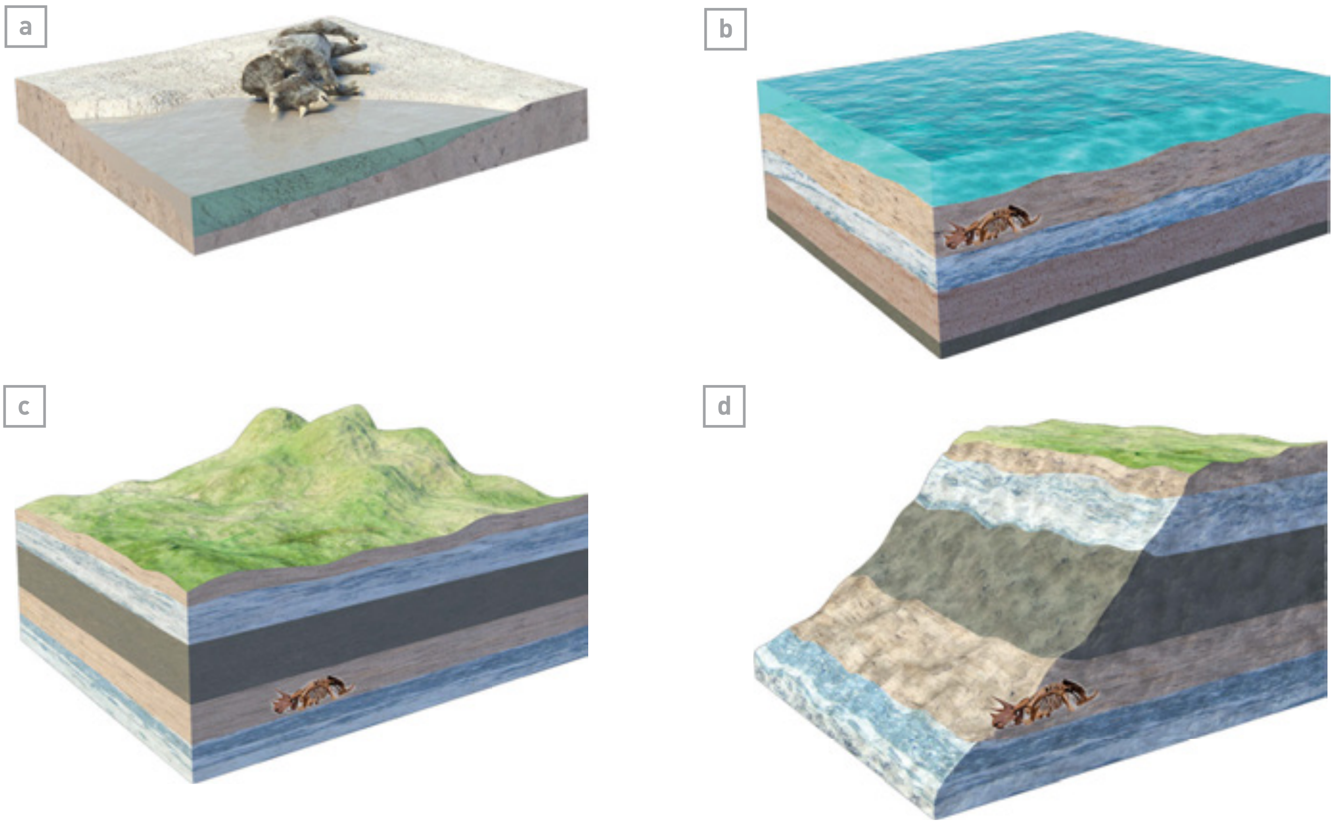

Figure 2.13 Formation of a fossil. (a) and (b) If an organism dies near water, it has a greater chance of being covered by sediment. The sediment protects the body from predators and weathering. (c) Over millions of years, more sediment is deposited and the remains are transformed gradually into sedimentary rock. (d) Years of geological movement, weathering and erosion may eventually expose the fossil.

These are the most common form of fossilised remains. Figure 2.13 shows how the process of fossilisation occurs.

Transitional fossils

Darwin's theory suggests that life originated in the sea, crawled onto land and then took to the skies or grew fur. The evidence that links these stages is in the form of transitional fossils, which are sometimes referred to as 'missing links', although the reality is a 'chain of missing links' is required over many generations.

When Darwin first published his theory, he stressed that the lack of transitional fossils was the largest obstacle to his theory because, at that time, very little was known about the fossil record. Since then, many excellent examples of transitional fossils have been found, such as *Archaeopteryx* (Figure 2.14), which was discovered in the Solnhofen area of Germany just 2 years after Darwin's work was published. *Archaeopteryx* is the earliest and most primitive bird.

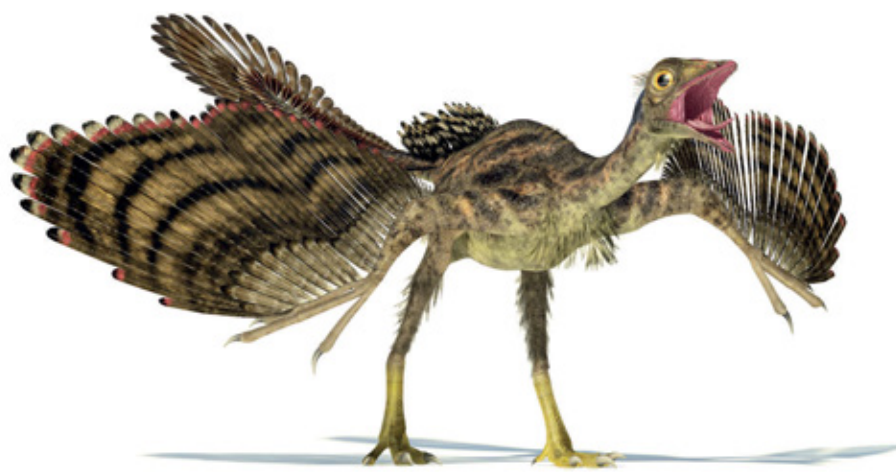

Figure 2.14 *Archaeopteryx* is an important transitional fossil. It displays a number of features common to both birds (hollow wishbone and feathers) and reptiles (teeth, flat sternum/breastbone, three claws on the end of its wings and a long bony tail).

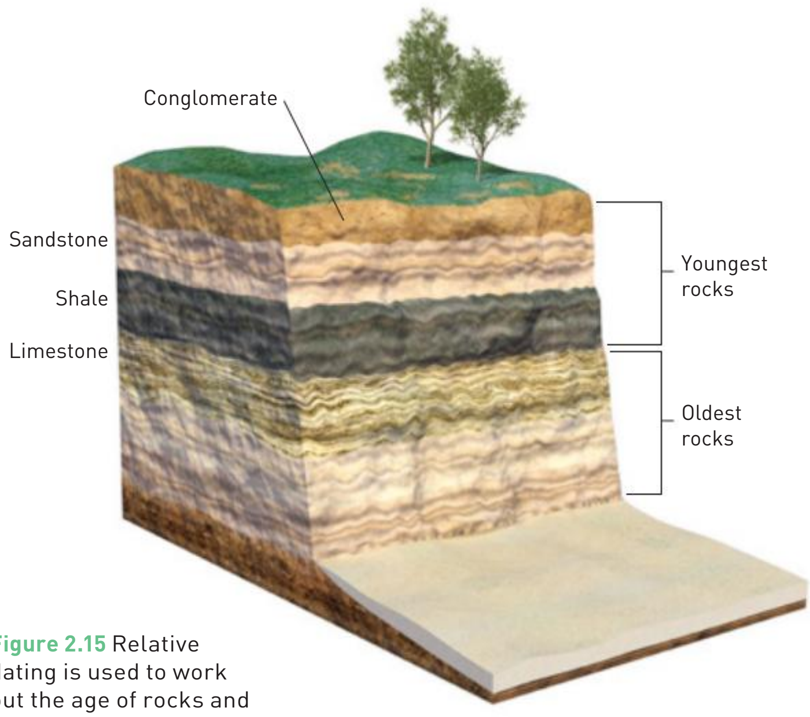

Figure 2.15 Relative dating is used to work out the age of rocks and fossils. Older rocks are found below younger rocks.

Dating fossils

It is possible to find out how a particular group of organisms evolved by arranging its fossil records in a chronological sequence. Relative dating can provide approximate dates for most fossils because fossils are found in sedimentary rock. Sedimentary rock is formed by layers (or strata) of silt or mud on top of each other (Figure 2.15). The deeper the layer, the older the rock. Each layer contains fossils that are typical for that specific time period. Older fossils are buried deeper than younger fossils.

Advances in our understanding of matter have led to technologies that can provide more accurate time frames for fossils. Absolute dating relies on the level of radioactivity in rocks containing radioisotopes. Every living organism maintains a constant low level of radiation. When an organism dies, the amount of radioactivity starts decreasing. The time it takes for half the radioactivity to decrease

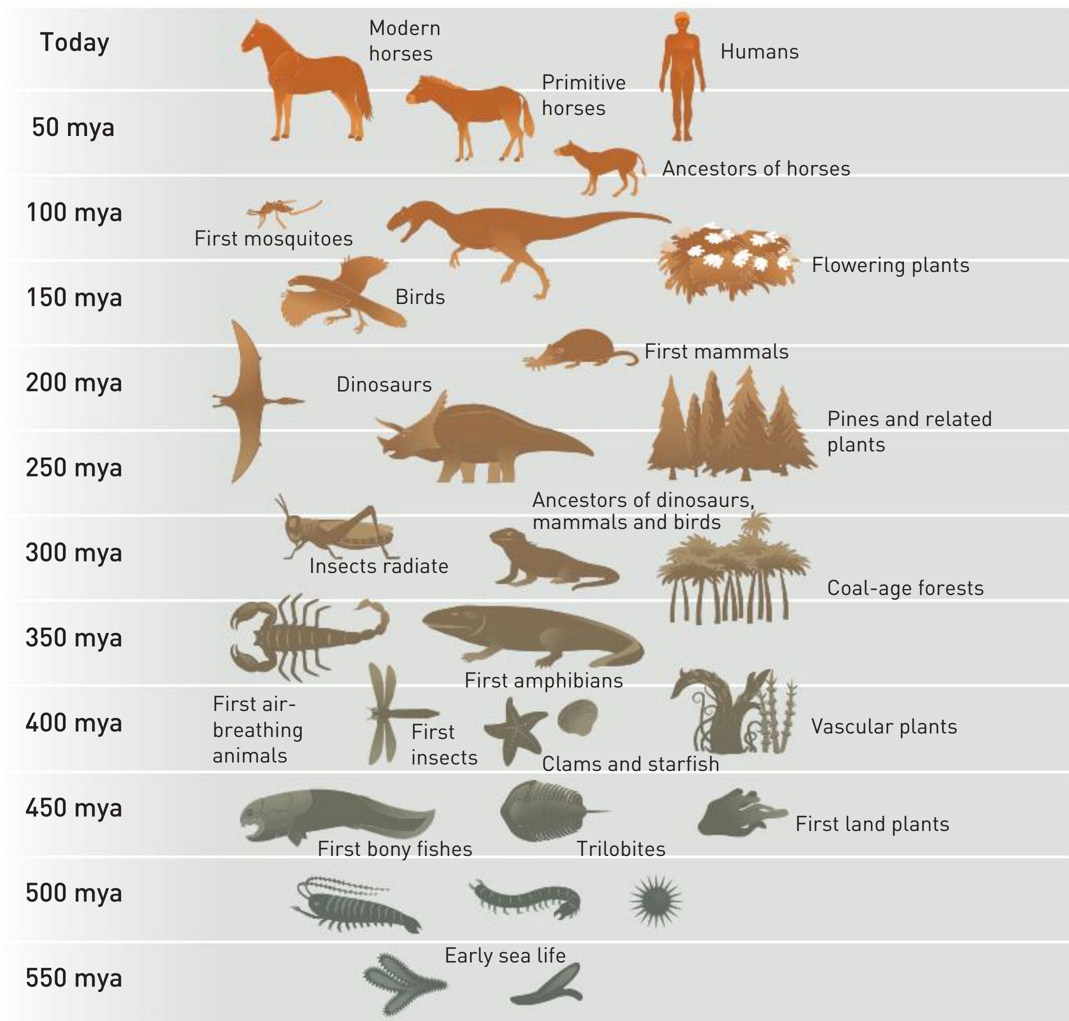

Figure 2.16 The history of living things, as determined by palaeontology (the study of fossils).

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is called the **half-life**. In one half-life, there is a 50% decrease in the initial radioactivity level. In the second half-life, the remaining radioactivity decreases by half again, leaving only 25% of the starting radioactivity level. This will continue until only very small levels of radioactivity are left. If scientists know the length of an element's half-life, they can determine how many half-lives have passed by measuring the amount of radioactivity. Therefore, they can determine the age of the fossil or rock.

Living fossils

According to fossil records, some modern species of plants and animals are almost identical to species that lived in ancient geological ages (for example, coelacanths, Figure 2.17). **Living fossils** are existing species of ancient lineages that have not changed in form for a very long time. This means the selection pressures for these organisms have not changed and therefore there is no pressure for the organism to change.

Figure 2.17 Unique in the animal kingdom, the coelacanth is a 400 million-year-old species of living fossil fish. Coelacanths pre-date dinosaurs by millions of years and were thought to have become extinct with them. In 1938, coelacanths were discovered living in caves off the continental shelf. This environment has changed little over the past 400 million years and, as a result, neither has the coelacanth.

Check your learning 2.4

Remember and understand

1 What parts of organisms are most likely to be found in fossils? Explain your answer.

2 How does relative dating work? Why is it often used before absolute dating is used?

3 Describe what a transitional fossil is.

4 Living fossils have remained relatively unchanged, often for millions of years, while around them other species have adapted or become extinct. How has this been possible?

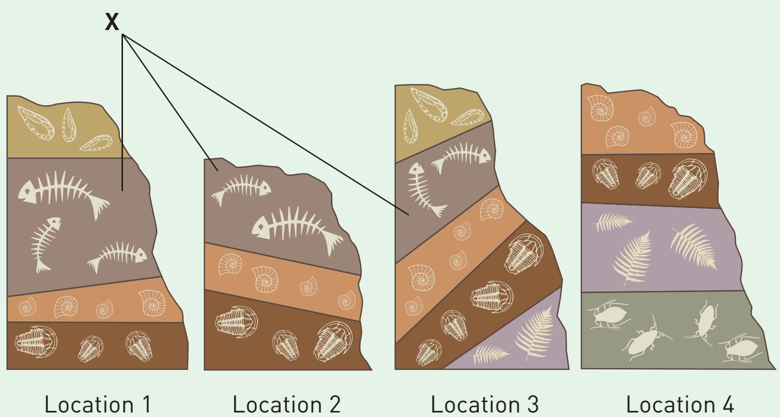

Figure 2.18 Fossils found at four different locations.

Apply and analyse

5 Will the theory of evolution ever become fact? Explain your answer.

6 How might observations of extant (living) organisms contribute to the evidence for evolution?

7 Fossils were found at four locations (Figure 2.18). Use relative dating to determine which fossil is the oldest.

2.5 Multiple forms of evidence support evolution

Biogeography is the study of how the continents move across the Earth, and how this directly affects the location of organisms. The breaking up of the supercontinent Pangaea into Laurasia and Gondwana caused organisms to diverge. When continents collide, species can spread, and when continents separate the new species move with them. The study of how genetic material affects the development of embryos (embryological studies) is a new and growing field of study. The sharing of common genes that control how an embryo develops is further evidence of evolution.

Figure 2.19 The jigsaw fit of Africa and South America supports the theory of continental drift.

Biogeography

At the beginning of the 17th century, the English philosopher Francis Bacon noted that the east coast of South America and the west coast of Africa looked as though they could fit together like pieces of a jigsaw (Figure 2.19). Since then, our knowledge of the structure of the Earth has developed and the theory of **continental drift** through plate tectonics continues to be supported by observations of various phenomena across the planet. It is now thought that at one time all the continents were connected in a single landmass – Pangaea (Figure 2.20). This supercontinent then broke in two to form Gondwana in the south and Laurasia north of the equator.

The theory of continental drift has had a major impact on evolutionary theory because living organisms were carried on the landmasses.

The distribution of the fossils of extinct plants and animals, as well as modern-day species, supports the theory of continental drift (Figure 2.21). Some continents have very similar organisms even though they are separated by large stretches of ocean. Animals that can fly or swim could travel from continent to continent, but for the rest, continental drift is the only convincing explanation for their distribution.

Continental drift provides a well-supported explanation for the geographical isolation of species that eventually results in speciation – divergent evolution. Groups of similar species, such as the ratites (flightless birds), and the existence of marsupials on several continents, can be explained by biogeography (Figures 2.21 and 2.22). 'Coincidence' is simply not a scientific explanation.

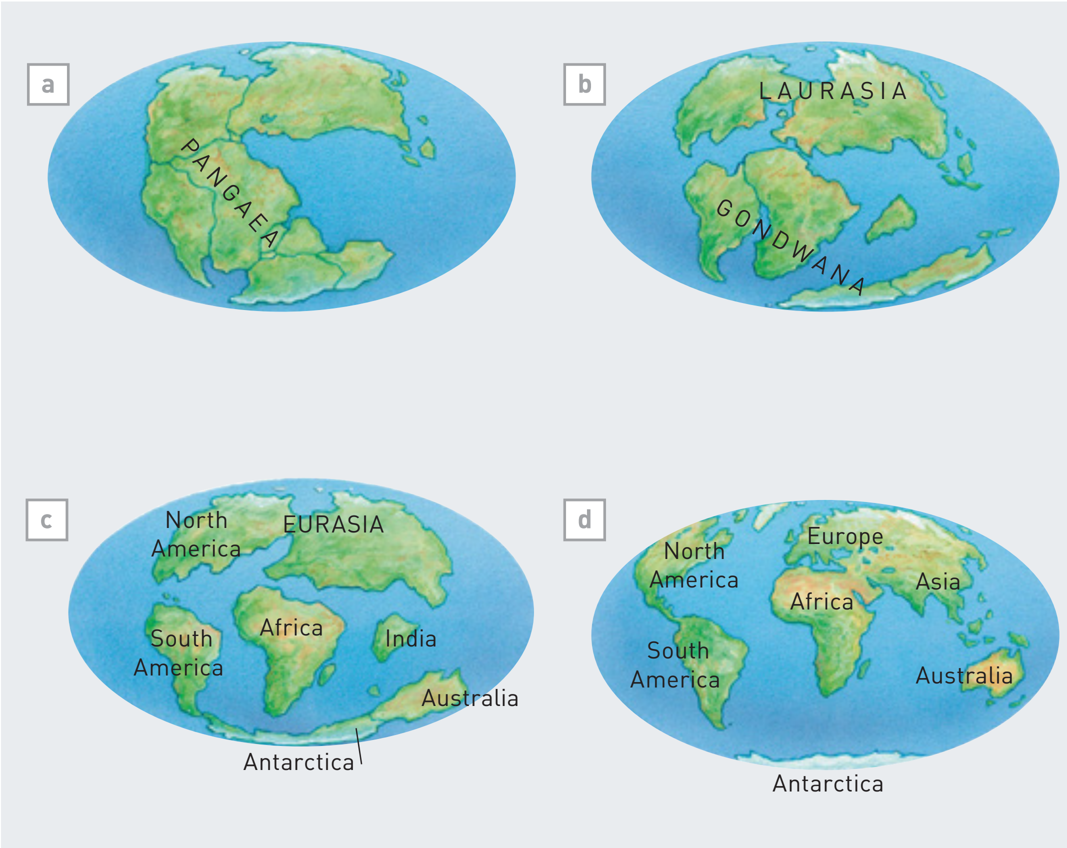

Figure 2.20 How the continents have drifted: (a) 220 million years ago; (b) 135 million years ago; (c) 65 million years ago; and (d) today.

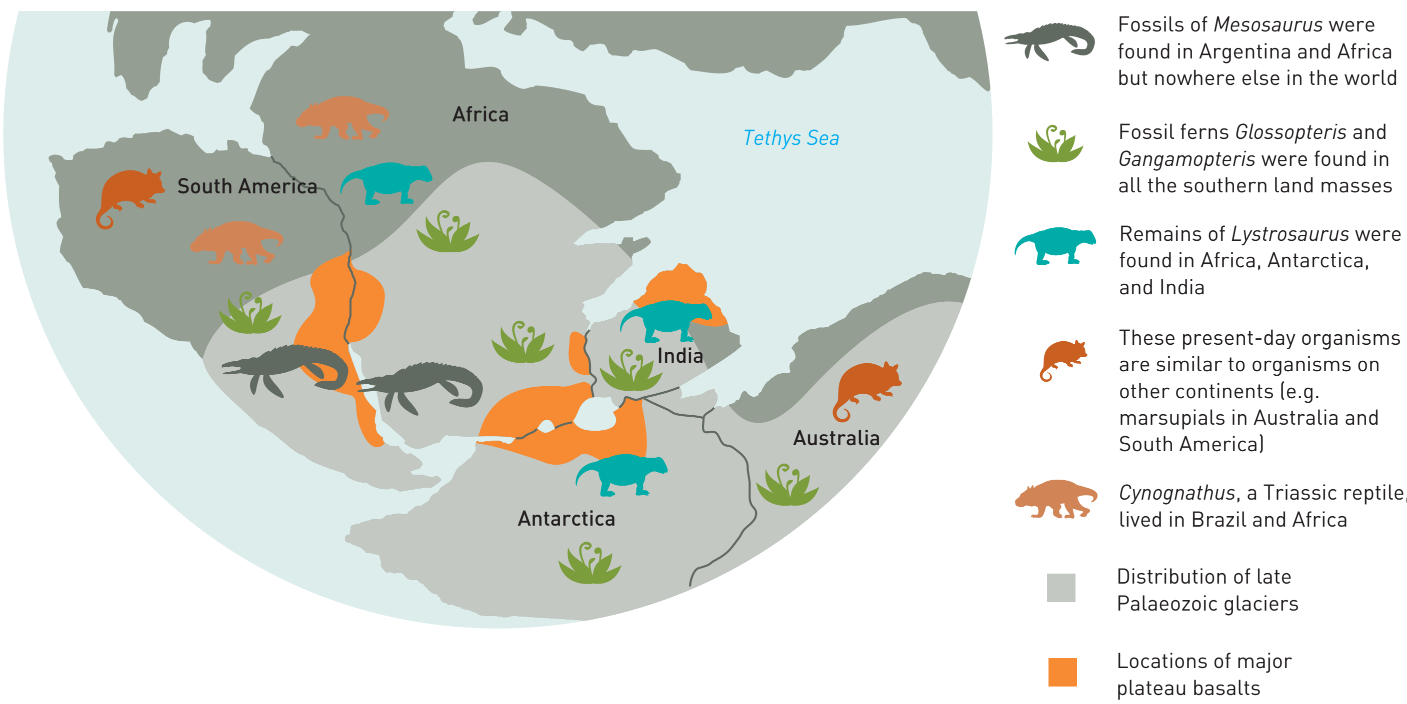

Figure 2.21 Evidence for the existence of the supercontinent Gondwana is provided by the similarity of fossils on different continents.

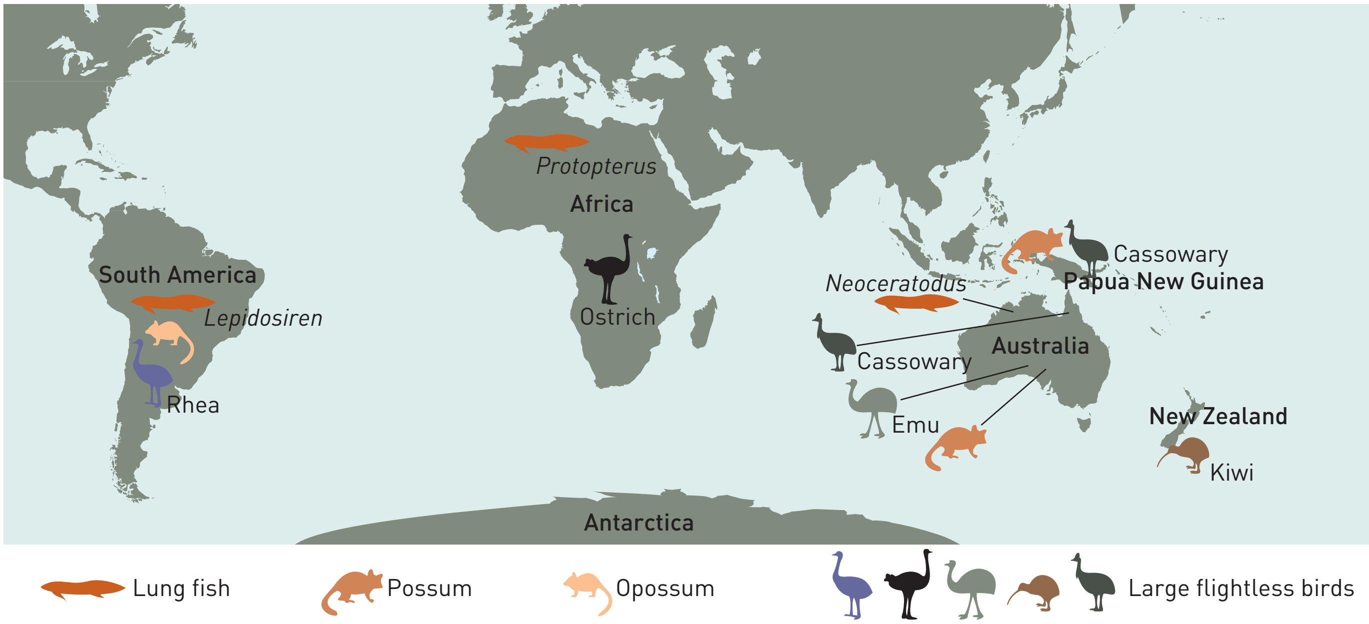

Figure 2.22 Similar lungfish are found in South America, South Africa and Australia. Similar marsupials are found in South America and Australia.

Vestigial structures

Vestigial structures are functionless structures found in organisms. They have puzzled naturalists throughout history and were noted long before Darwin first proposed the concept of evolution from a common ancestor (also called common descent). We now understand that individual organisms contain, within their bodies, abundant evidence of their histories. Some of these structures are clearly selected to perform a certain function that is no longer required. However, these features were not selected against and so they remained. Without the theory of evolution, the tiny wings of a cassowary are a puzzling structure. So, too, are the hindlimb buds of many snake species, which still carry vestigial pelvises hidden beneath their skin (Figure 2.23).

Vestigial structures are now interpreted as evidence of an ancestral heritage in which these structures once performed other tasks. The wings of a cassowary are a reminder that a distant relative of this organism once used its wings to fly. Similarly, snakes evolved from a four-legged ancestor. Humans, too, carry the evolutionary baggage of our ancestry. The ancestors of humans are known to have been herbivorous, and molar teeth are required for chewing and grinding plant material. More than 90% of all adult humans develop third molars (otherwise known as 'wisdom teeth'). Usually these teeth never erupt from the gums and in one-third of all individuals they are malformed and impacted. These useless teeth can cause significant pain and an increased risk of injury, and may result in illness and even death if they are not removed.

Analysing embryos

Scientists have noticed that, although adult vertebrates have certain differences, many embryos demonstrate similarities during the early stages of development. For example, a chicken and a human are very different when fully formed, but chicken embryos are very similar to human embryos (Figure 2.25). Even reptile embryos are similar to human embryos. Embryos may also show many interesting features that are not seen in the fully developed animal. As the embryo develops, it goes through a variety of stages. Many of these stages show homologous structures with different species.

If the various life forms developed independently, one would think that their embryonic development would be different and reflect what the organism would look like when it was fully developed. It would make more sense for a horse to develop a hoof directly rather than first develop five finger-like digits that are then modified into a hoof.

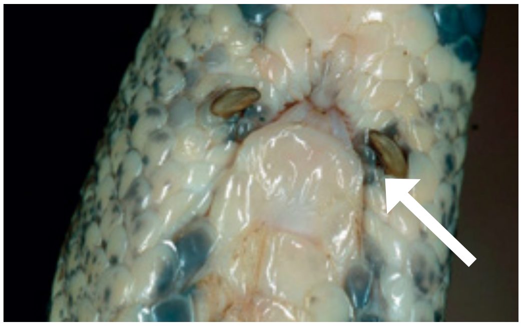

Figure 2.23 The rear legs on a snake (arrows) are an example of a vestigial structure.

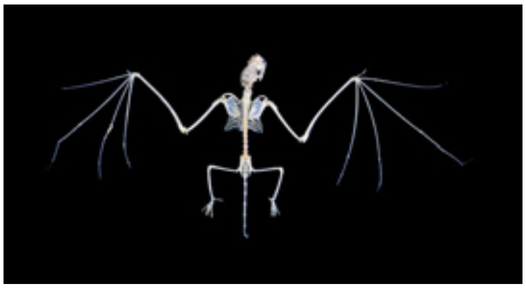

Figure 2.24 As an embryo, the 'finger genes' of the bat become more active. As a result, the bat's fingers grow much faster than the fingers of other embryos.

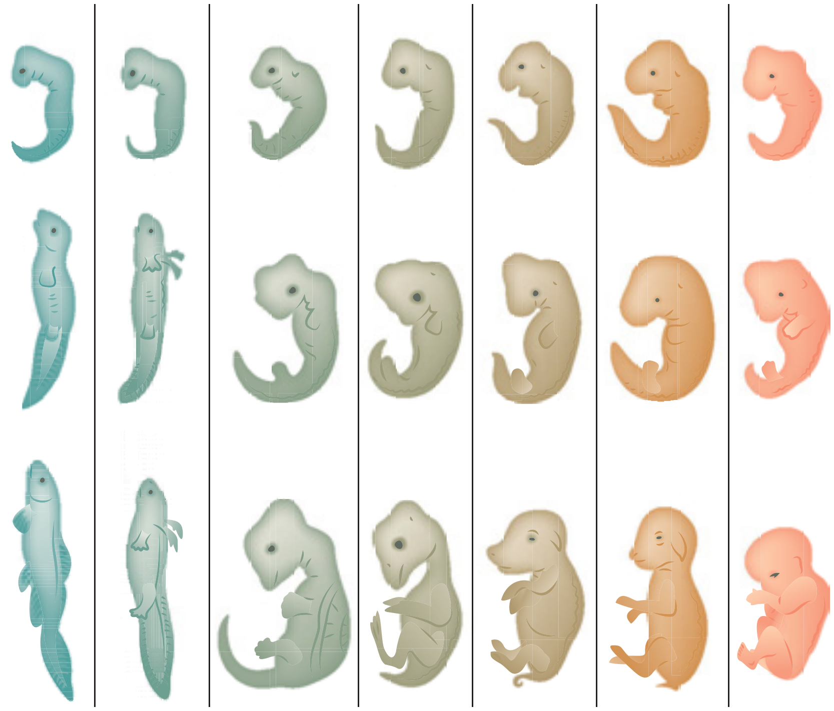

Figure 2.25 Common structures in the early stage of embryonic development of vertebrates.

The embryological similarities are explained by inferring that these organisms all had a common ancestry with common genes. Whales start developing teeth embryonically because they evolved from ancestors that had the genes for teeth. Human embryos develop gill-like structures and tails during their early development because they have the genes for these structures. These genes get turned up or down or 'switched off' during later stages of development. For example, the gene for a bat's fingers become 'supercharged' during embryological development so that the fingers start growing faster than the rest of the body (Figure 2.24). This makes the fingers of the bat extra-long compared to the rest of its body. The long fingers then develop into support structures in the bat's wing.

Check your learning 2.5

Remember and understand

1 The frogs in Australia show their closest evolutionary relationships to frogs in Africa and South America. How is this possible? Did humans carry them on boats?

Apply and analyse

2 If native Australian marsupials were found in North America, would this disprove the theory of continental drift? Explain your answer.

3 How does the presence of vestigial structures support the theory of evolution?

4 Why do human embryos temporarily develop gill-like structures?

5 How can the gene that forms fingers be changed to form the wings on a bat?

6 Geologists are identifying ancient magnetic rocks that suggest magnetic north has moved over millions of years. How could this information be used to support the theory of continental drift? How could it impact the theory of evolution?

2.6 DNA and proteins provide chemical evidence for evolution

The basic structure of DNA and proteins is identical for all species on Earth. **Proteins** are long chains of amino acids arranged in different sequences. Many proteins that are essential for keeping organisms alive are conserved between species. Small differences in the sequences of amino acids can be used to determine the **evolutionary relationship** between species. The sequences in nucleotides in DNA can also be compared between different species. Mutations cause small differences that can accumulate over time. The more differences in the nucleotide sequence between organisms, the more time has passed since they shared a common ancestor, and the greater the evolutionary distance between the species.

Comparing amino acids in proteins

Proteins are like long necklaces made up of a series of beads. The beads are called **amino acids**. Genes in DNA provide the instructions for the order of the amino acid beads. Proteins range in size from approximately 50 amino acids to thousands of amino acids and are among the most important chemicals in life. They can be enzymes that control chemical reactions, or hormones, the chemical messengers in the body. The characteristics of a protein are determined by the order or sequence of amino acids.

All livings things use the same 20 amino acids to make proteins. If life evolved from a common ancestor with only these 20 amino acids, we may expect that these same amino acids are always used.

The same type of proteins in different species can be very much alike. Cytochrome c is one such example. Several types of cytochrome c proteins are found among different vertebrates and invertebrates. These cytochrome molecules are all very similar in structure and all serve the function of making energy in the cell (through cellular respiration), yet the order of their amino acid sequences can be slightly different (Table 2.1).

Comparing the sequence of amino acids in a protein can show the evolutionary relationship between different species. Before the two species diverge, they will have exactly the same protein with an identical sequence of amino acids. When the two species diverge, the number of mutations gradually accumulates. This may not affect the structure or function of the protein, but it can change a few amino acids in the long chain. The more time that passes, the more the changes to the amino acid

Figure 2.26 There are many different sequences of amino acids that could make a functional cytochrome c molecule.

Table 2.1 The sequence of amino acids that make up cytochrome c in different animals

HUMAN	Val	Glu	Lys	Gly	Lys	Lys	Ile	Phe	Ile
CHICKEN	Ile	Glu	Lys	Gly	Lys	Lys	Ile	Phe	Val
LUNGFISH	Val	Glu	Lys	Gly	Lys	Lys	Val	Phe	Val
FLY	Val	Glu	Lys	Gly	Lys	Lys	Leu	Phe	Val

EXPERIMENT 2.6: WHO IS MY COUSIN?
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sequence can accumulate. Therefore, the more similar the proteins, the more closely related the species. This means organisms with similar proteins share a very recent common ancestor.

Comparing DNA

The best evidence in support of evolutionary theory comes from a study of gene sequences. Comparing DNA sequences examines the relationship between different species. If the theory of evolution is supported, then species that share a common ancestor will have inherited that ancestor's DNA sequence. Any mutations (permanent changes in the order of DNA nucleotides) will cause slight differences between the species. The more alike the two DNA sequences are, the more closely related the two species are. The more differences in the DNA sequence, the more time has passed since they had a common ancestor and the less related the species are now (Figure 2.28).

Phylogenetic trees

Before scientists were able to compare proteins and DNA, they examined the structures of organisms to determine if they were related. The difficulty with this is some organisms, such as dolphins and sharks, look very similar because of convergent evolution. Currently, scientists use the differences in DNA sequences to compare the evolutionary relationship. This relationship is shown in a **phylogenetic tree** (Figure 2.28).

Early DNA sequencing work on the genome of humans and great apes has shown that humans share a common ancestor with gorillas and chimpanzees. In fact, the chimpanzee is our closest living relative, with a 98% similar genome. DNA sequencing of the β-haemoglobin gene has also confirmed this.

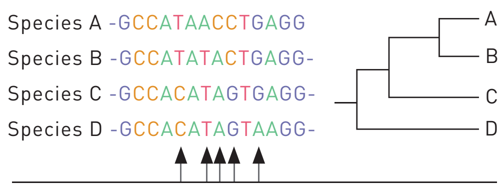


Figure 2.27 Comparing the DNA sequences allows scientists to determine the evolutionary relationship between different species. Species A is most closely related to B. Species D is the most distant relative of A. A phylogenetic tree for the four species is shown on the right.

Figure 2.29 Humans share an ancestor with chimpanzees.

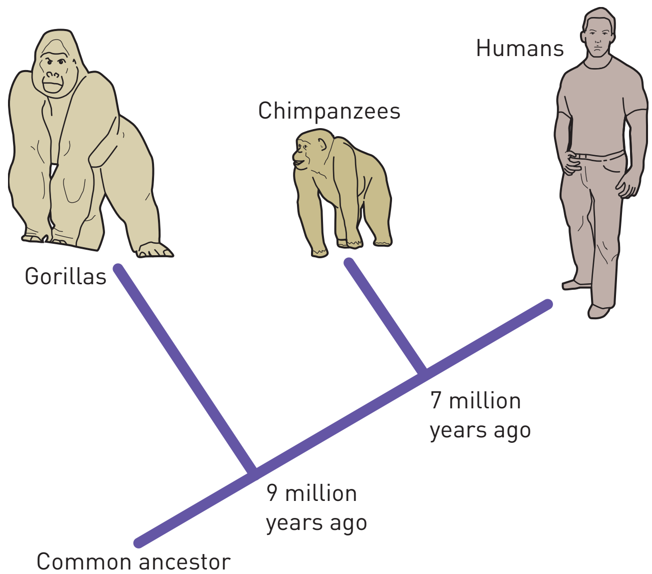


Figure 2.28 Gene sequencing has shown that humans, gorillas and chimpanzees all evolved from a common ancestor.

Check your learning 2.6

Remember and understand

1 What smaller (bead-like) structures make up proteins?

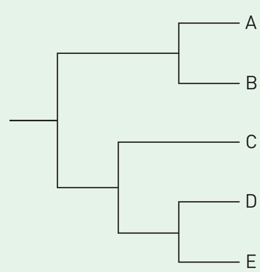
2 Cytochrome c is of interest to biologists studying evolution. What is the function of this molecule?

3 Table 2.1 shows a small section of the cytochrome c molecule for humans, chickens, lungfish and flies. Which species shows the greatest similarity to humans? Explain your answer.

4 What causes gradual changes to the sequence of nucleotides in DNA?

Apply and analyse

5 Use the phylogenetic tree on the right to determine which species is most closely related to species A.



6 Explain how DNA sequencing supports the concept of evolution from a common ancestor.

2.7 Humans artificially select traits

Artificial selection occurs when humans breed organisms that have desirable traits. This increases the likelihood of that trait occurring in the next generation. Over time, these organisms become domesticated and dependent on humans for survival. The frequent and incorrect use of antibiotics selects for resistant bacteria. Rapid regrowth through **binary fission** or **horizontal transfer** has led to an increase in some bacteria such as methicillin-resistant *Staphylococcus aureus* (MRSA).

Selective breeding

Humans have practised selective breeding for more than 10 000 years. When many human populations moved from the hunter–gatherer way of life to more permanent settled communities, they captured and tamed wildlife for their own purposes. Wild sheep grew wool in winter climates to keep warm. During the warmer summer months, they shed their wool in large clumps. Early humans chose the wild sheep that produced the most wool and bred from them. A random mutation caused the wool to grow all year round. These sheep were selected by breeders and the offspring of these wild animals became more reliant on humans to survive. Over many generations, the 'wild' traits were lost and the species was considered 'domesticated'.

Figure 2.30 Some animals have become so dependent on humans that they struggle to survive in natural conditions. This sheep was found with wool 42 cm long. The fleece weighed over 40 kg when it was eventually shorn.

Artificial selection

Artificial selection occurs when humans choose breeding partners for animals and other organisms in an effort to 'select' certain traits for their offspring. This is most evident in our pets. Many breeds (or subspecies) of dogs result from certain traits being selected by breeders (Figure 2.31).

Evolution of super-bacteria

One of the deadliest species of bacteria in hospitals is methicillin-resistant *Staphylococcus aureus* (MRSA or Golden Staph). This bacteria has arisen as a result of humans overusing antibiotics. *Staphylococcus aureus* is normally found on the skin and in the noses and

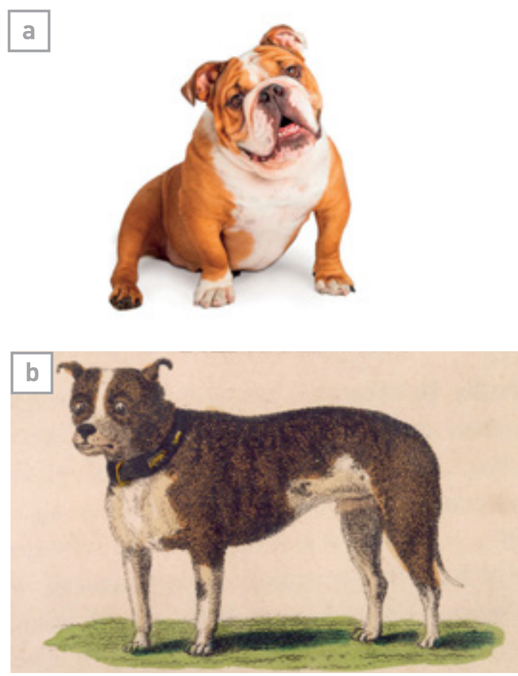


Figure 2.31 (a) Modern bulldog and (b) the bulldog 200 years ago. Over the last 200 years, breeders of British bulldogs have selected dogs with large flat faces. This has resulted in many birthing difficulties for female dogs. Up to 90% of bulldogs are born by caesarean. The flat faces also make the dogs more prone to breathing difficulties.

CHALLENGE 2.7: SELECTIVE BREEDING OF DOGS
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throats of many individuals in the population. Antibiotics prevent these cells from repairing or producing new cell walls, causing the cells to die rather than reproduce. In some populations, random mutations caused some *Staphylococcus aureus* cells to be unaffected by antibiotics. These bacteria became resistant.

When a person has a bacterial infection, a doctor will often prescribe an antibiotic. If there is a single bacteria present that is able to resist the antibiotic for a short time, then it will survive longer than the rest of the bacteria. If the person feels better and stops taking the antibiotic, that partially resistant bacteria will start reproducing again through a process called binary fission. This makes the person sick again, so they take the rest of the antibiotics. Once again the partially resistant bacteria slows its growth, but this time another random mutation causes a fully resistant bacteria to start growing. This bacteria is not affected by the antibiotic and can easily spread to other patients in a hospital. MRSA is such a bacteria. The misuse of antibiotics by humans selected the bacteria for its resistance (Figure 2.32).

Some bacteria do not have to wait for a random mutation to develop resistance to antibiotics. Sometimes the gene for antibiotic resistance can be transferred from one bacteria to another in a process called horizontal transfer. Because bacteria reproduce so quickly, they evolve very quickly.

Figure 2.34 Selected for its hairless coat, the sphynx cat was recognised as a new breed in 2008. Would these animals survive in the wild?

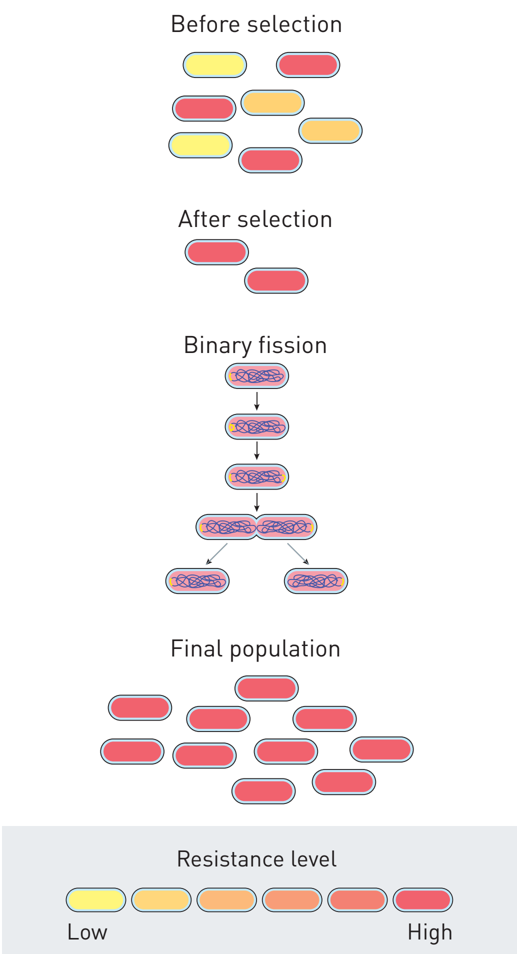

Figure 2.32 The frequent use of antibiotics allows for the selection of bacteria that are resistant to antibiotics. This increases the allelic frequency of resistance.

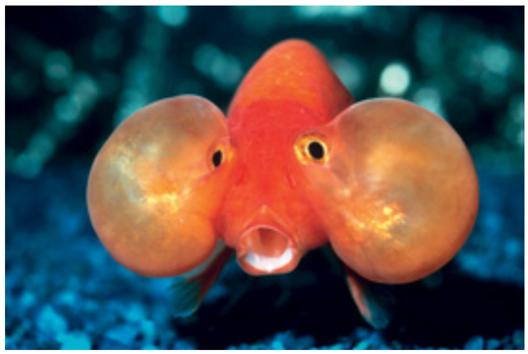

Figure 2.33 The bubble-eye goldfish can have problems with buoyancy, which affects their ability to swim. Could these fish survive in the wild?

Check your learning 2.7

Remember and understand

1. What is selective breeding?
2. Give an example of how selective breeding was used to produce an animal.
3. What is MRSA?

Apply and analyse

4. How can misusing antibiotics contribute to the existence of MRSA?
5. A student claimed that artificial selection has interfered with nature. Provide two reasons to support their claim. Provide two reasons that disagree with their claim. Which view do you agree with?

//SCIENCE AS A HUMAN ENDEAVOUR//

2.8 Natural selection affects the frequency of alleles

*Sickle cell anaemia is a disease that affects the structure and function of red blood cells. Sufferers have sickle-shaped cells that are unable to carry oxygen effectively around their body. Sickle cell anaemia is caused by a mutated gene for haemoglobin. Carriers of the sickle cell allele cannot contract malaria (a deadly disease that is contracted through mosquito bites). The number of sickle cell anaemia carriers is much higher in countries with a higher incidence of malaria. Therefore, malaria is a selection pressure for the sickle cell anaemia allele.

Sickle cell anaemia

Sickle cell anaemia is a genetic disease that causes swelling of the hands and feet, fatigue and pain. It is an autosomal recessive disease (see Chapter 1) that affects the haemoglobin protein found in red blood cells. The haemoglobin protein is made from four genes found on chromosome 11. It is responsible for carrying oxygen around the body. Most people have normal versions (or alleles) of the haemoglobin genes. Some people have a mutated allele, which causes the haemoglobin to clump together (Figure 2.35). A single copy of the mutated allele will not affect the quality of a person's life. However, two copies of the mutated allele will cause all the haemoglobin to clump together and the red blood cells to become shaped like a sickle (a curved cutting instrument).

These sickle-shaped cells can become stuck in the blood vessels, causing strokes or damaging the joints and organs of the body. People suffering sickle cell anaemia must be treated regularly to prevent infections. Thirty years ago, sufferers would die by the age of 20. Today, life expectancy is approximately 50 years.

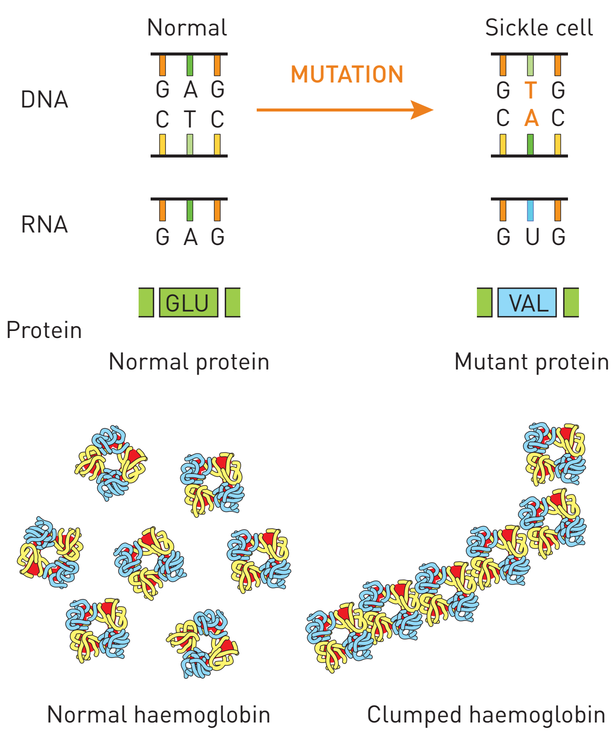

Figure 2.35 A single change in the nucleotide sequence causes a change in the amino acid sequence of haemoglobin. This causes the haemoglobin to clump together in people with sick cell anaemia.

Selection pressures

The rate of sickle cell anaemia is very low in Australia. It is thought that only 5% of the world's population is a carrier for sickle cell anaemia. This means they have one copy of the sickle cell allele and one copy of a normal

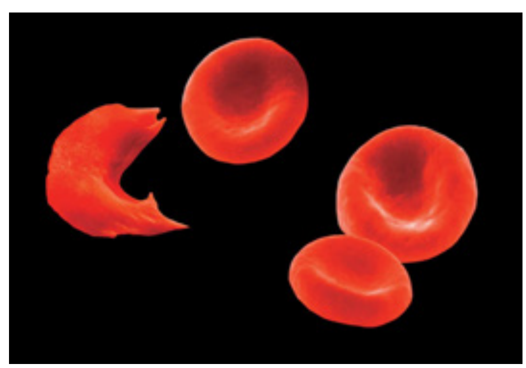

Figure 2.36 A person with sickle cell anaemia has crescent-shaped red blood cells (left) that are unable to effectively transport oxygen around the body.

EXPERIMENT 2.8: SELECTING FOR SICKLE CELL ANAEMIA
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haemoglobin allele. However, in some areas the rate of carriers for anaemia is closer to 25% (Figure 2.37). This is because a person who is a carrier for sickle cell anaemia is protected from contracting malaria (an infectious disease that is contracted through mosquito bites). This means that people who:

> are not carriers of the allele for sickle cell anaemia are at risk of catching malaria and dying
> are carriers of the sickle cell allele do not get sickle cell anaemia or malaria
> have two copies of the sickle cell allele have sickle cell disease and may die young.

Malaria is the selection pressure that selects for the sickle cell carriers.

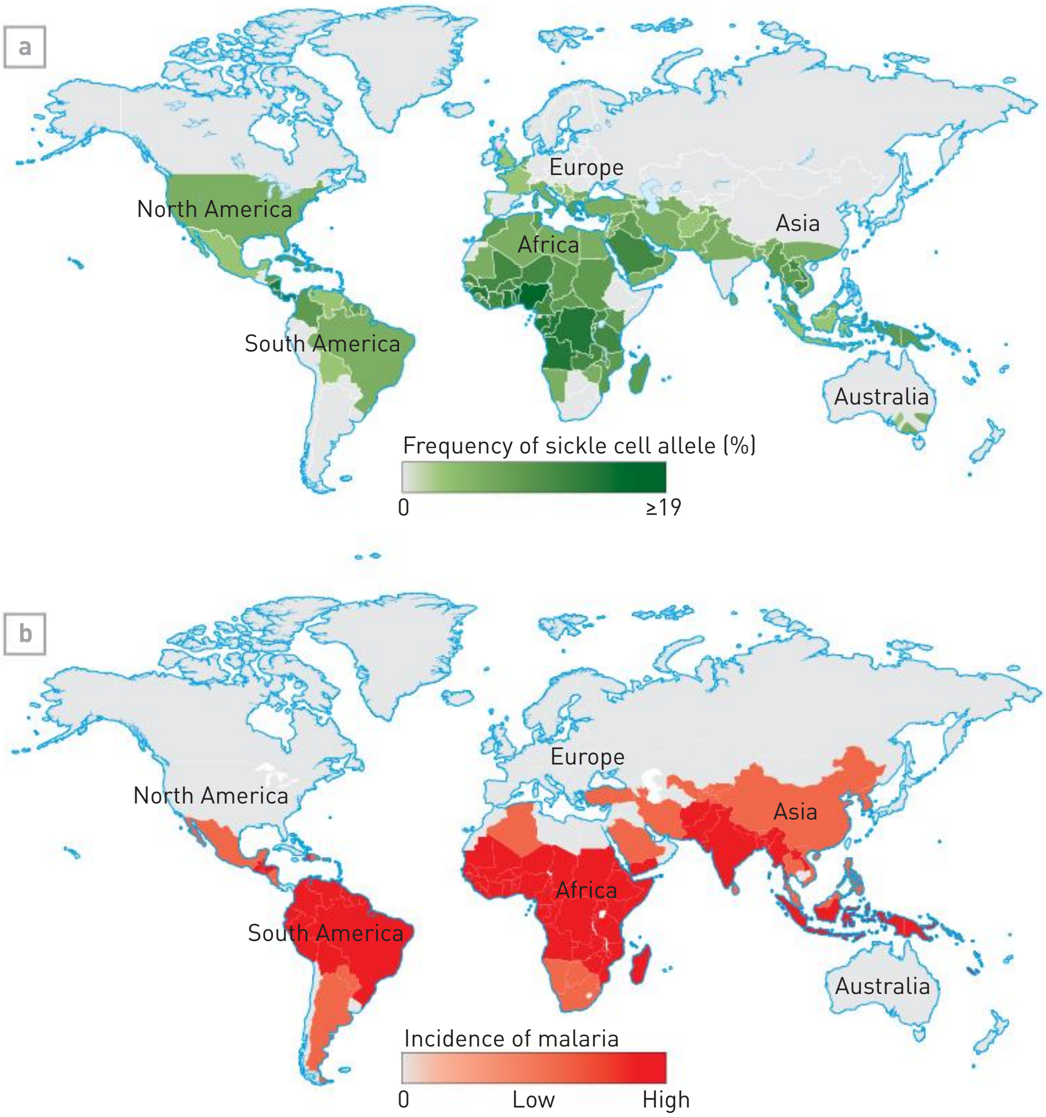


Figure 2.37 There is a strong correlation between (a) countries that have a high number of carriers for the sickle cell anaemia allele and (b) countries that have a high incidence of malaria.

Extend your understanding 2.8

1 How does sickle cell anaemia get its name?
2 What are the symptoms of sickle cell anaemia?
3 What does being a 'carrier for sickle cell anaemia' mean?
4 What is a selection pressure?
5 How does malaria select for carriers of sickle cell anaemia?
6 Research the cause and symptoms of malaria. Why is resistance for malarial drugs increasing in some areas? Use natural selection to explain your answer.

Remember and understand

1 What is the difference between a hypothesis and a theory?

2 What is natural selection and what are the four essential factors for this process?

3 Explain the difference between incorrectly suggesting an organism has evolved as opposed to correctly suggesting that a population of organisms has evolved.

4 Define the term 'gene pool'.

5 What is the professional title for a person who studies the fossil record and geological time periods?

6 *Archaeopteryx* had features of both birds and lizards. What term is applied to fossils that show the evolutionary progression between two very different forms?

7 What is or was Gondwana?

8 The layering of sedimentary rocks is useful in relative dating. What is the basic principle of comparative dating?

9 Distinguish between the terms 'transitional fossil' and 'living fossil'.

10 Explain precisely how fossils provide evidence for evolution.

Apply and analyse

11 Use examples to illustrate the two critical deductions that Darwin made – the struggle for existence and the survival of the fittest.

12 *Callistemon* (bottlebrushes) are unusual because their stems (branches) do not terminate in flowers. Instead, the stem keeps growing out past the old flower. Consequently, a mature plant may contain the ripe seeds of numerous years in its branches. How has this adaptive feature enabled *Callistemon* to exploit the current Australian environment?

13 Connect the terms 'allopatric speciation' and 'gene flow'.

14 Suggest why a vestigial structure, once it has been reduced to a certain size, may not disappear altogether.

Evaluate and create

15 The tortoises of the Galapagos Islands either have a domed shell and a short neck (on islands with significant rainfall) or a shell with the front flared up and a long neck (on islands that are more arid). The tortoises feed on prickly pear cactus. On islands with no tortoises, the prickly pear plant is low and spreading, but on islands with long-necked tortoises, the prickly pear plant is tall and has harder spines protecting it.

Figure 2.38

a Why might the tortoises have two very different phenotypes?

b Would the tortoises that originally reached the islands be likely to resemble any of the tortoises that live there today?

c Using the terms 'variation' and 'survival of the fittest', explain why the prickly pear plant is so different on islands with long-necked tortoises compared with those plants growing elsewhere.

d What type of speciation is occurring on these islands?

16 Only two species of native non-marine mammals (both bats) existed in New Zealand before the Polynesians introduced rats and dogs 1500 years ago. This unusually small number of mammal species, along with New Zealand's separation from Gondwana 60–80 million years ago, has led many to speculate on which land mass mammals originally evolved. The earliest known mammal-like fossil remains are over 160 million years old. Considering this information, explain whether a Gondwanan origin for mammals is likely.

17 How does the study of DNA sequences help in our understanding of evolution?

Ethical understanding

18 Through selective breeding, humans are able to bring about speciation. Discuss the various scenarios in which this has occurred in the past and may occur now and in the future. Provide three examples of human intervention being positive and three examples of detrimental intervention. Support your choices.

Critical and creative thinking

19 Research the various explanations for changes in the natural world before evolutionary theories. Select one example and present your findings and analysis to the class in an appropriate and interesting format.

20 The theories of Lamarck and Darwin are often compared and contrasted in the form of cartoon strips. Prepare a three-part cartoon strip for each theory that clearly identifies the similarities and differences between these theories.

21 Present the strengths and weaknesses of the various forms of evidence that support evolution.

Diversity and evolution

22 In what ways are the terms 'diversity' and 'evolution' linked? How does one rely upon the other? Can evolution occur without diversity? Can diversity occur without evolution?

Research

23 Choose one of the following topics for a research project. A few guiding questions have been provided for you, but you should add more questions that you want to investigate. Present your research in a format of your own choosing, giving careful consideration to the information you are presenting.

> **Darwin and the Galapagos Islands**
Much of Darwin's theory developed while he was visiting the Galapagos Islands. Which new species did he find there? What was so unique about these species? How did Darwin's findings help him develop his ideas? What was unique about the Galapagos Islands that helped Darwin develop his theories?

> **Modern-day evidence for evolution**
There is evidence of current populations evolving by natural selection all around us. Research one of the following topics and see whether you can find evidence of evolution by natural selection occurring today.

- Can controlled breeding modify organisms?
- When fewer predators are present, how does brighter colouration evolve?
- How does natural selection lead to pesticide resistance?

> **Climate change and natural selection**
How do you think climate change will affect species on Earth? Which species do you think will be most affected? Why is this? What could these species do to avoid becoming extinct as a result of changing habitats? How could they do this? Would all species be able to avoid the effects of climate change? Do you think new species may evolve as a result of climate change?

> **Real-time evolution**
Significant advances in our understanding of evolution by natural selection have been vital to the study of diseases and pests. Antibiotic resistance in bacteria and the tolerance to herbicides in crops and pesticides in general agriculture are monitored closely. Why are these examples important? Why do they need close monitoring? Why do these organisms demonstrate evolution at such a fast rate?

KEY WORDS

2

absolute dating
a method that uses the amount of radioactivity remaining in the rock surrounding the fossil to determine its age

adaptation
a characteristic or behaviour of a species that allows it to survive and reproduce more effectively

amino acids
small molecule that makes up a protein

analogous structures
structures in organisms that perform the same function but are structurally different

artificial selection
when humans breed organisms that have desirable traits, increasing the likelihood of that trait occurring in the next generation

continental drift
the continuous movement of the continents over time

convergent evolution
the process whereby unrelated organisms evolve to have similar characteristics as a result of adapting to similar environments

diverge
two species can experience different selection pressures, and gradually become more different; may lead to the two species becoming reproductively isolated.

evolution
gradual change in the genetic material of a population of organisms over a period of time

evolutionary relationship
refers to how two species or populations are related with respect to their evolutionary descent

fossil
the remains or traces of an organism that once existed

fossilisation
the process of an organism becoming a fossil

gene flow
genes will flow from one generation to the next, or one population to the next as different families or groups in the population choose partners and mate

gene pool
all the genes or alleles in the entire population

half-life
the time it takes the radioactivity in a deceased organism to decrease by half

homologous structure
a structure that is found across organisms and has a similar plan but different function

horizontal transfer
the transfer of genetic material (usually containing antibiotic resistance) between different bacteria

isolation
the division of a population into two groups

living fossil
an existing species of ancient lineage that has remained unchanged in form for a very long time

pentadactyl limb
a limb with five digits

protein
a chain of amino acids that are an essential part of any cell

selection pressure
the environmental factors that affect an organism's ability to survive

speciation
the process that results in the formation of a new species

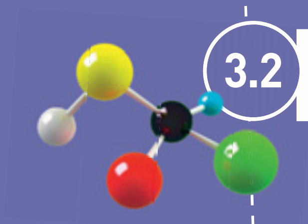
transitional fossil
a fossil or an organism that shows the intermediate state between an ancestral form and that of its descendants; also known as a 'missing link'

vestigial structure
a structure in an organism that no longer has an apparent purpose

THE PERIODIC TABLE

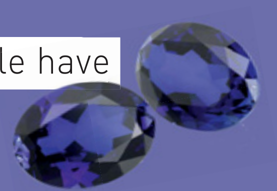
3

3.1 Scientists refine theories and models over time



3.2 The structure of an atom determines its properties

3.3 Groups in the periodic table have properties in common



3.4 Non-metals have properties in common

3.5 Metal cations and non-metal anions combine to form ionic compounds

3.6 Non-metals combine to form covalent compounds

3.7 Metals form unique bonds

3.8 Nanotechnology involves the specific arrangement of atoms

What if?

What you need:

glass of pure water (distilled or de-ionised), multimeter or speaker, 3 wires, 9 V battery, fine NaCl crystals

What to do:

1 Use the wires to connect an open circuit that includes the battery and the multimeter.

2 Place the open ends of the circuit in the glass of water so that they do not touch.

3 Does the electricity pass through the pure water?

What if?

» What if two teaspoons of salt were mixed through the water?

» What if the electricity was passed through the salt crystals with no water?

3.1 Scientists refine models and theories over time

The development of the periodic table involves scientists building on the work of previous generations. The discovery of new **elements**, the ability to recognise patterns and predict the existence of previously unknown elements all result from scientists analysing and refining models. The creation of the periodic table is often credited to Dmitri Mendeleev, who constructed a table with gaps for elements yet to be discovered. However, the ideas he used were first suggested decades before, and refined centuries after his work began.

2000 years ago

The ancient Greeks thought that everything was made of four 'elements' mixed together in different ratios (Figure 3.1).

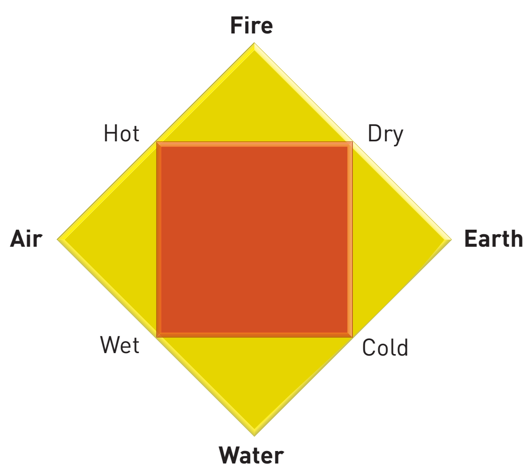


Figure 3.1 The four Greek 'elements'.

1661

Irish-born chemist Robert Boyle (Figure 3.2) suggested that an element was a substance that cannot be broken down into a simpler substance in a chemical reaction.

Figure 3.2 Robert Boyle

1789

Antoine Lavoisier, a French nobleman (Figure 3.3), made a detailed list of the substances that he believed to be elements. Assisted by his wife Marie-Anne, his list contained 33 elements grouped into metals and non-metals. Lavoisier's list also included some substances that we now know to be compounds.

1820s

Jakob Berzelius was a Swedish chemist who replaced the geometric patterns being used as chemical symbols with letters that were an abbreviation of the element's name. Berzelius used English names for most elements, with just a few retaining their non-English (usually Latin) names. In addition, Berzelius used the weight of hydrogen to develop an organised system of atomic weights. Because hydrogen was the lightest element, it was given a value of 1, with all remaining elements believed to have a whole number above 1.

Figure 3.3 Antoine Lavoisier and his wife Marie-Anne.

Figure 3.4 Jakob Berzelius gave the elements abbreviated symbols such as He for helium.

1829

As more elements were identified, more chemists studied them and their properties. In Germany, Johann Döbereiner was aware of 40 elements. He noted that some groups of three elements had similar properties and named these groups 'triads'. These groupings were important in identifying patterns of behaviour, which helped with more accurate predictions about atomic structures.

1864

English chemist John Newlands arranged the elements according to their atomic weights. He noticed that every eighth element had similar properties. This pattern was considered a recurring, or '**periodic**', feature among the elements. Newlands made the mistake of comparing the properties of the elements to music, with musical notes being grouped eight per octave. This comparison, called the law of octaves, was not taken seriously by Newlands' peers.

Table 3.1 Predicted properties of ekasilicon compared with the actual properties of germanium

EKASILICON (SYMBOL Es) AS PREDICTED IN 1871	GERMANIUM (SYMBOL Ge) AS DISCOVERED IN 1886
Atomic mass: 72	Atomic mass: 72.6
Density: 5.50 g/mL	Density: 5.36 g/mL
Colour: grey metal	Colour: grey metal
Forms oxide EsO_2: density 4.70 g/mL, slightly basic	Forms oxide GeO_2: density 4.70 g/mL, slightly basic
Forms chloride $EsCl_4$: boiling point 100°C, density 1.90 g/mL	Forms chloride $GeCl_4$: boiling point 86°C, density 1.88 g/mL

Figure 3.5 This sculpture in Saint Petersburg, Russia, honours Dmitri Mendeleev and the periodic table.

1869

Dmitri Mendeleev is hailed as the creator of the modern periodic table. Building on the ideas of his contemporaries, Mendeleev, who lived in Russia, knew of 63 elements (Figure 3.5).

It is said that Mendeleev wrote the names and properties of each element on a small card that he then arranged in order of atomic weight. The cards were then rearranged, maintaining their order, into groups with similar properties.

With this organisation complete, Mendeleev proposed the periodic law:

> 'Elements have properties that recur or repeat according to their atomic weight.'

More importantly, Mendeleev's organisation of cards identified 'holes' that he attributed to elements that had yet to be discovered. Mendeleev predicted the properties of 21 unknown or undiscovered elements. His predictions started scientists searching for the missing elements. When these elements were discovered, their properties were found to be very close to the properties that had been predicted by Mendeleev. This convinced many chemists of the accuracy and value of Mendeleev's periodic table. Table 3.1 compares the properties of germanium with an element Mendeleev predicted called ekasilicon.

Mendeleev is given sole credit for the development of the periodic table. This is because of the evidence he provided to support his table and because he assumed that there were missing elements and he accurately predicted the properties of these elements.

1894

William Ramsay, a Scottish chemist, used the emerging technology of refrigeration to liquefy and separate the components of air. He successfully removed water, carbon dioxide, oxygen and nitrogen, but found he had some unknown gas left behind. This was argon, the first in its group to be discovered. Further experimentation identified helium, neon, krypton and xenon. All these gases form the group of **noble gases** at the far right of the periodic table.

1911

Marie Curie (Figure 3.6) was one of the many female scientists who identified and purified elements of the periodic table. Curie won two Nobel Prizes for her work on radiation.

Figure 3.6 Marie Curie developed the theory of radioactivity. She won the Nobel Prize in Chemistry in 1911 for her discovery of radium and polonium.

1913

By the early 1900s, X-rays could be used to determine the atomic number of each element. Using this technology, Henry Moseley (Figure 3.7), a young English physicist, refined the order of some of the elements in Mendeleev's periodic table and proposed a minor change to the periodic law:

> 'Elements have properties that recur or repeat according to their atomic number.'

Figure 3.7 Henry Moseley's name is linked to significant advances in X-ray-related chemistry and physics, with many believing him worthy of a Nobel Prize. His work was cut short when he died at just 27 years of age in the Battle of Gallipoli during the First World War.

1940

With the development of nuclear processes, elements heavier than uranium could be created. The US scientist Glen Seaborg, winner of the 1951 Nobel Prize in Chemistry, led a team of scientists who used a cyclotron to bombard uranium atoms with neutrons. This produced the very first atoms of neptunium and plutonium.

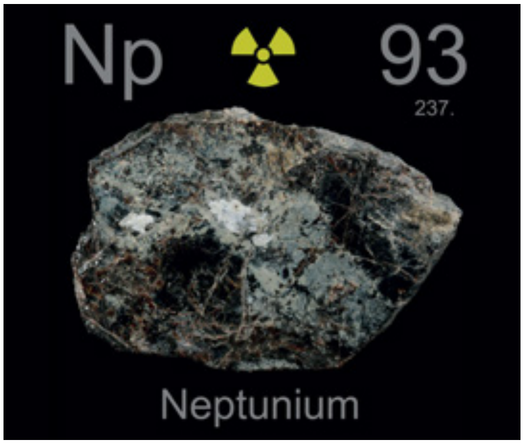


Figure 3.8 Atoms heavier than uranium are called the 'transuranium' or 'transuranic' elements. None of them occur naturally. The image shows a sample of neptunium.

Today

Since the 1940s, similar nuclear processes have been used to synthesise the elements up to and including element 118. These elements are given names based on their atomic number: 118 is called 'ununoctium' (1-1-8-ium).

Extend your understanding 3.1

1. Who proposed the modern idea of an element and when?
2. What was a triad? Why were triads important?
3. Who was the first chemist to lead a team that produced elements that did not occur naturally?
4. When Mendeleev proposed the periodic table, he went one step further. What else did he do and why is this significant?
5. Originally, geometric symbols were used to represent each element. What would be some of the problems associated with using geometric symbols for the elements today?
6. Why were the gases that Ramsay discovered not able to be discovered any earlier?
7. Moseley changed the periodic law proposed by Mendeleev by changing one word. What word was changed, and how did this improve the periodic table?

3.2 The structure of an atom determines its properties

*

The atomic number and name of an atom is determined by the number of protons it contains in its nucleus. The relative atomic mass is the sum of the number of positive protons and number of neutral neutrons. Negatively charged electrons have negligible mass and move about the nucleus in electron shells. The outermost electron shell is called the **valence shell** of the atom. The number of electrons in the valence shell determines many of the properties of an element and therefore its position in the periodic table.

The periodic table

The periodic table shows the types of atoms, or elements, in rows and columns (Figure 3.9). The rows are called **periods**. The atomic number increases by one for each element as you go across a period. The vertical lists of elements are called **groups**, with the elements in each group having similar properties. These groups are similar to the triads described by Döbereiner.

The columns and rows in the periodic table have been given names and numbers. This makes communication easier, because these elements have similar properties and trends.

Atoms and their electrons

The protons and neutrons of an atom are located within the nucleus. These subatomic particles are responsible for most of the mass of the atom and therefore have a strong influence on the properties of the atom. The number of protons is called the **atomic number** and is used to order the elements in the periodic table.

In contrast, electrons have almost negligible mass. However, because they orbit around the nucleus, these subatomic particles interact with other atoms.

Electron configurations

The **Bohr model** of the atom can be used to consider how electrons are arranged in an atom. In this model, the electrons are arranged in areas of space around the nucleus. These areas are called shells. The electron shells are numbered from the nucleus outward. These are shown in Table 3.2, along with the maximum number of electrons in each shell.

Table 3.2 The Bohr model of the atom

SHELL NUMBER (FROM THE NUCLEUS OUTWARDS) (n)	MAXIMUM NUMBER OF ELECTRONS IN THE SHELL ($2n^2$)
1	2
2	8
3	18*
4	32

*The formula $2n^2$ works for most atoms until we get to atomic number 19 (potassium). Once the third electron shell has eight electons, remaining electrons start moving into the fourth shell.

Table 3.2 shows that the further the electron shell is from the nucleus, the more electrons it can contain. The maximum number of electrons a shell can hold is related to its shell number by the simple formula $2n^2$, where n is the number of the shell from the nucleus.

Bohr also stated that the electrons of an atom are normally located as close to the nucleus as possible. This is because the negatively charged electrons are attracted to the positive charges of the protons. This is a lower energy state for the atom and is therefore more stable.

Key: 6 — Atomic number; C — Chemical symbol; 12.01 — Atomic mass; Carbon — Name of element

	Group 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1	1 **H** 1.01 Hydrogen																	2 **He** 4.00 Helium
2	3 **Li** 6.94 Lithium	4 **Be** 9.01 Beryllium											5 **B** 10.81 Boron	6 **C** 12.01 Carbon	7 **N** 14.01 Nitrogen	8 **O** 16.00 Oxygen	9 **F** 19.00 Fluorine	10 **Ne** 20.18 Neon
3	11 **Na** 22.99 Sodium	12 **Mg** 24.31 Magnesium											13 **Al** 26.98 Aluminium	14 **Si** 28.09 Silicon	15 **P** 30.97 Phosphorus	16 **S** 32.07 Sulfur	17 **Cl** 35.45 Chlorine	18 **Ar** 39.95 Argon
4	19 **K** 39.10 Potassium	20 **Ca** 40.08 Calcium	21 **Sc** 44.96 Scandium	22 **Ti** 47.87 Titanium	23 **V** 50.94 Vanadium	24 **Cr** 52.00 Chromium	25 **Mn** 54.94 Manganese	26 **Fe** 55.85 Iron	27 **Co** 58.93 Cobalt	28 **Ni** 58.69 Nickel	29 **Cu** 63.55 Copper	30 **Zn** 65.39 Zinc	31 **Ga** 69.72 Gallium	32 **Ge** 72.63 Germanium	33 **As** 74.92 Arsenic	34 **Se** 78.96 Selenium	35 **Br** 79.90 Bromine	36 **Kr** 83.80 Krypton
5	37 **Rb** 85.47 Rubidium	38 **Sr** 87.62 Strontium	39 **Y** 88.91 Yttrium	40 **Zr** 91.22 Zirconium	41 **Nb** 92.91 Niobium	42 **Mo** 95.94 Molybdenum	43 **Tc** (98) Technetium	44 **Ru** 101.07 Ruthenium	45 **Rh** 102.91 Rhodium	46 **Pd** 106.4 Palladium	47 **Ag** 107.87 Silver	48 **Cd** 112.41 Cadmium	49 **In** 114.82 Indium	50 **Sn** 118.71 Tin	51 **Sb** 121.76 Antimony	52 **Te** 127.60 Tellurium	53 **I** 126.90 Iodine	54 **Xe** 131.29 Xenon
6	55 **Cs** 132.91 Caesium	56 **Ba** 137.33 Barium	57 to 71	72 **Hf** 178.49 Hafnium	73 **Ta** 180.95 Tantalum	74 **W** 183.84 Tungsten	75 **Re** 186.21 Rhenium	76 **Os** 190.23 Osmium	77 **Ir** 192.22 Iridium	78 **Pt** 195.08 Platinum	79 **Au** 196.97 Gold	80 **Hg** 200.59 Mercury	81 **Ti** 204.38 Thallium	82 **Pb** 207.2 Lead	83 **Bi** 208.98 Bismuth	84 **Po** (209) Polonium	85 **At** (210) Astatine	86 **Rn** (222) Radon
7	87 **Fr** (223) Francium	88 **Ra** 226.03 Radium	89 to 103	104 **Rf** (261) Rutherfordium	105 **Db** (262) Dubnium	106 **Sg** (271) Seaborgium	107 **Bh** (272) Bohrium	108 **Hs** (277) Hassium	109 **Mt** (276) Meitnerium	110 **Ds** (281) Darmstadtium	111 **Rg** (280) Roentgenium	112 **Cn** (285) Copernicium	113 **Uut** (284) Ununtrium	114 **FL** (289) Flerovium	115 **Uup** (288) Ununpentium	116 **Lv** (298) Livermorium	117 **Uus** (294) Ununseptium	118 **Uuo** (294) Ununoctium

Transition metals (groups 3–12) · Non-metals (groups 13–17) · Metals

Atomic masses in parentheses are from the most stable of common isotopes.

Series															
Rare earth elements Lanthanoid series	57 **La** 138.91 Lanthanum	58 **Ce** 140.12 Cerium	59 **Pr** 140.91 Praseodymium	60 **Nd** 144.24 Neodymium	61 **Pm** (145) Promethium	62 **Sm** 150.4 Samarium	63 **Eu** 151.97 Europium	64 **Gd** 157.25 Gadolinium	65 **Tb** 158.93 Terbium	66 **Dy** 162.50 Dysprosium	67 **Ho** 164.93 Holmium	68 **Er** 167.26 Erbium	69 **Tm** 168.93 Thulium	70 **Yb** 173.04 Ytterbium	71 **Lu** 174.97 Lutetium
Actinoid series	89 **Ac** 227.03 Actinium	90 **Th** 232.04 Thorium	91 **Pa** 231.04 Protactinium	92 **U** 238.03 Uranium	93 **Np** 237.05 Neptunium	94 **Pu** (244) Plutonium	95 **Am** (243) Americium	96 **Cm** (247) Curium	97 **Bk** (247) Berkelium	98 **Cf** (251) Californium	99 **Es** (252) Einsteinium	100 **Fm** (257) Fermium	101 **Md** (258) Mendelevium	102 **No** (259) Nobelium	103 **Lr** (260) Lawrencium

Figure 3.9 The periodic table of elements.

The arrangement of electrons in an atom is termed its **electronic configuration**.

Electron configurations are often represented by simple **shell diagrams** that show the electron shells as circles. The electrons are presented in pairs. This makes it easier to draw the diagrams and is scientifically correct because, in atoms, electrons exist in pairs within the shells. The outermost occupied shell of atoms is known as the valence shell.

ELECTRONIC CONFIGURATION OF OXYGEN

The atomic number of oxygen is 8, so an uncharged atom contains eight electrons.

- Oxygen is in period 2, so it has two electron shells.
- The first shell can only hold two electrons.
- The second shell holds the other six electrons.
- The electronic configuration of oxygen is written as 2,6.

ELECTRONIC CONFIGURATION OF CALCIUM

The atomic number of calcium is 20, so an uncharged atom contains 20 electrons.

- Calcium is in period 4, so it has four electron shells.
- The first shell can only hold two electrons.
- There are 18 electrons left to place in shells. The second shell can only hold eight electrons. The third shell is stable with eight electrons (even though it holds a maximum of 18).
- The fourth shell holds the last two electrons.
- The electronic configuration of calcium is written as 2,8,8,2.

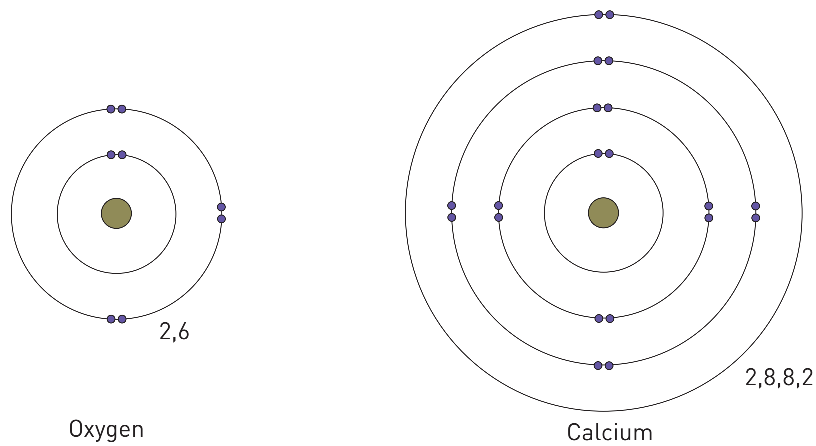


Figure 3.10 The electronic configurations for oxygen and calcium are shown as simple shell diagrams.

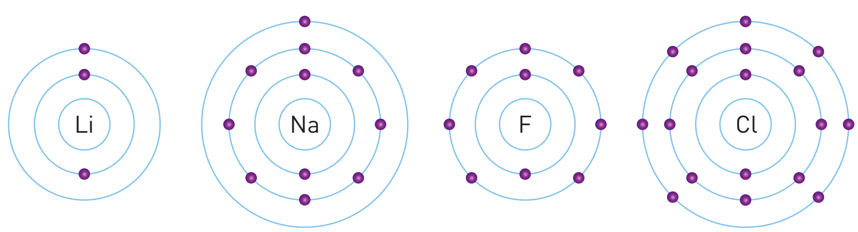


Figure 3.11 In group 1, the electronic configuration of lithium is 2,1, whereas that of sodium is 2,8,1 and that of potassium is 2,8,8,1. The atoms of all other group 1 elements also have one electron in their outer valence shell of electrons.

Electrons and properties of elements

The electronic configurations of the elements can explain the properties of the elements. Being able to confidently navigate the periodic table enables you to identify trends in electrons, the properties of elements and the uses of compounds formed from them.

Groups and valence electrons

The groups of the periodic table are numbered 1–18. Elements in the same group have similar chemical properties that we now know are due to the arrangement of their electrons.

Elements in the same group have the same number of electrons in their outermost or valence shell. The valence shell electrons often interact with other atoms.

Emission spectra and electron shells

When atoms are heated in a flame, the electrons gain heat energy from the flame and become 'excited', jumping from their normal shell to one further out from the nucleus. When the electrons move back to their usual shell, this 'extra' energy is given back out in the form of light. Because the energy gaps between electron shells vary from one atom to the next, the energy released by the different atoms also varies. This variation is seen as different levels of light energy, which have different frequencies; different frequencies of light have different colours. Hence, the emission spectrum of each atom will be a 'fingerprint' of different colour patterns. These spectra cause different-coloured flames when different elements are burned, as you would have seen in an experiment in Year 9.

Check your learning 3.2

Remember and understand

1 What is the valence shell of an atom?

2 What determines the atomic number of an atom?

3 For the Bohr model of the atom, what is the maximum number of electrons that the fourth electron shell can contain?

Apply and analyse

4 A potassium atom contains 19 protons.

a How many electrons will be present in a potassium atom? Justify your answer.

b What is the electronic configuration of a potassium atom according to the Bohr model?

c From the electronic configuration of potassium, it is clear that electrons do not normally occupy the fifth shell. What could be done to potassium atoms for electrons to jump into this shell?

5 Copy and complete the following table.

ELEMENT	ATOMIC NUMBER	ELECTRON CONFIGURATION
Beryllium		
	9	
Magnesium		
Neon		
		2,8,3
	11	
		2,8,7
Sulfur		

3.3 Groups in the periodic table have properties in common

The two main types of elements are metals and non-metals, with metals constituting nearly three-quarters of all elements. **Metals** are defined by their lustrous appearance and their ability to conduct heat and electricity. The **alkali metals** in group 1 of the periodic table have a single electron in their outer shell and as a result are highly reactive when mixed with water. The alkali metals have low melting points and are relatively flexible. **Transition metals** have properties that are unique to groups 3–12.

Metals

Metals have many properties in common. Pure metals are:

> lustrous (shiny)
> able to conduct heat and electricity
> malleable (can be beaten into a new shape)
> ductile (can be drawn into a wire).

Group 1 metals

The alkali metals, such as sodium and potassium, are found in group 1 – the far left column. Their position tells you that their uncharged atoms have just one electron in their outer shell. The alkali metals have quite low melting points and are soft and highly reactive. In their pure state, they often resemble plasticine that, when cut, is very briefly shiny silver before reacting with the air to become white again (Figure 3.12). Alkali metals react very strongly – some violently – with water, producing hydrogen gas and an alkaline solution. (An alkali is a soluble base.) As you go down the group, this reaction becomes more violent (Figure 3.13).

Figure 3.12 Freshly cut sodium, a group 1 metal.

Group 2 metals

The **alkaline earth metals**, such as magnesium and calcium, are found in group 2. Their position tells you that their atoms have two electrons in their outer shell. The alkaline earth metals have quite low melting points and are relatively soft and very reactive, although in general they are not quite as reactive as group 1 alkali metals. Like the alkali metals, alkaline earth metals react with water, some strongly, producing hydrogen gas and an alkaline solution. As you go down the group, the metals become more reactive (Figure 3.14).

Transition metals

The transition metals are found in a large block of the periodic table that consists of the ten groups across the centre (groups 3–12). Many transition metals have special properties that are not shown by group 1 or 2 metals.

EXPERIMENT 3.3: REACTIVITY OF METALS
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Figure 3.13 Potassium reacts spectacularly with water.

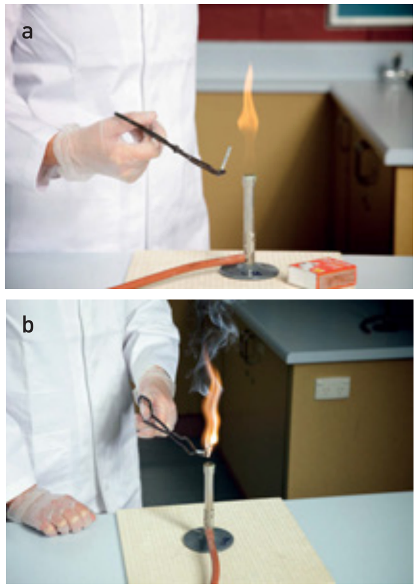

Figure 3.14 Magnesium, an alkaline earth metal (a) before burning and (b) during burning.

Figure 3.15 Calcium is a soft grey metal; calcium carbonate is a white powder or stone.

> A small number are magnetic.
> Gold and copper are the only metals that are not silvery in colour.
> Many form coloured compounds (Figure 3.16).
> Many form more than one compound with a non-metal such as chlorine. For example, iron forms $FeCl_2$ and $FeCl_3$.

Figure 3.16 Gemstones contain atoms of different metals, which results in different colours.

Check your learning 3.3

Remember and understand

1 What is the difference between a period and a group in the periodic table?
2 Examine the periodic table in Figure 3.9 (page 71).
   a Identify the period and group for each of the following elements: fluorine, bromine, tin, radium, potassium, platinum, arsenic.
   b Are any of the elements in part a in the same group? What would this tell you about them?
   c Are any of the elements listed in part a in the same period?
3 What proportion of the periodic table is composed of metals?
4 What properties are shared by all metallic elements?
5 Which metal will react most strongly with cold water: copper, iron, magnesium, sodium or zinc? Explain your answer.
6 Why is copper found as a native element on Earth, but calcium metal is never found as a native element?

Apply and analyse

7 Name two properties shown by some transition metals that are not shown by group 1 or group 2 metals.

Evaluate and create

8 Design a way to represent the different groups of metals clearly and informatively, identifying the distinguishing properties of each group.

3.4 Non-metals have properties in common

Non-metals are elements found in groups 14–18 of the periodic table. They do not conduct electricity or heat very well and are very brittle. They do not reflect light and as a result have a dull appearance. **Metalloids** are found between metals and non-metals in the periodic table. Their properties are a combination of those of metals and non-metals.

Figure 3.17 Silicon and germanium are widely used in electronic devices because of their semiconductor properties – they conduct electricity in a very controlled way.

Metalloids

Metalloids are the small set of elements along the 'staircase' diagonal boundary between the metals and non-metals (Figure 3.18). As might be expected from this location, metalloids exhibit properties between those of metals and non-metals. Most of their properties would be considered un-metallic; however, metalloids conduct electricity like the metals. Three of the metalloids are semiconductors (Figure 3.17), which means that they only conduct electricity in a certain way under certain conditions.

Non-metals

Non-metals, as the name suggests, are elements that do not have the set of properties common to all metals. Non-metals are not lustrous (shiny), or ductile (easily manipulated); a small number of non-metals are coloured; some are brittle. In addition, non-metals have a much larger range of melting points and boiling points than the metals do. At room temperature, several non-metals are gases and one (bromine) is a liquid, whereas all the metals except for one (mercury) are solids at room temperature. Only 18 elements in the periodic table are considered non-metals, compared with more than 80 metals. Despite this, non-metals make up most of the crust and atmosphere of the Earth, as well as the bulk of living organisms' tissues.

Only two groups (vertical columns) in the periodic table are made up entirely of non-metals: groups 17 and 18.

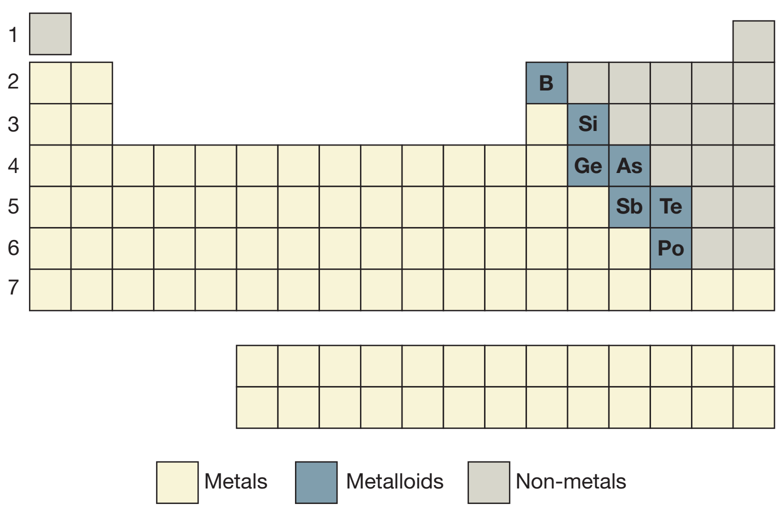

Figure 3.18 Regions of the periodic table.

Figure 3.19 Boron and silicon are combined to form borosilicate glassware, such as the common Pyrex brand. This glassware is tough and has excellent heat-conduction properties that make it suitable for cooking.

CHALLENGE 3.4: IDENTIFYING PATTERNS IN THE PERIODIC TABLE
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Group 17: the halogens

The **halogens**, such as fluorine and chlorine, are found in group 17. The atoms of all the halogens have seven electrons in their outer shell. The halogens are mostly known for their capacity to react with metals to form salts. The word 'halogen' means 'salt-forming' and the term was coined for this group by Jakob Berzelius. Some halogens have bleaching properties as well (Figure 3.20).

Figure 3.20 Bleaches often contain halogens.

As you go down the group, the melting points and boiling points of the halogens increase. At room temperature, fluorine and chlorine are gases, bromine is a liquid and iodine and astatine are solids. This is the only group in which the elements range from gas to liquid to solid at room temperature. Astatine is radioactive and very unstable.

Unlike the metals in groups 1 and 2, the further down you go in this group of non-metals, the less reactive the element. Fluorine is the most reactive non-metal of all and is extremely dangerous to handle (Figure 3.21). Halogens are very effective cleaning and sterilising substances because of the lethal effects they can have on bacteria and fungi.

Group 18: the noble gases

The noble gases, such as neon and argon, are found in group 18. The uncharged atoms of the noble gases have eight electrons in their outer shell, except for helium, which has two. The noble gases are so called because they are all gases at room temperature and are unchanged if mixed with other elements; that is, they are very unreactive, or inert. The first three in the group (helium, neon and argon) do not react with any other element and form no compounds. It was first thought that the same was true of xenon and krypton, but recently chemists have discovered that these two elements will react with fluorine under certain conditions and form a very small number of compounds. The last member of the group, radon, is very dangerous – not because of any chemical reactivity, but because it is a radioactive gas (Figure 3.22).

Figure 3.22 Radon is responsible for most background radiation experienced in public spaces. It occurs naturally as the decay product of uranium and can be found in natural springs.

Check your learning 3.4

Remember and understand

1 Why are non-metals named according to what they are 'not' rather than what they have in common?

2 The two main groupings of non-metals are in groups 17 and 18.
  a What does the group number tell you about the elements it contains?
  b What properties do members of each of these groups share?

3 What is a semiconductor?

4 What is the dominant state of matter within the groups of non-metals?

Evaluate and create

5 Why could the term 'metal-like' be used to describe metalloid elements? Suggest a better name for this group of elements. Explain your answer.

Figure 3.21 Fluorine, the most reactive non-metal, is used to etch glass. It is extremely dangerous to handle.

Figure 3.23 Halogen lamps have been commonly used in car headlights and outdoor lighting for decades. The halogen reversibly reacts with a tungsten filament to provide a bright light that also keeps the bulb clean.

3.5 Metal cations and non-metal anions combine to form ionic compounds

Metals form **cations** when they lose electrons to achieve a full, stable valency shell. Non-metals form **anions** when they gain electrons to achieve a full, stable valency shell. Polyatomic ions form when two or more atoms combine to form a charged ion. Positive cations are attracted to negative anions and form **ionic compounds**. The properties of ionic compounds reflect the ionic bonds that hold the ions together.

Forming ions

Electron shells are most stable when they are full – containing eight valence electrons. The behaviour of valence electrons can be explained by the atom seeking a stable state. The atom may gain or lose electrons in an attempt to gain a full outer electron shell. In certain cases, electrons are shared between atoms to achieve this balance.

The easiest way to achieve stability for atoms with only a few (1–3) valence electrons is to lose these electrons. For example, it is easier for an atom with two electrons in its outer shell to lose two electrons than to gain six electrons. In contrast, if the valence shell is almost full (seven electrons), it is more likely that atom will gain an electron to fill the gap in the shell. The number of positive protons does not change, even when the electrons move. Therefore, if an atom gains a negative electron, the overall charge of the atom becomes negative (more negative electrons than positive protons). If an atom loses electrons, then it becomes positively charged (more positive protons than negative electrons). In both these cases, the atom is then referred to as an **ion** – a charged atom.

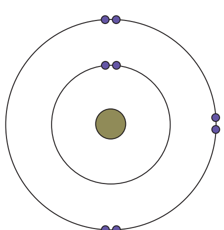

Figure 3.24 Oxygen tends to gain two electrons to fill its valence shell. Overall, there will be two more negative charges than positive charges (from the protons in the nucleus), so the ion is written as O^{2-}.

Metals are usually found on the left-hand side of the periodic table. This means they have fewer than four electrons in their valency shell. Therefore, metals tend to lose electrons and become positively charged. Positively charged metals are called cations.

In contrast, most non-metals have almost–full valency shells. This means they need to gain electrons to achieve a full valency shell of electrons. As a result, non-metals will become negatively charged. Negatively charged ions are called anions.

Positively charged cations are attracted to negatively charged anions. A cation with a 2+ charge is likely to combine (bond) with an anion of 2– charge or with two anions each with a charge of 1–. The positive charge is balanced by an equal negative charge. The bonds that are formed when ions interact are referred to as **ionic bonds**.

Properties of ionic compounds

Compounds that are held together by ionic bonds are called ionic compounds. As an ionic compound forms, the like-charged ions repel each other and the oppositely charged ions attract each other. After all the pushing and pulling, the ions settle into alternating positions, as shown in Figure 3.27, because this is the most stable arrangement. The particles are held together by strong electrostatic forces of attraction between the positively charged ions and the negatively charged ions. Because these forces bind the ions together, this is known as ionic bonding.

A lot of energy is required to move the ions out of their positions. This means that ionic compounds are hard to melt. At room

EXPERIMENT 3.5: CONDUCTIVITY OF IONIC COMPOUNDS
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SKILLS LAB 3.5: IONIC COMPOUNDS
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temperature, they are in the form of hard, brittle crystals. The most commonly known example of an ionic compound is sodium chloride (table salt). Its melting point is 801°C. If you use a salt grinder at home, you will be aware of how hard and brittle salt crystals are.

Polyatomic ions

A number of ions are made up of more than one atom. These are termed **polyatomic ions**. Figure 3.28 shows some examples of polyatomic ions.

These clusters of atoms have a charge because the total number of protons does not equal the total number of electrons present. For example, in the hydroxide ion, which is made up of two atoms (one each of oxygen and hydrogen), there are nine protons and ten electrons. This means the two atoms that form the ion have an overall charge of 1–.

Calcium carbonate, the main constituent of marble, is an example of an ionic compound that contains a polyatomic ion. Calcium carbonate contains calcium ions (Ca^{2+}) and carbonate ions (CO_3^{2-}). These ions must be present in the ratio 1 : 1 so that the total positive charge equals the total negative charge. The formula of calcium carbonate is $CaCO_3$.

Ammonium carbonate is used in smelling salts. It contains ammonium ions (NH_4^+) and carbonate ions (CO_3^{2-}). In this case, the ions need to be present in the ratio 2 : 1. The formula of ammonium carbonate is $(NH_4)_2CO_3$.

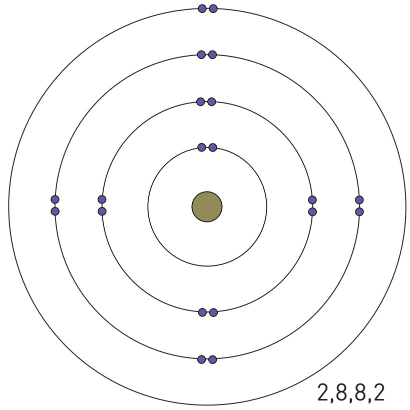


Figure 3.25 Calcium has two electrons in its valence shell, so it tends to lose them to achieve stability. The calcium ion formed is then written as Ca^{2+} to show that there are two extra protons compared with the number of electrons.

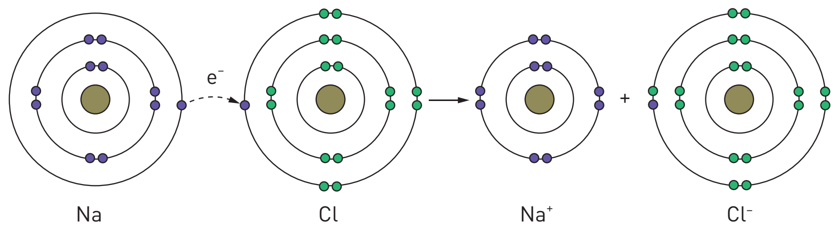


Figure 3.26 Sodium chloride is formed when sodium donates an electron to chlorine.

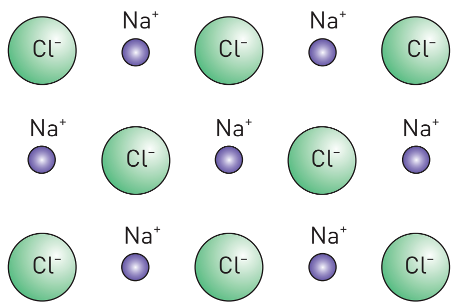


Figure 3.27 In an ionic compound, such as sodium chloride, the ions are arranged in alternating positions.

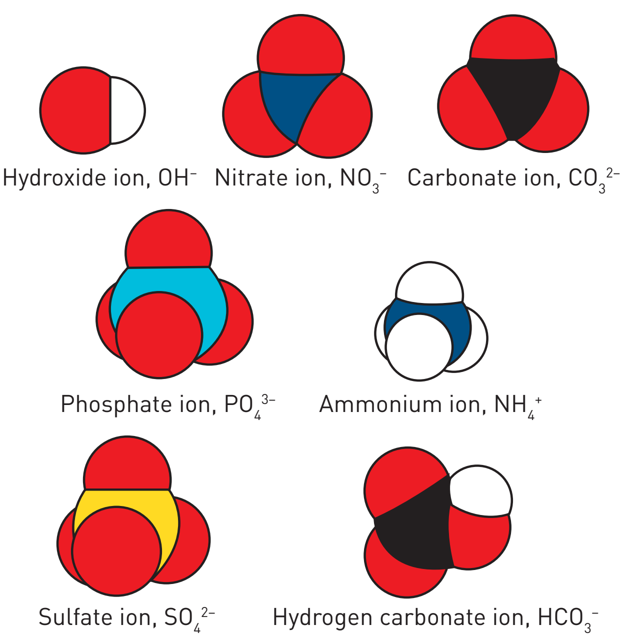


Figure 3.28 Some common polyatomic ions.

Check your learning 3.5

Remember and understand

1 Carefully examine the periodic table in Figure 3.9 (page 71).
   a Which elements are likely to form positively charged ions?
   b Which elements are likely to form negatively charged ions?
   c What does this tell you about which elements will combine to form ionic compounds?
2 What kinds of particles are present in ionic compounds?

Apply and analyse

3 How does the group in which an element is found in the periodic table quickly identify one or more of its properties?
4 What is the maximum number of electrons that can be gained or lost by an atom? Why?
5 Use your knowledge of atomic structure and valence electrons to explain why many ionic compounds are made up of a metal and a non-metal.

3.6 Non-metals combine to form covalent compounds

Two non-metals need a full outer shell of electrons to remain stable. As a result, they merge their valency shells to share two electrons (one from each atom). This sharing of pairs of electrons between atoms is called a **covalent bond**. Covalent compounds form when two or more elements share pairs of electrons so that each has a full valency shell. The bonds between these atoms help explain the compound's properties.

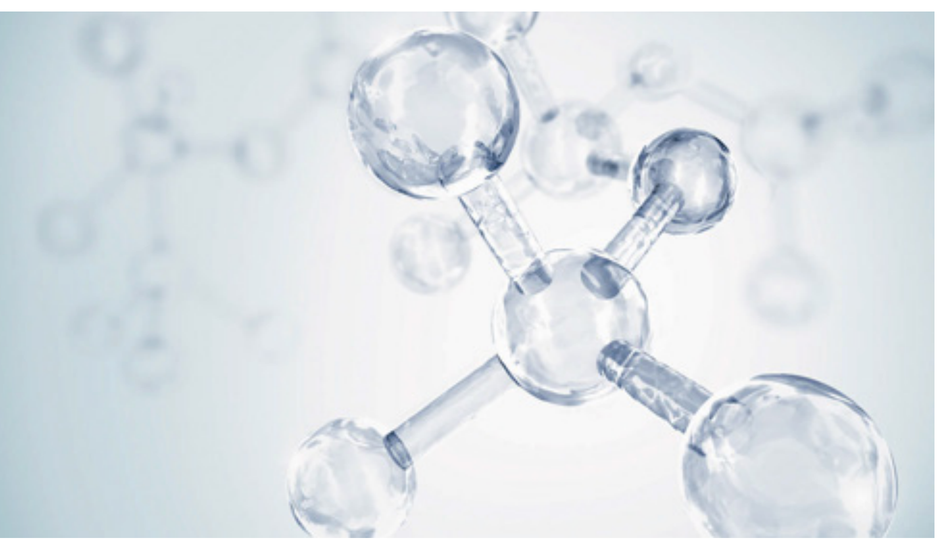
Electrons and molecules

You have seen that when electrons are transferred from one atom to another, positive and negative ions are produced and ionic compounds are formed. However, two non-metals that complete their outer shells of electrons by gaining electrons can also bond together.

We can see this with the smallest, lightest atom: hydrogen.

Hydrogen molecules

An uncharged atom of hydrogen has just one electron in the first shell. If it could gain one more electron, this shell would contain its maximum number of electrons – two. If hydrogen was in contact with a reactive metal such as lithium, the hydrogen atom could gain that extra electron from a lithium atom. An ionic compound would form as a result. But what if only other uncharged hydrogen atoms were present? The only way each hydrogen atom can gain an extra electron is by sharing its electron with another.



As two uncharged hydrogen atoms come close together, the electrons are drawn into the region between the two nuclei. The atoms partially merge into one another, with the nuclei of both atoms now sharing the two electrons. The electrons travel in the spaces surrounding the nuclei of each atom. In effect, each atom now has a stable electron configuration because its outer shell is full.

The particle produced has two hydrogen atoms bonded strongly together and is called a molecule. A molecule is a particle produced when two or more atoms combine so that the atoms share electrons. A molecule has no overall charge because the total number of electrons and the total number of protons is the same.

The hydrogen molecule is given the formula H_2 because there are two hydrogen atoms present in the cluster.

The hydrogen molecule is an example of a molecule of an element. It is called a **diatomic molecule** because it is made up of two atoms. Other examples of diatomic molecules of non-metals are fluorine (F_2), chlorine (Cl_2), oxygen (O_2) and nitrogen (N_2).

In a molecule such as the hydrogen molecule, there is strong electrostatic attraction between each positively charged nucleus and the negatively charged electrons that they share.

CHALLENGE 3.6: MODELLING COVALENT MOLECULES
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The electrons spend a considerable part of their time between the two nuclei. This electrostatic attraction is termed covalent bonding. The two shared electrons create a strong bond between the two atoms.

Molecular compounds

Like elements, compounds also form molecules. Water is an example of a **molecular compound**. Its formula is H_2O. You are now in a position to understand why it has this formula. To gain a more stable electron configuration, an:

> uncharged hydrogen atom, which has one valence electron, requires one more electron
> uncharged oxygen atom, which has six valence electrons, requires two more electrons.

A single hydrogen atom cannot supply the two electrons the oxygen atom needs, but two hydrogen atoms can. This is why there are two hydrogen atoms and just one oxygen atom in a water molecule. An oxygen atom now effectively has eight electrons in its valence shell and each hydrogen atom has two electrons. This is shown in Figure 3.30. Notice that each atom now has a full outer shell of electrons.

There are other ways of representing the structure of molecules, including with three-dimensional models. However, remember that in any representation, a single chemical bond holding the molecule together is actually a pair of negative electrons, shared between two atoms, attracted to the positive nuclei of both of these atoms.

Properties of molecular substances

Almost all molecular substances do not conduct electricity, even in the liquid state, because the molecules do not have free charged particles and so they cannot carry a current. There are no strong forces of attraction between molecules, so most molecular substances are liquids or gases at room temperature. It does not take much energy to separate the individual molecules and get them to move around.

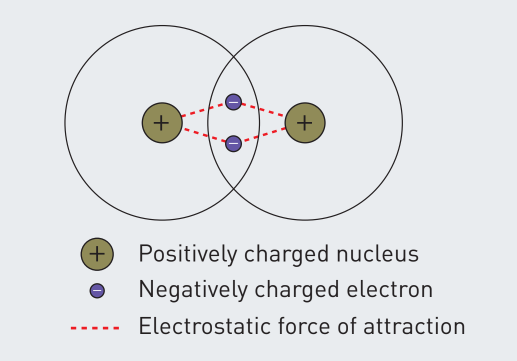

Figure 3.29 Covalent bonding within a hydrogen molecule.

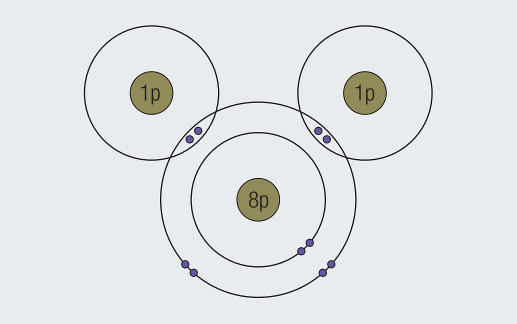

Figure 3.30 A shell diagram of a water molecule.

Check your learning 3.6

Remember and understand

1 What is a diatomic molecule?
2 What types of atoms form covalent bonds?

Apply and analyse

3 Explain why molecular substances cannot conduct electricity.
4 In terms of the structure of the substance, why is it easier to turn liquid water into a gas than to break the bonds between the hydrogen and oxygen atoms?
5 a When chlorine atoms combine to form molecules, how many electrons need to be shared between the two chlorine atoms?
  b Would this be the same for two oxygen atoms combining to form a molecule? Explain your reasoning.

3.7 Metals form unique bonds

Metals form the largest collection of elements in the periodic table. They have many properties in common. All metals arrange their atoms into layers that can easily slide over each other. Some valence electrons are delocalised, and are able to freely move from one atom to another. This enables most metals to be good conductors. Metal alloys are mixtures of two or more metals that are stronger than pure metals. Smart alloys are metal mixtures that are able to retain a memory of their original shape.

Metallic structure

Many metals are malleable (can be bent into any shape). This property of metals is a result of the arrangement of atoms. Metal atoms arrange themselves into layers. When the metal is bent or hammered into shape, the atoms slide over one another (Figure 3.31).

Metals and conductivity

Remember that metals are found on the left-hand side of the periodic table. Metals do not have many electrons in their outer shells, and it does not take much energy for these outer electrons to move from one atom to another. This is the clue as to why metals are so good at conducting electricity.

A substance will conduct electricity if it contains charged particles that are free to move around the structure. In metals, these charged particles are electrons. Scientists refer to the outer-shell electrons as **delocalised electrons** because they are not 'stuck' in one locality. (Most electrons in metal atoms are not delocalised because they move about the nucleus of each metal atom in the inner electron shells.) Metals are good electrical conductors because the outer-shell electrons are free to move from nucleus to nucleus along the metal.

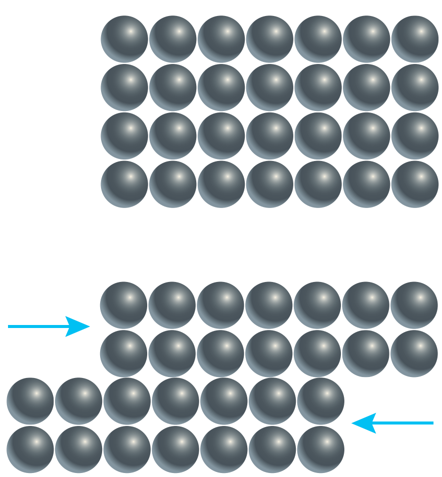

Figure 3.31 The arrangement of atoms in metals allows them to slide over each other when bent or hammered into shape.

Table 3.3 gives the electrical conductivity of a number of elements at 25 °C.

All metals conduct electricity in the solid state, some better than others. They continue to conduct electricity when molten, but more weakly. The higher the temperature, the lower their electrical conductivity.

Only some metals are used for their electrical conductivity. For example, power lines have a core of steel and an outside layer of aluminium. Household wiring is usually copper, which is coated with a special kind of plastic. Metals like silver and gold are used in more specialised applications, such as in electronic devices.

Table 3.3 Electrical conductivities of some common elements at 25 °C

ELEMENT	ELECTRICAL CONDUCTIVITY ($\times 10^6$ ohm^{-1} cm^{-1})
Aluminium	0.37
Silver	0.63
Carbon (graphite)	0.100
Copper	0.596
Gold	0.452
Iron	0.093
Lead	0.048
Magnesium	0.226
Sodium	0.210

CHALLENGE 3.7: MODELLING ALLOYS
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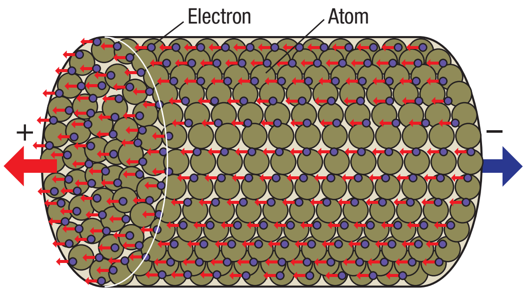


Figure 3.32 Delocalised electrons move about randomly in a metal, but move towards the positive terminal of the power source when connected into a circuit.

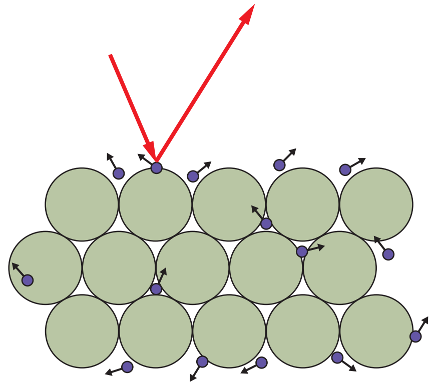


Figure 3.33 The delocalised electrons in the surface of a metal reflect light and cause it to be lustrous.

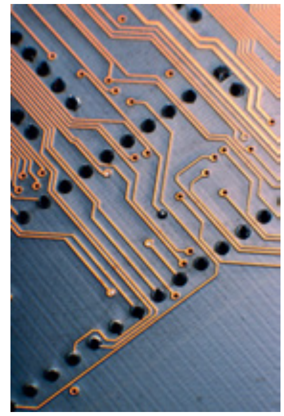


Figure 3.34 Gold bonding wire is used in integrated circuits.

Delocalised electrons are responsible for a pure metal being so lustrous (shiny). The delocalised electrons in its surface reflect light exceptionally well (Figure 3.33).

Metal alloys

A metal alloy is a mixture of two or more metals. Because the metal atoms are different sizes, the atoms are not arranged in the usual arrangement. This means there are no layers of atoms to slide over one another. As a result, alloys are harder than pure metals.

Soft metals such as copper, gold and aluminium are often mixed with other metals to make them hard enough for everyday use.

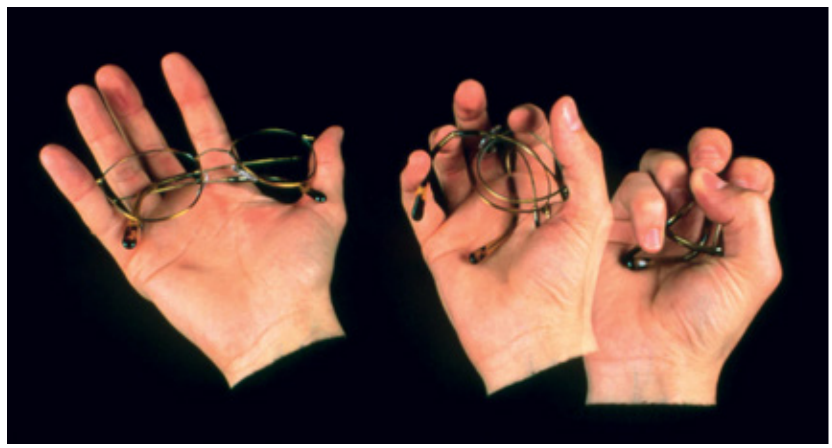
Brass (70% copper and 30% zinc) is used in electrical fittings and hinges.

Jewellery is often made of 18-carat gold (75% gold and 25% copper and other metals).

Smart alloys

Some alloys have unique properties. When Nitinol (a mixture of nickel and titanium) is cast into a particular shape and heated to 500°C, the atoms arrange themselves into a compact and regular pattern. This allows it to create a memory of this shape. If the alloy is bent out of shape, heat or electrical current can cause it return to its original shape. These metals are often called memory alloys (Figure 3.35).

An example of such memory wires are those used in orthodontic wires. The wires will constantly return to their original shape, reducing the need to retighten or adjust the wire.



frames, allowing them to be bent out of shape without breaking.

Check your learning 3.7

Remember and understand

1. Describe the structure of a metal.
2. Identify the arrangement of atoms in a metal that enables each of the following properties.
   a. Malleability
   b. Conductivity
   c. Shiny appearance
3. What is an alloy?

Apply and analyse

4. Compare the properties of an alloy with those of pure metal.
5. Memory alloys have been used to repair broken bones. Suggest why a memory alloy would be beneficial in this situation.

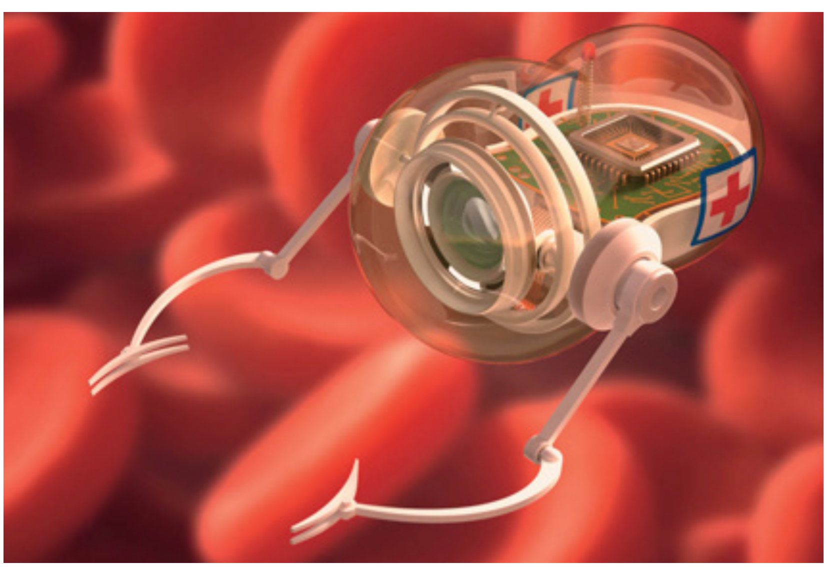
//SCIENCE AS A HUMAN ENDEAVOUR//

3.8 Nanotechnology involves the specific arrangement of atoms

The average atom is 0.3 nanometres (0.000 0003 mm) in diameter. Understanding the structure and properties of individual atoms allows scientists to control how these atoms are arranged. Scientists are able to manipulate atoms to design nanobots, very small structures no larger than the width of a human hair. These nanobots can be used to boost the immune system, repair parts of the body or clean up the environment.

Nanotechnology operates at the scale of the nanometre, which is approximately one ten-thousandth of the width of a human hair. This is the level of atoms or molecules. Nanotechnology allows artificial manipulation of atoms or molecular processes or objects. For example, computers the size of blood cells with tiny wireless transmitters could report on the health of a person without that person requiring surgery. Nanomachines (or nanobots) are tiny structures that are being designed to rearrange the atoms in our bodies, or to detect imbalances in chemical reactions. Scientists hope to develop nanobots as small as viruses or bacteria to perform tasks on a nanometre scale.

Figure 3.36 Nanobots can be used to treat viruses.



Nanobots in medicine

Many medical scientists are very excited about the use of nanobots in medicine. Imagine tiny structures monitoring a patient's body, constantly looking for viruses or bacteria that can cause disease. If a virus is detected, the nanobot could break it down molecule by molecule.

Nanotechnicians have designed a nanobot that is capable of carrying 9 billion oxygen and carbon dioxide molecules. This could potentially remove the need for blood transfusions in the future.

Carbon nanotubes

A **carbon nanotube** is an arrangement of carbon atoms that has very different properties from other arrangements of carbon atoms, such as graphite and diamond. Carbon nanotubes are the focus of intensive research for many applications in the future.

Carbon nanotubes are extremely hard, have very high tensile strength and are very efficient conductors of heat and electricity. That is, carbon nanotubes exhibit many properties usually found in metals. However, in contrast with most metals, carbon nanotubes are extremely light and flexible.

Carbon nanotubes might be used:

- in medicine, where their high electrical conductivity may make them suitable to bypass faulty nerve cell wiring in damaged brains
- to create clothing with unique properties, such as protection against bullets and other missiles
- in computing and television, where they are being used to develop flat, folding, futuristic television screens with greater image resolution than the human eye can detect
- for renewable energy devices, such as solar panels, due to their efficient absorption

of heat, and in wind turbines for making blades lighter and stronger
> to break down pollution in waterways or in smog-ridden cities.

How carbon nanotubes are made

The emergence of nanotechnology as a key scientific force has resulted from relatively recent and rapid developments in the capacity of scientists to:

> put nano-sized quantities of matter where they are wanted
> use controlled amounts of nano-sized materials for a practical purpose
> detect and monitor the location and configuration of nanoscale materials.

There are two manufacturing approaches to making nano-sized materials.

1 The top-down method involves using mass materials and breaking them down by physical or other means into nanoscale components.
2 The bottom-up method, also referred to as molecular manufacturing, is a more complicated process because it relies on the construction of templates on which nanomolecules will form under the appropriate chemical and physical conditions.

A good example of the top-down method can be found in the sunscreen industry, where materials to block UV light, such as titanium oxide and zinc oxide, can be transformed by a grinding process from their white, opaque mass forms into invisible, nano-sized particles. These are known as nanopowders.

A good example of the bottom-up method is the production of carbon nanotubes. A layer of metal catalyst particles is exposed to high heat and a carbon-containing gas. The nanotubes form at the interface between the gas and the metal catalyst.

Extend your understanding 3.8

1 How many nanometres are in a millimetre?
2 How many average-sized atoms would fit in a single nanometre?
3 What is a nanobot?
4 What is a carbon nanotube? Describe its structure.
5 What two main manufacturing processes are used to make nanomaterials?
6 All powders are made up of small particles. How is a nanopowder different from a normal powder?

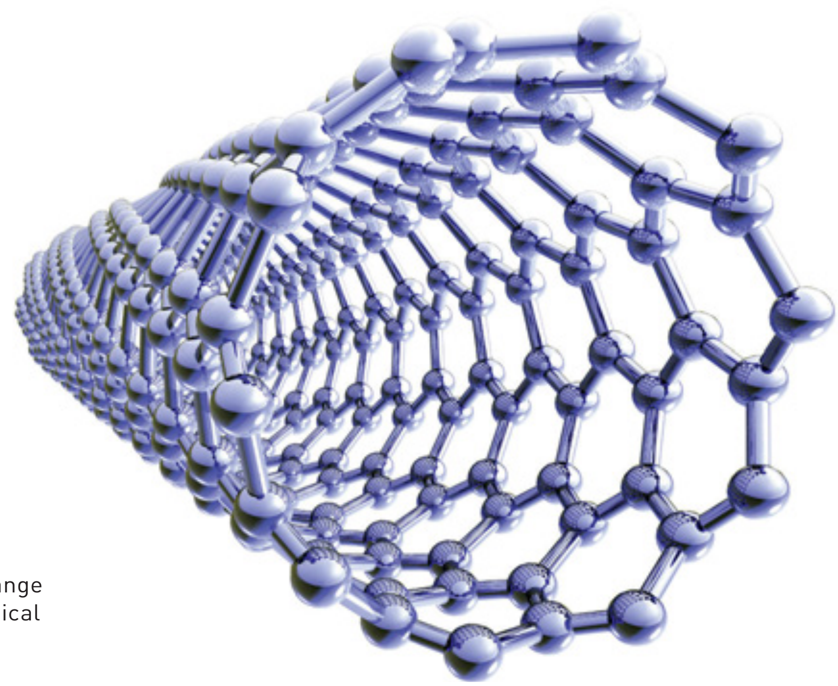


Figure 3.37 Nanotube technology is being investigated for a wide range of technological and medical uses.

3

Remember and understand

1 What is the atomic number of the element known as ununpentium?

2 What is the overall order of elements in the periodic table based on?

3 What is the difference between an atom and an element?

4 What is the name given to the following features of the periodic table?
- a Horizontal row
- b Vertical column
- c The set of 10 groups from group 3 to group 12

5 State the group number of the:
- a alkaline earth elements
- b halogens
- c noble gases
- d alkali metals.

6 What is a valence shell?

7 State the features that elements in the same group have in common.

8 Suggest why transition metals are much more widely used than the alkali metals.

9 An inert substance is one that will not react with any other substance. Originally, group 18 elements were known as the 'inert gases'. Suggest why the name was changed to 'noble gases'.

10 What special feature of metals allows them to conduct electricity in the solid state?

11 What number of electrons in the valence shell makes an atom particularly stable?

12 When naming an ionic compound, which ion is written first?

13 Give explanations for the following.
- a Argon will not react with any other element.
- b The reaction between sodium and chlorine gives out a lot of heat and light.
- c When you accidentally spill sodium chloride onto a stove while cooking, it does not melt.

Apply and analyse

14 Only two elements are liquids at room temperature – bromine and mercury. Bromine is a non-metal and mercury is a metal. Describe how these two liquids are likely to appear and behave differently from each other.

15 Consider the following pairs of elements:
- i chlorine and oxygen
- ii nitrogen and lithium
- iii fluorine and argon
- iv aluminium and potassium.

- a Which pair(s) will react to form an ionic compound?
- b Which pair(s) will react to form a molecular compound?
- c Which pair(s) will not react to form a compound?

In each case, justify your answer.

Evaluate and create

16 Scientists such as Berzelius and Mendeleev worked on their own to produce new ideas. Others, such as Seaborg, worked in a team. Now most scientists work in teams. What are the advantages of working in a team?

17 Scientists deduce what it is like inside an atom from indirect evidence, similar to how astronomers determine the temperature and composition of stars. List three advantages and three disadvantages of using indirect evidence to develop scientific theories.

18 What two elements would you expect to react together in the most violent way? Justify your answer.

19 Before the 1980s, the groups of the periodic table were numbered with Roman numerals. Some scientists prefer this version because the atoms of the elements in group III (now 13) have three electrons in their valence shell, those in group IV (now 14) have four electrons in their valence shell and so on. Examine how the groups of transition metals were numbered in the old way. Which numbering system do you think is the most helpful? How can you deduce the number of electrons in the valence shell from the new group number?

20 A certain particle was found to contain 16 protons and 18 electrons.

a What element must it be? State your reasoning.

b Is the particle neutral, positively charged or negatively charged?

c What is the formula of the particle? Justify your answer.

21 When the uncharged atoms of potassium lose an electron, they then have an electronic configuration of 2,8,8. This is the same as the electronic configuration of argon. Does this mean that the potassium atoms have become argon atoms? Discuss.

Ethical understanding

22 Meyer and Mendeleev each published a periodic table within months of each other. However, Mendeleev is given sole credit for developing the periodic table.

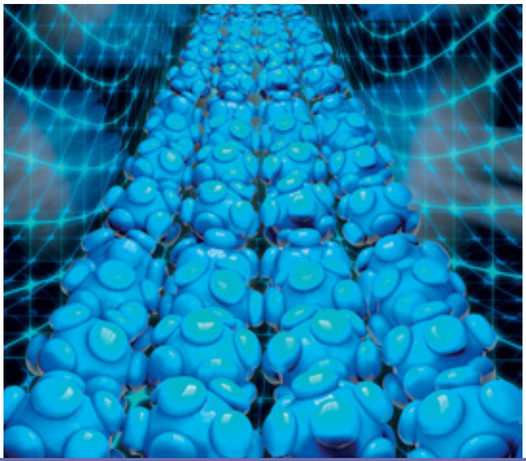
a Is it fair that the person who first discovers, develops or publishes something receives the credit for this discovery?

b What did Mendeleev do to get sole credit for developing the periodic table?

Critical and creative thinking

23 A substance will conduct electricity if it contains charged particles that are free to move across the sample. The charged particles can be electrons or ions. Suggest why ionic compounds cannot conduct electricity when in the solid state, but can conduct electricity when melted.

24 A student claimed that sodium chloride is made of molecules. Is the student correct? Discuss.



Research

25 Choose one of the following topics for a research project. Some questions have been included to help you begin your research. Present your report in a format of your own choosing.

> **The noble gases**
> The story behind the discovery of the noble gases is a fascinating one. The challenge was this: how do you detect the existence of something that only exists as a gas that does not react with anything and, except for argon, is only present in the air in extremely small concentrations? How was the first noble gas found? What role did the periodic table of that time play in helping chemists hunt for other noble gases?

> **Hydrogen**
> Hydrogen is a most unusual non-metal because it can form H^+ ions and H^- ions depending on what it reacts with. Although alkali metals do not react with one another, hydrogen will react with alkali metals and form compounds, such as lithium hydride (LiH). Show why the hydride ion (H^-) is stable. What are the properties of metal hydrides such as lithium hydride? What uses are made of these compounds?

> **Nanotechnology**
> Nanomaterials are now being used to assist in a range of chemical reactions, often to increase the rate of very specific reactions that produce valuable products. Research the products that are produced by using nanoparticles and how the use of these has improved the production method.

KEY WORDS

3

alkali metal
an atom found in group 1 of the periodic table

alkaline earth metal
an atom found in group 2 of the periodic table

anion
a negatively charged ion

atomic number
the number of protons of an atom

Bohr model
a way to represent the electrons of an atom in a series of shells around the atomic nucleus

carbon nanotube
a very small tube made by the careful arrangement of carbon atoms

cation
a positively charged ion

covalent bond
a bond formed when two or more atoms share electrons

delocalised electron
an electron in a molecule that can easily move between atoms

diatomic molecule
a molecule that consists of two atoms

electronic configuration
the arrangement of electrons in each electron shell surrounding an atom

element
a pure substance made up of one type of atom, e.g. oxygen, carbon

group
a vertical list of elements found in the periodic table that have characteristics in common

halogen
the group of elements found in group 17 of the periodic table

ion
an atom that has gained or lost electrons, resulting in a negative or positive charge

ionic bond
a bond that forms between a negatively charged anion and a positively charged cation

ionic compound
a molecule that is formed by a negatively charged anion and a positively charged cation

metals
a collection of elements found on the left-hand side of the periodic table; they are malleable, lustrous, ductile and highly conducting

metalloids
a small collection of elements that have a mixture of characteristics of metals and non-metals

molecular compound
a molecule that is formed through covalent bonding

nanotechnology
the manipulation of individual atoms to form structures

noble gases
a collection of gaseous elements found in group 18 of the periodic table

non-metals
a collection of elements that are found on the right-hand side of the periodic table

period
a horizontal list of elements found in the periodic table

periodic
the arrangement of elements into a table according to their chemical elements

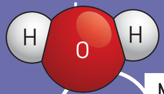
polyatomic ion
a charged ion that consists of two or more atoms bonded together

shell diagram
a diagram that shows the arrangement of electrons and electron shells in an atom

transition metals
the elements found in groups 3–12 of the periodic table

valence shell
the outermost electron shell in an atom that contains electrons

CHEMICAL REACTIONS 4



4.1 Mass is conserved in a chemical reaction

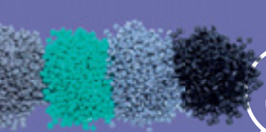
4.2 The rearrangement of atoms in a chemical reaction can be show using a balanced chemical equation

4.3 Synthesis and decomposition reactions can be represented by equations

4.4 Acid reactions depend on strength and concentration

4.5 The solubility rules predict the formation of precipitates

4.6 Combustion reactions between hydrocarbons and oxygen produce carbon dioxide, water and energy



4.7 Polymers are long chains of monomers

4.8 Temperature, concentration, surface area and stirring affect reaction rate

4.9 Catalysts increase the rate of a reaction

4.10 Green chemistry reduces the impact of chemicals on the environment

What if?

What you need:

9 V battery, wires with crocodile clips, 250 mL beaker, strip of copper foil (1 cm wide), 0.5 M copper sulfate solution, brass key (to be plated)

What to do:

1. Pour 100 mL of copper sulfate solution into the beaker.
2. Fit the copper foil inside the beaker with the top 2 cm bent back over the edge of the beaker.
3. Use a wire to connect the positive terminal of the battery to the copper foil.
4. Use a wire to connect the negative terminal of the battery to the key.
5. Place the key into the copper sulfate solution, ensuring it does not touch the copper foil.
6. Observe any changes in the key.

What if?

» What if a smaller battery was used?

» What if water was used instead of copper sulfate?

» What if a carbon rod was used instead of the copper foil?

4.1 Mass is conserved in a chemical reaction

In chemical reactions, the substances on the left-hand side of the arrow are the substances we start with, and are called the **reactants**. The substances on the right-hand side of the arrow are the substances that are formed in the reaction, known as the **products**. The law of conservation of mass states that the total mass of the reactants is equal to the total mass of the products.

Representing chemicals

When examining chemical reactions, we can represent the substances in different ways. The substances that are present at the start of a chemical reaction are called the reactants. The substances formed by the chemical reaction are called the products. We can write this using a simple word equation. Consider the reaction of the acid in vinegar with sodium bicarbonate. This reaction produces water, carbon dioxide gas and a substance called sodium acetate, and it can be represented as:

acetic acid (in vinegar) + sodium bicarbonate →
sodium acetate + carbon dioxide + water

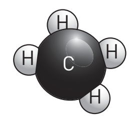
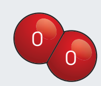
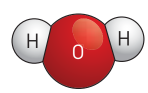
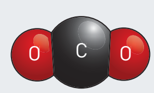
The acetic acid and sodium bicarbonate are the reactants for this reaction. The products formed by this reaction are sodium acetate, carbon dioxide and water.

The law of conservation of mass

When you do Experiment 4.1, you will find that when the products of a chemical reaction are not allowed to escape, the mass or quantity of elements of the products after the observed reaction is the same as the mass of the reactants that you started with. This is a very important observation. It shows that the total mass of the chemicals is not changed in a chemical reaction.

When a chemical reaction takes place, the chemicals interact, causing the atoms to break apart from each other before forming into new arrangements. However, no atoms are produced in the process and no atoms are destroyed. This is one of the most important laws in science.

Table 4.1 Representations of four chemicals

CHEMICAL NAME	FORMULA/ SYMBOL	DIAGRAM
Methane	CH_4	
Oxygen	O_2	
Water	H_2O	
Carbon dioxide	CO_2	

EXPERIMENT 4.1: COMPARING MASS BEFORE AND AFTER A CHEMICAL REACTION
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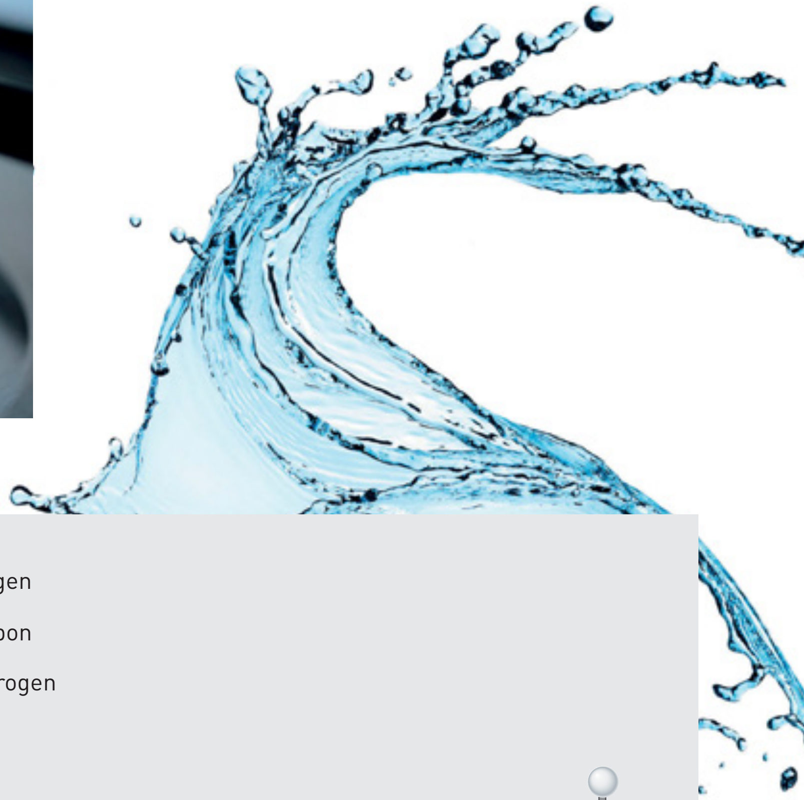
Figure 4.1 Methane gas burning on a stove.



Example of a chemical reaction

Methane gas (CH_4) is the main gas present in natural gas, which is used in the home for cooking and heating. When it burns, it combines with oxygen (O_2) in the air to form carbon dioxide (CO_2) and water (H_2O).

Figure 4.2 shows what happens to the atoms during this reaction. Different atoms are represented by different colours.

1 Count the number of each type of atom in the reactants (left-hand side of the arrow) and count the number of each type of atom in the products (right-hand side of the arrow). What do you notice?
2 Describe what has happened to the hydrogen atoms during the chemical reaction.
3 Describe what has happened to the oxygen atoms. Make sure you use the correct names of the chemicals in your description.

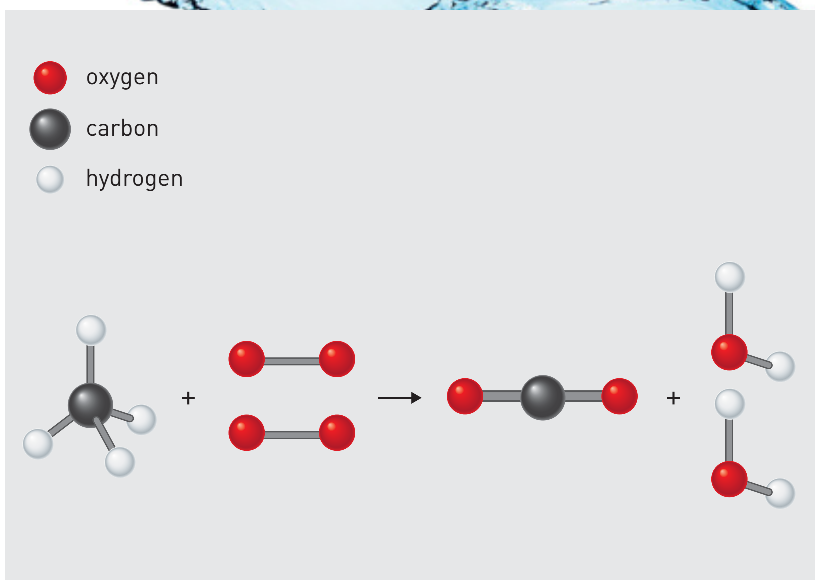


Figure 4.2 Atoms are rearranged during a chemical reaction.

Check your learning 4.1

Remember and understand

1 What is mass?
2 Use Table 4.1 to identify:
   a an element composed of molecules
   b a compound composed of molecules.
3 If no mass is lost or gained in a chemical reaction, what does this tell you about the atoms involved in the reaction?

Apply and analyse

4 Explain how the products have properties very different from those of the reactants, even though the total mass remains the same.
5 Early alchemists repeatedly tried to turn lead into gold. Explain, using the law of conservation of mass, why this would be impossible.

4.2 The rearrangement of atoms in a chemical reaction can be shown using a balanced equation

Chemical reactions can be described through observations, word equations or symbols. The law of conservation of mass is used to write a balanced chemical equation. A balanced chemical equation has equal numbers of each type of atom on both sides of the equation.

Describing chemical reactions

Figure 4.3 shows sodium metal reacting with water. Perhaps you have seen this reaction at school or on the Internet. There are different ways to describe this reaction.

> *Describing observed changes:* The sodium metal dissolves in the water; heat is produced; fizzing is caused by the production of hydrogen gas. If there is enough heat, the hydrogen gas catches fire above the sodium metal.

> *Using a word equation:* The reactants are sodium and water and they interact to form the products, which are sodium hydroxide and hydrogen gas. A word equation summarises the changes:

sodium + water →
sodium hydroxide + hydrogen

Figure 4.3 Sodium metal reacts violently with water, undergoing a chemical change.

> *Using a chemical equation:* This includes the formulas of all the substances involved and the ratio in which they react:

$$2Na(s) + 2H_2O(l) \rightarrow 2NaOH(aq) + H_2(g)$$

Each representation tells us something different about the changes occurring in the chemical reaction.

Reacting hydrogen and oxygen

When hydrogen gas burns in oxygen, large amounts of heat energy are produced. If this reaction happens in uncontrolled conditions, it is very dangerous. This reaction caused the destruction of the *Hindenburg* airship in 1937 when a spark set a huge amount of hydrogen gas ablaze. Thirty-five passengers died. Under controlled conditions, hydrogen can be used safely as a fuel. In the future, your family might be driving a car fuelled by hydrogen. An advantage of using hydrogen as a fuel is that the only product is water. (There are no carbon emissions.)

In this reaction, the oxygen atoms and hydrogen atoms have split up from each other and have joined to form molecules of water (H_2O). The atoms have not been created or destroyed. You can show what is happening using a diagram, or by using a chemical equation.

CHALLENGE 4.2: MODELLING CHEMICAL EQUATIONS
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Writing chemical equations

Hydrogen combines with oxygen to produce water. The equation can be written by using the following steps.

1 Write out the word equation for the reaction.

hydrogen + oxygen → water

2 Write a simplified chemical equation using the formulas of the substances involved.

$$H_2 + O_2 \rightarrow H_2O$$

3 Work out the numbers of each type of atom in the reactants (left-hand side) and in the products (right-hand side).

	REACTANTS		→	PRODUCTS	
Type of atom:	H	O	→	H	O
Number of atoms:	2	2		2	1

4 Compare the number of each type of atom in the reactants with the number in the product. In this case, there are three atoms in the products and four atoms in the reactants. This doesn't fit the law of conservation of mass. We can't have just 'lost' an oxygen atom.

To ensure that there are the same numbers of each atom at the end of the reaction as there were at the start, we include numbers (called coefficients) before the formula of the substances. This allows the number of reactant atoms to equal the number in the product – the equation is said to be balanced.

$$2H_2 + O_2 \rightarrow 2H_2O$$

Type of atom: H O H O
Number of atoms: 4 2 4 2
This balanced equation shows how the atoms are rearranged to form the water molecules.

Figure 4.4 The reaction of hydrogen with oxygen caused the *Hindenburg* explosion.

Check your learning 4.2

Remember and understand

1 Which way of describing a chemical reaction tells us most about what is happening to the atoms?

2 Which representation of a chemical reaction tells us most about the chemicals? Explain your reasoning or discuss your answer with others.

Apply and analyse

3 What do you think the '(s)', '(l)', '(g)' and '(aq)' stand for in the chemical equation for the reaction of sodium metal with water?

4 Why are chemical reactions that are not 'balanced' always incorrect?

5 Balance the following equations by adding numbers as required:

a ____Na + ____H_2O → ____NaOH + ____H_2

b ____H_2 + ____O_2 → ____H_2O

c ____CH_4 + ____O_2 → ____CO_2 + ____H_2O

d ____Mg + ____HCl → ____H_2 + ____$MgCl_2$

EXPERIMENT 4.3A: DIRECT SYNTHESIS WITH A 'POP'
GO TO PAGE 215

4.3 Synthesis and decomposition reactions can be represented by equations

Almost every substance that you will use today was made in a chemical reaction. The role of chemists is to understand chemical reactions and the products they form. Classifying reactions into different types helps us predict the products produced by reactions and understand what reactants are required to produce particular products. To assist in classifying reactions, we can sort compounds into types, such as acids, bases, salts, hydrocarbons and polymers. Balanced chemical equations use the law of conservation of mass.

Types of chemical reactions

Classifying compounds into groups makes them easier to name and identify. Because all the compounds in the same group have similar properties, you can predict most of the properties of an unknown substance if you know to which group it belongs.

Similarly, the chemical reactions that are used to make compounds can also be classified. Reactions can be classified as synthesis, decomposition, combustion or hydrolysis (reaction with water) reactions, among others.

Synthesis reactions

Synthesis is the building up of compounds by combining simpler substances, normally elements:

$$A + B \rightarrow AB$$

This equation is a general equation and it helps you determine what will be produced in a synthesis equation. In synthesis reactions, the two reactants combine to form a new product. For example:

sodium + chlorine → sodium chloride

WRITING CHEMICAL EQUATIONS

Once you have predicted the product that will be formed and written the word equation, you can write the chemical equation.

1 Write the symbols for the elements:

$$Na + Cl \rightarrow NaCl$$

2 Write the chemical formula for each of the molecules. Are they ionic compounds or covalent compounds? Use smaller subscript numbers to indicate the number of each atom in the molecule:

$$Na + Cl_2 \rightarrow NaCl$$

3 Count the number of atoms on each side of the equation to ensure that no atoms are created or destroyed (law of conservation of mass). If more atoms are needed, add a large number before the molecule:

$$2Na + Cl_2 \rightarrow 2NaCl$$

4 Determine if the reactants and products are solids (s), liquids (l), gases (g) or aqueous solutions (a soluble solution mixed with water) (aq):

$$2Na(s) + Cl_2(g) \rightarrow 2NaCl(s)$$

EXPERIMENT 4.3B: DECOMPOSING A CARBONATE
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EXPERIMENT 4.3C: ELECTROLYSIS
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AMMONIA

Ammonia (NH_3) is a very important chemical produced by the direct combination of its elements, nitrogen and hydrogen. It is used in a large number of fertilisers, as well as in a range of household cleaning products. The modern method used to produce ammonia is called the Haber process, which relies on the reaction:

$$3H_2(g) + N_2(g) \rightarrow 2NH_3(g)$$

Nitrogen is not a very reactive element, so specific conditions are required for this reaction to occur. It involves heating the two gases so that the reaction will happen quickly enough.

Decomposition reactions

Decomposition reactions are the breakdown of compounds into simpler substances, either elements or more simple compounds. These reactions often require energy in the form of electricity or heat.

Electrolytic decomposition is the breakdown of a compound as a result of an electric current passing through a solution. An example is the formation of hydrogen and oxygen from water:

$$2H_2O(l) \rightarrow 2H_2(g) + O_2(g)$$

Electrolysis equipment has two diodes – an anode and a cathode. A different chemical reaction occurs at each diode (Figure 4.5). These reactions are endothermic because they need energy for the reaction to occur.

Electrolytic decomposition is used in the smelting of aluminium. Aluminium ore (bauxite) contains alumina (Al_2O_3). When an electrical current is passed through a solution of alumina, a decomposition reaction occurs:

$$2Al_2O_3 \rightarrow 4Al + 3O_2$$

Quicklime, or calcium oxide (CaO), is an important industrial product. It is used in agriculture as a fertiliser and to neutralise acidic soils. It is also a key component in building materials, such as mortar. Calcium oxide is produced by the thermal decomposition of calcium carbonate ($CaCO_3$):

copper(II) carbonate →
copper(II) oxide + carbon dioxide

$$CuCO_3 \rightarrow CuO + CO_2$$

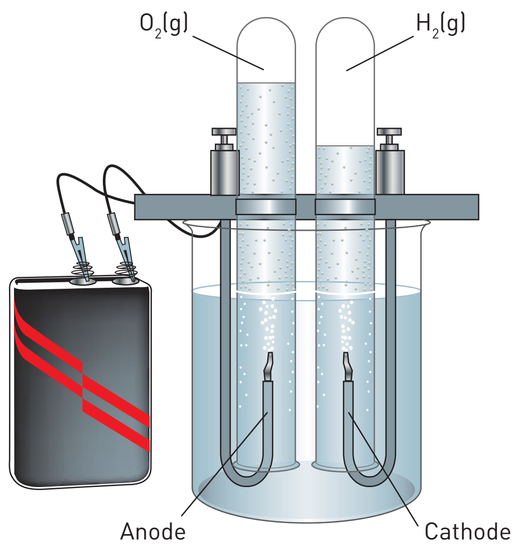

Figure 4.5 Electrolysis equipment. At the anode, water is being broken down into oxygen gas and hydrogen ions. At the cathode, hydrogen gas is being produced from hydrogen ions and electrons.

The most common and cheapest naturally occurring form of calcium carbonate is limestone. For many centuries, calcium oxide was produced from limestone in lime kilns. These stone structures were fuelled by coal, with blocks of limestone broken up, often by hand, and added to the kiln, where the temperatures could reach close to 1000°C.

Today, limestone is roasted in more modern furnaces, often fuelled by gas, where the temperature can be regulated by controlling the flow of gas and air into the furnace.

Check your learning 4.3

Remember and understand

1 What is the law of conservation of mass?
2 Why do decomposition reactions always produce more than one product?

Apply and analyse

3 Why are synthesis reactions sometimes called combination reactions?
4 Describe, in terms of the types of chemical reactions, major differences between the reaction used to produce ammonia and the reaction used to produce calcium oxide.
5 Why is energy required in:
   a decomposition reactions?
   b direct synthesis reactions?
6 Predict the products of the following synthesis reactions and write a balanced chemical equation for each one.
   a Calcium and oxygen
   b Hydrogen and chlorine

4.4 Acid reactions depend on strength and concentration

Acids have a pH less than 7. Bases have a pH greater than 7. Neutralisation reactions occur when acids react with a base to produce a neutral solution (pH 7). Acids react with metals to produce hydrogen and a metal salt. A **concentrated acid** has many acid molecules present with very little water. A **strong acid** readily donates a hydrogen ion to a base.

Acids

Acids are a group of chemicals with similar properties. They taste sour, turn litmus paper red and have a pH of less than 7. Strong acids are dangerous because they are corrosive and can cause severe burns. Weak acids are much less reactive and many are found in food and drinks, such as lemonade. All acids contain hydrogen. Although most acids are molecular compounds (with covalent bonding), when they dissolve in water they form ions. This is called an ionising reaction. This reaction is what gives acids their name. All acids donate a hydrogen ion (H^+) to a base. A hydrogen ion is a hydrogen atom that has lost its electron, so it is really just a proton.

Bases

A base is defined as a substance that gains a hydrogen ion. All bases have a bitter taste, turn litmus paper blue, feel slippery and have a pH of greater than 7. Bases that dissolve in water are called alkalis. Like acids, some bases are more reactive than others. Some, such as caustic soda (NaOH), can burn the skin.

Neutralisation reactions

When an acid and a base are mixed together, hydrogen ions from the acid combine with hydroxide ions (OH^-) commonly found in bases to form water. The remaining ions form a metal salt. Water is considered neutral (pH 7).

Figure 4.6 Zinc metal reacting in acid.

This reaction is called a **neutralisation** reaction:

acid + base (metal hydroxide) → water + metal salt

For example:

$$HCl + NaOH \rightarrow H_2O + NaCl$$

EXPERIMENT 4.4: ACID TITRATIONS
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Acid and metal reactions

The reaction between acids and metals is most obvious with acid rain. The carbon dioxide or sulfur dioxide gases in the air cause the formation of acid rain. This contributes to the corrosion of metalwork on buildings:

acid + metal → salt + hydrogen

For example:

sulfuric acid + zinc → zinc sulfate + hydrogen

$H_2SO_4(aq) + Zn(s) \rightarrow ZnSO_4(aq) + H_2(g)$

Note: Only the more reactive metals will form a metal salt and hydrogen when reacting with acids. Copper, silver and gold are unreactive metals.

Acids and metal oxides

An acid and a metal oxide react to form a metal salt and water:

acid + metal oxide → metal salt + water

For example:

nitric acid + magnesium oxide → magnesium nitrate + water

$2HNO_3(aq) + MgO(s) \rightarrow Mg(NO_3)_2(aq) + H_2O(l)$

Acids and metal carbonates

An acid and a metal carbonate react to form a metal salt, water and carbon dioxide:

acid + metal carbonate → metal salt + water + carbon dioxide

For example:

nitric acid + calcium carbonate → calcium nitrate + water + carbon dioxide

$2HNO_3(aq) + CaCO_3(s) \rightarrow Ca(NO_3)_2(aq) + H_2O(l) + CO_2(g)$

Concentrated or strong?

If you were to make a drink of cordial and not add enough water, you might describe it as 'too strong'. A chemist would describe it as 'too concentrated'. The strength and concentration of an acid or a base are two different things, so chemists need to be precise when using these terms.

The **concentration** of an acid or base is a measure of how many molecules of the acid or base are present in each litre of solution. A concentrated acid or base has very little water present: it is mostly molecules of acid or base. The labels of a container of concentrated hydrochloric acid might say, 'Conc. HCl' or '10 M HCl'. These solutions are very dangerous to handle.

The **strength** of an acid, is a measure of how readily it will give away the hydrogen ion to a base. Acid strength is compared at the same concentration, which is usually a very low concentration of 0.1 M, a very **dilute** (watered down) **solution**. Strong acids and strong bases are still dangerous at this concentration.

Check your learning 4.4

Remember and understand

1 What must you react with an acid to produce:
   a hydrogen gas?
   b carbon dioxide?
2 What is the reaction of an acid with a base called? Why is it given this name?

Apply and analyse

3 Write equations for:
   a dilute nitric acid (HNO_3) reacting with magnesium metal
   b dilute ethanoic acid (CH_3COOH) reacting with solid potassium carbonate (K_2CO_3)
   c dilute hydrochloric acid reacting with calcium hydroxide solution.
4 Why is it unsuitable to store acids in metal containers?
5 Would it require more, less or the same amount of base to neutralise 20 mL of 0.1 M strong acid than it would to neutralise 20 mL of 0.1 M weak acid?

4.5 The solubility rules predict the formation of precipitates

If a compound is soluble, it can dissolve in a liquid solvent. A **precipitation reaction** involves two soluble ionic solutions being mixed to form an insoluble solid product called a **precipitate**. The ions that do not take part in the reaction are called **spectator ions.** The solubility of a compound can be predicted from the solubility rules.

Precipitation reactions

A precipitate is an insoluble solid that can form as part of a reaction between two ionic solutions.

This can be written in a general form:

$$AB(aq) + CD(aq) \rightarrow AD(s) + CB(aq)$$

In a water (aqueous) solution, the ions A and B separate, as do the ions C and D. Positive ion A forms a bond with negative ion D and positive ion C forms a bond with negative ion B. It is important to note that the positive ions (A and C) are always written first. This is called a double displacement reaction as both substrates change (or displace) their partners. It becomes a precipitation reaction if either AD or CB is insoluble, and forms a solid. The formation of an insoluble solid precipitate can be predicted by using a set of solubility rules. The data shown in Table 4.2 can be used to decide whether a precipitate will form.

For example, a solution of lead(II) nitrate ($Pb(NO_3)_2$) consists of lead ions (Pb^{2+}) and nitrate ions (NO_3^-) together with many water molecules.

When a solution of lead(II) nitrate is added to potassium iodide – both colourless solutions – a bright yellow precipitate of lead iodide (PbI_2) is formed. The reaction can be written as:

lead(II) nitrate + potassium iodide →
lead(II) iodide + potassium nitrate

$$Pb(NO_3)_2(aq) + 2KI(aq) \rightarrow PbI_2(s) + 2KNO_3(aq)$$

The lead ions and the iodide ions have combined to form an insoluble precipitate of lead(II) iodide. This new compound forms as a solid in the solution. The potassium and nitrate

Table 4.2 Solubility of some common ionic compounds in water

SOLUBLE	INSOLUBLE	SLIGHTLY SOLUBLE
Group 1 elements		
All ammonium salts		
All nitrate salts		
Most chlorides, bromides and iodides	AgCl, AgI, AgBr, $PbCl_2$, PbI_2, $PbBr_2$	
	Most carbonate and phosphate compounds	
Group 1 hydroxides, $Ba(OH)_2$ and $Sr(OH)_2$	Most hydroxides and sulfates	$Ca(OH)_2$, Ag_2SO_4, $CaSO_4$

EXPERIMENT 4.5: PRECIPITATION REACTIONS
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ions are still dissolved in solution. They are not taking part in the reaction. They are called spectator ions. Because of this, it is possible to write the equation in a different way that shows only those ions that are changing in the reaction:

$$Pb^{2+}(aq) + 2I^{-}(aq) \rightarrow PbI_2(s)$$

Because the lead ions and iodide ions are dissolved in the solution, they are described as aqueous (aq). This reaction is shown in Figure 4.7.

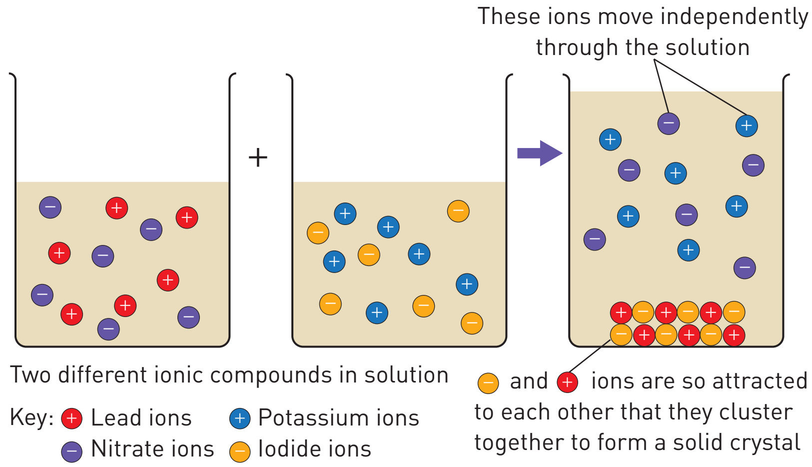

Figure 4.7 At the particle level, when a solution of lead(II) nitrate ($Pb(NO_3)_2$) is added to potassium iodide (KI), the ion partners are swapped.

Using precipitation reactions

Precipitation reactions are important for chemical analysis. PbI_2 is insoluble, so, if any soluble lead(II) compound is mixed with any soluble iodide, a precipitate of PbI_2 will form (Figure 4.8). Similarly, Table 4.2 tells us that $Cu(OH)_2$ is insoluble. This means that if any soluble hydroxide, such as NaOH, is mixed with any soluble copper(II) compound, such as $CuSO_4$, a precipitate of $Cu(OH)_2$ will form.

Chemists sometimes use precipitation reactions to find out which chemicals are present in a substance or how much is present.

Common table salt (NaCl) is essential in our diet because the sodium is needed to maintain the correct concentration of body fluids, assist in the transmission of nerve impulses and to help cells absorb nutrients. Chemical analysis can determine the amount of salt in foods by using a precipitation reaction with silver nitrate. The salt reacts with the silver nitrate to form a precipitate of silver chloride. The amount of sodium chloride present can be calculated by using the amount of silver chloride that has been precipitated:

$$NaCl(aq) + AgNO_3(aq) \rightarrow NaNO_3(aq) + AgCl(s)$$

Figure 4.8 Yellow lead(II) iodide forming in a precipitation reaction.

Check your learning 4.5

Remember and understand

1 Draw a diagram to show which particles are present in a beaker containing a sodium chloride solution.

2 What symbol is used to show the state of an insoluble compound?

Apply and analyse

3 Which of the following substances would be insoluble?

Copper(II) chloride, calcium hydroxide, silver nitrate, magnesium bromide, silver bromide, magnesium nitrate, potassium chloride, lead(II) nitrate, potassium nitrate, lead(II) chloride

4 What precipitate would form if solutions of lead(II) nitrate and sodium sulfate were mixed?

5 Complete the following word equations and then write balanced chemical equations for each reaction.

a zinc nitrate + potassium hydroxide →

b calcium nitrate + sodium carbonate →

4.6 Combustion reactions between hydrocarbons and oxygen produce carbon dioxide, water and energy

* **Oxidation reactions** occur when an element reacts with oxygen. Oxidation reactions with metals produce metal oxides. **Combustion** reactions between non-metals and oxygen produce large amounts of energy in the form of heat and light. Combustion of **hydrocarbons** produces water and carbon dioxide.

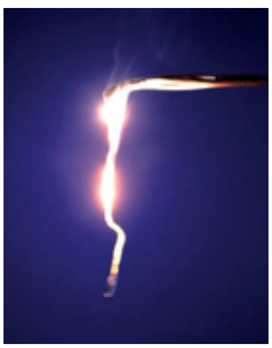

Figure 4.9 The oxidation of magnesium is highly exothermic and produces a very bright flame.

When an element reacts with oxygen, we say that is has oxidised. This is classified as an oxidation reaction.

Oxidation reactions with metals

When metals react with oxygen, a basic metal oxide is formed:

metal + oxygen → metal oxide

As the metal has formed a compound, this is also classified as a corrosion reaction. The metal oxide produced is an ionic compound.

In the case of very reactive metals, this oxidation is highly exothermic (energy producing) and rapid. For example:

magnesium + oxygen → magnesium oxide

$$2Mg(s) + O_2(g) \rightarrow 2MgO(s)$$

In the case of moderately reactive metals, the oxidation reaction is still exothermic, but slow.

Oxidation reactions with non-metals

Group 18 non-metals do not react with oxygen. Other non-metals do react with oxygen, which is also a non-metal. Reaction results in the formation of a covalent bond. Consider the formation of water and carbon dioxide:

$$2H_2(g) + O(g) \rightarrow 2H_2O(g)$$

$$C(s) + O_2(g) \rightarrow CO_2(g)$$

Both of these reactions are highly exothermic. The first reaction can cause explosions. (This is the reaction that causes the 'pop' in the pop test for hydrogen.) Carbon is the principle constituent of coal. Both reactions produce a flame and so are classified as reactions.

Combustion reactions require oxygen and a fuel. A fuel is a substance that will undergo a chemical reaction in which a large amount of useful energy is produced at a fast but controllable rate. According to this definition, fuels are the substances we use to produce heat and/or electricity, and to run engines and motors.

Combustion of hydrocarbons

The most common fuels we use for combustion are compounds of carbon and hydrogen (known as hydrocarbons). When pure hydrocarbons burn in unlimited oxygen, carbon dioxide and water are produced:

EXPERIMENT 4.6: COMBUSTION OF WIRE WOOL
GO TO PAGE 220

hydrocarbon + oxygen → carbon dioxide + water

When there is less oxygen available, carbon monoxide forms:

hydrocarbon + limited oxygen → carbon monoxide + water

Carbon monoxide (CO) is a poison that binds tightly to the haemoglobin in red blood cells, much tighter than oxygen binds. Carbon monoxide poisoning can be fatal because of a lack of oxygen to the brain and other body tissues.

With even less oxygen, unburnt hydrocarbon (soot) is formed, with water:

hydrocarbon + limited oxygen → carbon + water

Small particles of soot cause breathing problems, especially in people with asthma. It is important that all users of hydrocarbon fuels burn them cleanly. In addition to releasing less pollution, burning these fuels cleanly provides more energy.

Our carbon economy

The chemical fuels that our society relies upon are based on carbon. Our ancestors burnt wood, which is mainly the carbon compound cellulose. Later generations burnt coal, which is close to pure carbon. Coal is made by the dehydration and compaction of buried plant remains. Our generation uses coal to produce electricity and petroleum as a liquid fuel for transport.

All these fuels contain molecules made of carbon. Cellulose is a chain of $C_6H_{10}O_5$ units arranged end-to-end, coal is 95% pure carbon (depending on the type) and petroleum is a mixture of hydrocarbons. Petrol is mostly octane (C_8H_{18}), diesel is a mixture with the average formula $C_{12}H_{23}$, natural gas is CH_4 and liquefied petroleum gas (LPG) is propane (C_3H_8).

Petrol, diesel, natural gas and LPG are fossil fuels. They are obtained from the Earth and were formed from the fossilised remains of plants and animals. The energy in them was captured by photosynthesis millions of years ago. This carbon has been locked away out of the atmosphere for millions of years. Even renewable fuels, such as biodiesel and ethanol, contain carbon atoms. The carbon atoms in renewable fuels were captured by photosynthesis in the last growing season.

It is fair to say that our society runs on carbon. It is a very important fuel. Carbon is the mainstream of our economy. This is why it is called a carbon economy.

Figure 4.10 In oil refineries, distillation towers are used to isolate the different liquid fractions in crude oil.

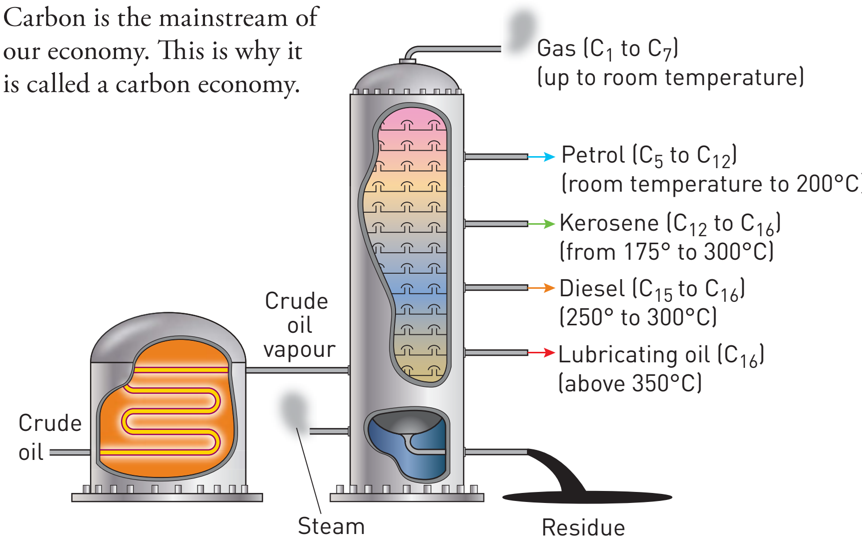

Figure 4.11 As the crude oil is slowly heated, vapour (gases) form. As the vapour rises, it cools. When the vapour reaches the height where the temperature is equal to the fraction's boiling point, it condenses into a liquid.

Check your learning 4.6

Remember and understand

1 Why are carbon fuels so important to our society?

2 Why does the amount of oxygen available affect the products formed in the combustion process?

3 Which group of elements do not react with oxygen?

4 Why is it important to burn hydrocarbons in a well-ventilated area?

Apply and analyse

5 Give an example of a substance that might be considered a fuel by a:
   a firefighter
   b chemist.

6 Write a balanced equation for the combustion of each of the following hydrocarbons in excess oxygen.
   a Petrol
   b LPG
   c Natural gas
   d Diesel

7 Which fuel in question 6 requires the most oxygen to burn cleanly?

4.7 Polymers are long chains of monomers

Polymerisation is the process of forming a long-chain **polymer** from smaller **monomer** molecules. Elastomers are bound to each other and will return to their original shape when stretched. **Cross-linked polymers** are giant lattices with many random linkages. Thermoplastic polymers will soften when heated. Thermoset plastics will not melt or change shape when heated.

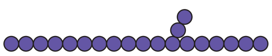

Figure 4.12 The basic structure of a linear polymer. The small circles represent small groups of atoms.

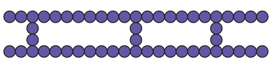

Figure 4.13 The basic structure of an elastomer.

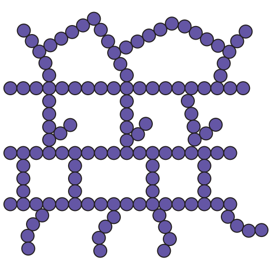

Figure 4.14 A cross-linked polymer.

Figure 4.15 Plastic film is a thermoplastic material.

Different types of polymers

The plastics we use every day are a result of polymerisation. A polymer is a giant molecule that has been produced by joining many, many smaller molecules together – often thousands. Polymer means 'many parts'. The small molecules from which the polymers are made are called monomers.

If the polymer has been produced by chemists or chemical engineers, it is called a synthetic polymer. An example of a synthetic polymer is nylon. Before nylon was created, stockings were made from silk, which is a natural fibre produced by silkworms. Apart from being expensive, stockings made from silk easily developed holes and 'ladders'. Toothbrush bristles were made from another natural fibre – the fine hairs from boars! Nylon could replace both silk and boar bristles because nylon fibre is much tougher and more suitable for these applications.

There are three types of polymer structures: linear polymers, occasionally cross-linked polymers (also known as elastomers) and cross-linked polymers.

Linear polymers are in the form of long chains (Figure 4.12). Generally, the chains consist of carbon atoms held together by covalent bonding, with other atoms or groups attached to the carbon atoms. In some linear polymers, the atoms of another non-metal are found at regular intervals along the chain of carbon atoms. For example, in nylon a nitrogen atom is found about every tenth atom along the chain. There may also be 'branches' hanging off the main chain.

The structure of **elastomers** is like a ladder (Figure 4.13). Elastomers are in the form of long chains that are connected every now and then with a small chain of atoms. They are termed 'elastomers' because they are elastic. That is, they can be stretched and, when you let them go, they spring back into shape.

Cross-linked polymers are giant covalent lattices (Figure 4.14). Generally, they are largely made up of carbon atoms, although the atoms are much more haphazardly arranged than the carbon atoms in other covalent lattices, such as diamonds.

Apart from being classified according to their structure, polymers are classified according to how they respond to heat. This is a very important property.

Thermoplastic polymers soften when heated gently and solidify again when nt shapes by warming and pressing them, squeezing them through holes or even blowing them into the required shape. 'Plastic' means being able to have its shape changed. So, these are the only polymers that really should be described as 'plastic'. Plastic film is a thermoplastic polymer (Figure 4.15).

Thermosetting polymers do not melt or change shape when heated. If heated very strongly, they may char (turn black). These polymers must be produced in a mould because once they are formed they will not change shape again. Once formed, they are hard and rigid (Figure 4.16).

EXPERIMENT 4.7: POLYMERISATION OF CASEIN
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Formation of polymers

There are many different types of **polymerisation** reactions, but they all follow the same process, with the small molecules being reacted under conditions (i.e. specific temperature and/or pressure) that allow them to join together in a chain reaction to form giant molecules that can contain thousands of atoms. Polythene is produced in this way, with molecules of ethene (C_2H_4) reacting together to form long-chain molecules of polyethene. This process can be represented using a diagram, as shown in Figure 4.17.

This polymerisation reaction requires high temperature and pressure, as well as a chemical catalyst.

How we use polymers today

Many different polymers are used today. More and more designer polymers are being developed and modified to suit particular applications. Many tents are made from nylon, which produces a lightweight, tear-resistant fabric (Figure 4.18). Bigger tents are made of cotton polyester. The bases of the tents are made of polyurethane, another useful, waterproof polymer.

Most people have at least one piece of clothing made of polar fleece, which is warm yet lightweight. Polar fleece is a synthetic wool made from PET, or PETE (polyethylene terephthalate). PET is a thermoplastic polymer and, for polar fleece, is sourced from recycled plastic bottles that have been processed into a clothing fabric. PET gives polar fleece its soft, warm, durable and fast-drying properties, which make it perfect for camping and other outdoor activities (Figure 4.19).

Figure 4.16 The plastics that make up the cover of a PlayStation are made of thermosetting polymers.

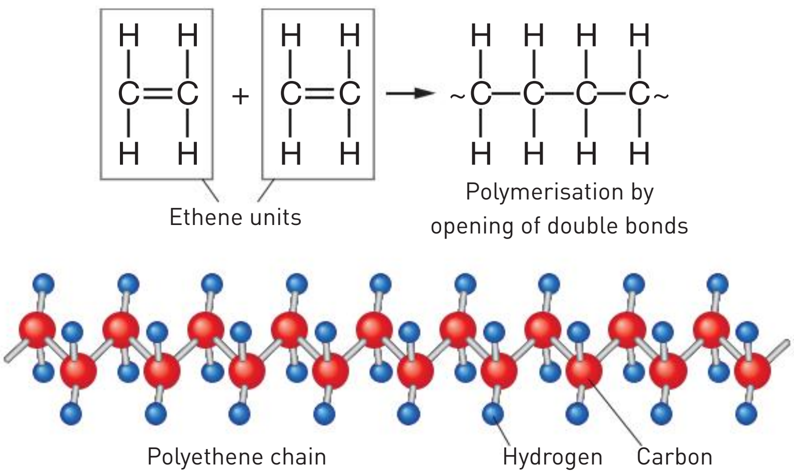

Figure 4.17 The formation of polyethene from ethene molecules.

Figure 4.18 Tents are made of nylon, which makes them lightweight.

Check your learning 4.7

Remember and understand

1 What are the differences between a linear polymer and a cross-linked polymer?

2 What is the monomer unit of polyethene?

3 What are the properties of elastomers? Use their structure to explain their properties.

Apply and analyse

4 For each of the following applications, state whether it would be better to make the object from a thermosetting polymer or a thermoplastic polymer.

a Food wrap

b Light switch

c Disposable cup for soft drinks

d Wash bottle for a science laboratory

e Handles of barbecue tongs

5 Which would you expect to be a thermosetting plastic: a linear polymer or a cross-linked polymer? State your reasoning.

Figure 4.19 Polar fleece is warm and light, which makes it very suitable for outdoor activities such as camping.

4.8 Temperature, concentration, surface area and stirring affect reaction rate

The speed at which a reaction occurs is called the rate of a reaction. For a reaction to occur, the reactants must collide in the correct orientation. This is called **collision theory**. The rate of a reaction can be increased by increasing the temperature, concentration, surface area or stirring the reactants.

Why reaction rates are important

A **reaction rate** is how fast a reaction proceeds. It is important to realise that this does not mean more products are formed in the reaction. This can be illustrated by a 100-metre race. A runner can run fast or slow; the only difference is how quickly the runner finishes the 100 metres. A fast reaction has a high reaction rate; a slow reaction has a low reaction rate.

In the chemical industry, controlling the rate of a reaction is vital. Reactions that are too slow are not economic, because equipment is tied up for a long time. Reactions that are too fast need to be controlled. Chemists and chemical engineers have the role of making chemical reactions as cheap as possible. A large part of this is achieved by controlling the rate of the reaction.

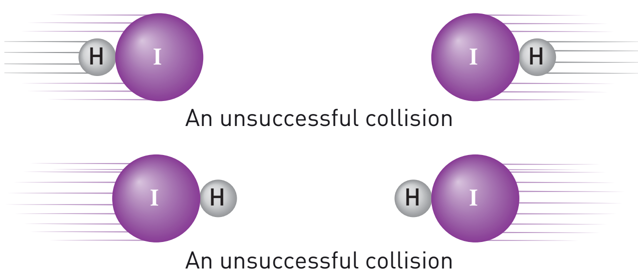

Figure 4.20 Not all collisions result in a chemical reaction.

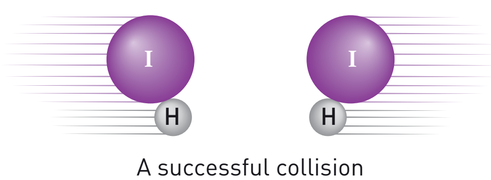

Figure 4.21 When the collisions between particles have enough energy, and the particles are aligned correctly, a reaction may occur.

Collision theory

For a chemical reaction to occur, the atoms or ions or molecules must collide with enough energy for that reaction to occur. This model is known as collision theory.

One reaction that has been studied is the decomposition reaction of hydrogen iodide. The reaction, in symbols, is:

$$2HI(g) \rightarrow H_2(g) + I_2(g)$$

Hydrogen iodide is a gas and its molecules travel quickly. Each hydrogen iodide molecule must collide with another hydrogen iodide molecule in order to react.

Some collisions do not result in a reaction. In these unsuccessful collisions, the hydrogen iodide molecules bounce apart with no reaction, as shown in Figure 4.20.

EXPERIMENT 4.8A: EFFECT OF TEMPERATURE ON REACTION RATE
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EXPERIMENT 4.8B: FACTORS AFFECTING REACTION RATE
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In the collision shown in Figures 4.21–23, there is a reaction. A weak chemical bond forms between the iodide ions and between the hydrogen ions. This intermediate substance is unstable and only exists for a short period of time before it breaks apart. Only some collisions result in a reaction. The molecules must collide in the correct orientation for a reaction to occur.

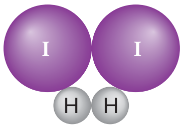

Figure 4.22 An intermediate stage during the reaction. The products of this reaction move apart. (This is partly due to electrical repulsion.)

Figure 4.23 The final products are formed.

Increasing the rate of collisions

To increase the rate of a reaction, you need to increase the number of collisions occurring. This can be done by increasing the:

- surface area of the particles reacting
- concentration of the reactants
- temperature of the reaction.

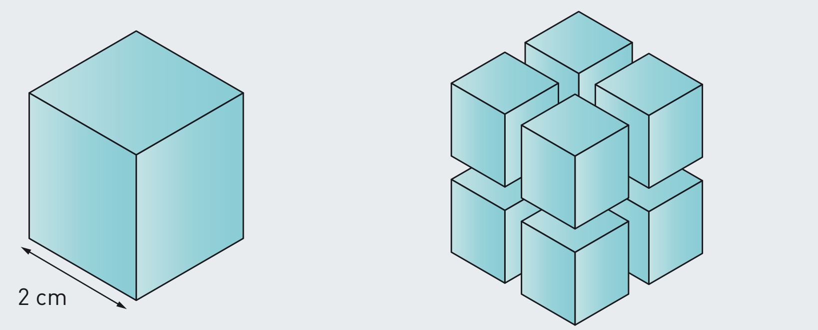

Figure 4.24 Many small particles have a larger surface area than a single large particle of the same volume.

INCREASE THE SURFACE AREA

A metal such as magnesium reacts with dilute hydrochloric acid. For a reaction to occur, hydrogen ions in the acid have to collide with magnesium atoms. There are more metal atoms exposed to the hydrogen ions if the metal is in small pieces. Because the reaction occurs on the surface of the magnesium, breaking it up into smaller pieces provides a larger surface area on which the reaction can occur.

Powders have a much larger surface area than large-sized bits of material. The surface area is not the size of the pieces, but the total area exposed to possible collisions (Figure 4.24).

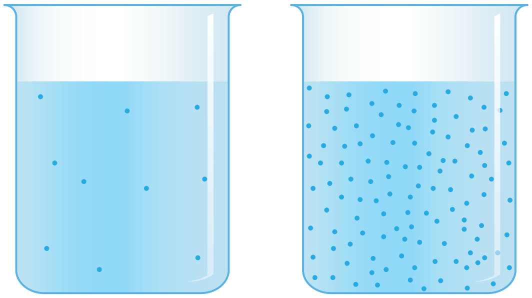

Figure 4.25 A concentrated solution will contain more dissolved particles than a dilute solution.

INCREASE THE CONCENTRATION

In a dilute solution, the particles (molecules or ions) of the reactant are spread out in a solvent, such as water. There is a lot of space between the reactant particles. In a concentrated solution, there are many more reactant particles in the same volume, so they are much closer together (Figure 4.25).

In the reaction between magnesium and hydrogen ions, the reaction will occur faster if there are more hydrogen ions in a given volume. So, using a hydrochloric acid solution with a higher concentration (i.e. more hydrogen ions in a given volume) will speed up the reaction. When there are more particles, there are more collisions and therefore a higher reaction rate.

INCREASE THE TEMPERATURE

Particles in a hot substance have more kinetic energy than particles in a cold substance. This means that the particles in a hot substance travel faster than the particles in a cold substance (Figure 4.26).

Particles in hot substances will collide faster and more often than cold particles will. A higher frequency of collisions, with a greater energy, means a greater proportion of collisions will result in a reaction.

Slow-moving gas molecules will be pushed apart by the repulsion of the electrons that orbit the atoms: they never come close enough to form new chemical bonds. Fast-moving molecules can ‘push through’ the repulsion and their electrons can orbit around a different atom. The faster the molecules, the higher the proportion of molecules with sufficient energy to change into products.

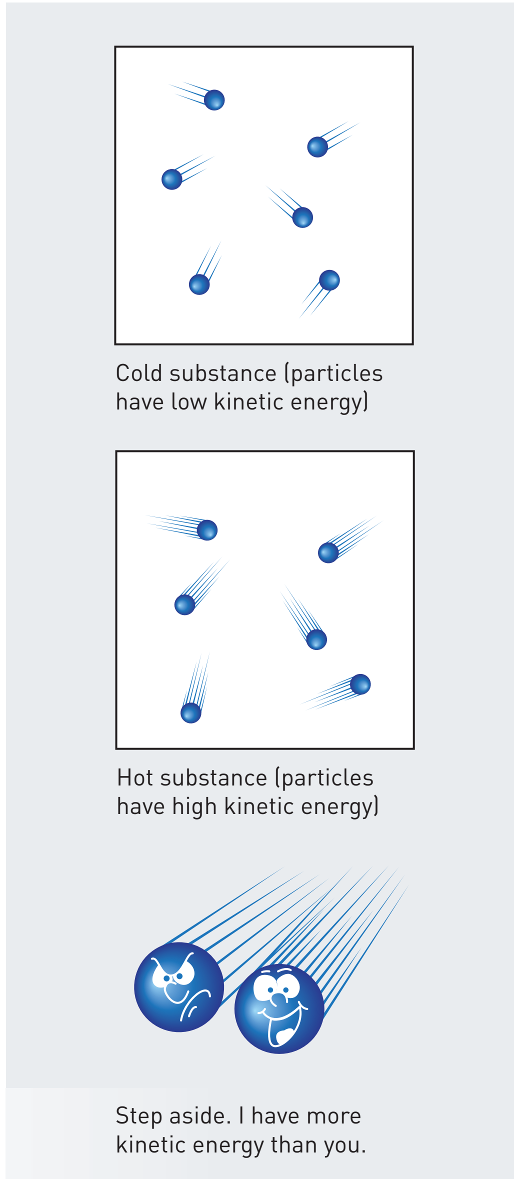

Figure 4.26 At higher temperatures, the average energy of the particles is increased and the particles travel faster.

Stir and mix

As a chemical reaction proceeds, the particles of the reactants get used up: when there are fewer particles of reactants, there are fewer collisions and so the reaction rate slows. To maintain the reaction rate, the products of the reaction should be removed and replaced with more particles of reactants. A basic way of doing this is by stirring or mixing the reactants.

In the reaction between magnesium and acid, one of the products is hydrogen gas. The gas forms bubbles that gather on the surface of the magnesium, covering the unreacted magnesium (Figure 4.27). This prevents the reaction from continuing. Stirring sweeps the hydrogen gas away so that more hydrogen ions can react with the fresh magnesium surface.

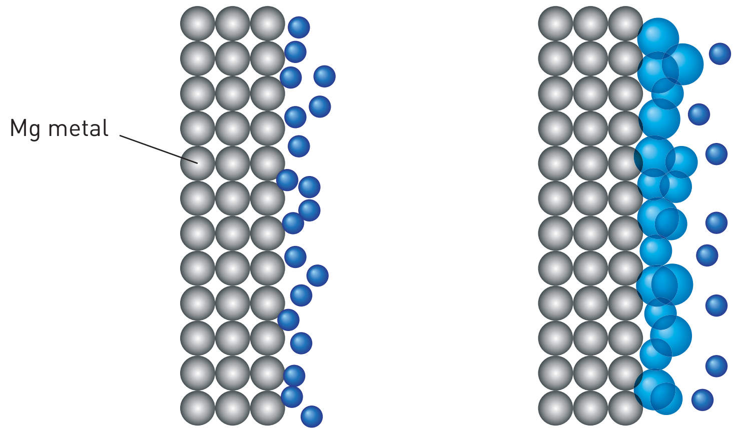

Figure 4.27 Sometimes the presence of the product can slow down a chemical reaction.

Check your learning 4.8

Remember and understand

1. Are products formed every time molecules of reactants collide? Explain your answer.
2. Why does increasing the surface area increase the rate of reaction?
3. Why does diluting a solution decrease the rate of reaction?
4. Why does a reaction occur faster when the reactants are stirred together?
5. How does collision theory explain the dramatic increase in the rate of a reaction as the reactants are heated?

Apply and analyse

6. A reaction is carried out in a well-ventilated environment with outside air regularly circulating. A chemical engineer noticed that a reaction that gave a high yield of a product in winter gave a low yield of that same product in summer, despite the reagents and concentrations being identical. What is a possible explanation for the different yields?

4.9 Catalysts increase the rate of a reaction

Catalysts increase the rate of a chemical reaction without being permanently changed. Some catalysts provide a surface on which the two reactants can meet in the correct orientation, allowing the products to be formed. The products are then released. Other catalysts take part in the initial reaction and are regenerated in the final reaction.

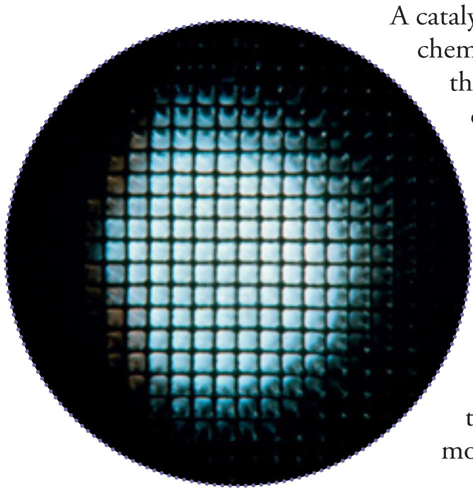

Figure 4.28 Catalysts are often used in the form of a grid to maximise the surface area.

A catalyst is a substance that speeds up a chemical reaction but is not used up in the reaction. Catalysts work in many different ways.

Solid catalysts provide a surface on which the reaction can occur. The particles of reactants get adsorbed (stuck onto) the surface, where they react to form the products. The products are then released from the surface of the catalyst. This frees up the catalyst to be used again by other reactant molecules.

Pollution control in cars

Solid catalysts are used in the catalytic converters of cars. A honeycomb-like grid of metals provides a large surface area (Figure 4.28). As the exhaust gases pass through the converter, they react on the surface of the metals to form harmless gases. The metals adsorb pollutant gases, but not clean gases such as nitrogen and carbon dioxide. These clean gases are passed through the car exhaust. The metals that act as catalysts are platinum, palladium and rhodium.

The overall reaction that occurs in the catalytic converter is:

$$2CO(g) + 2NO(g) \rightarrow 2CO_2(g) + N_2(g)$$

Sometimes these catalysts are poisoned. This is when an impurity prevents the catalyst from functioning fully. Impurities in petrol can poison a car catalyst.

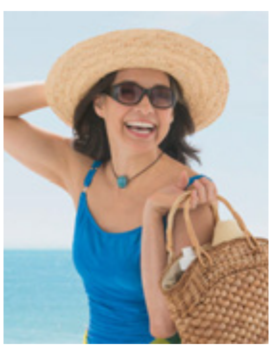

Figure 4.29 Ozone offers some protection from some harmful ultraviolet radiation.

Figure 4.30 Catalytic converters are used to reduce pollution from exhaust gases.

Reactions in the ozone layer

Another way in which catalysts work is to take part in the reaction and be regenerated later. This occurs in the destruction of ozone by chlorofluorocarbons (CFCs).

The ozone layer is part of the stratosphere. It is the region in the stratosphere from 10 to 50 km high, with the greatest concentration at an altitude of 30 km. Ozone in this region absorbs the ultraviolet (UV) light that would otherwise cause many more skin cancers and eye problems.

CFCs are the main destroyers of ozone. CFCs were developed as refrigerants for use in refrigerators. CFCs are non-flammable, non-toxic, cheap to manufacture, easy to store and chemically stable. They were used in aerosol cans (Figure 4.31), fire extinguishers and asthma inhalers, as well as in foam insulation for furniture, bedding, coffee cups and hamburger containers.

EXPERIMENT 4.9: USING A CATALYST
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CFCs such as CCl_3F (trichlorofluoromethane or freon-11) are broken apart by the UV rays from the Sun, releasing a free chlorine atom. This chlorine atom catalyses the destruction of ozone and is regenerated.

In this way, one chlorine atom from the original CFC can destroy up to 10 000 ozone molecules. The reactions occurring can be shown as follows.

CCl_3F breaks down to produce a chlorine atom:

$$CCl_3F \xrightarrow{\text{UV light}} CCl_2F + Cl$$

The chlorine atom reacts with ozone:

$$Cl + O_3 \rightarrow ClO + O_2$$

ClO reacts with by O atoms, making more Cl:

$$ClO + O \rightarrow Cl + O_2$$

The Cl atoms are then free to react with more ozone.

In 1987, the Montreal Protocol (an agreement made in Montreal, Canada) phased out the use of CFCs. Chemicals that were 'ozone friendly' were developed and used as replacements for the ozone-depleting substances.

Figure 4.31 Chlorofluorocarbons (CFCs) were used to pressurise the gas used in aerosol cans before it was proven that the CFCs damaged the ozone layer.

Enzymes as catalysts

An enzyme is a catalyst made and used in living cells. Enzymes play an important part in all cellular processes. All the reactions that occur inside a cell are catalysed by enzymes. There are numerous enzymes in our bodies to help speed up reaction rates. For example, enzymes in the digestive system help break down food. Enzymes only work with specific reactants and so will only catalyse certain reactions.

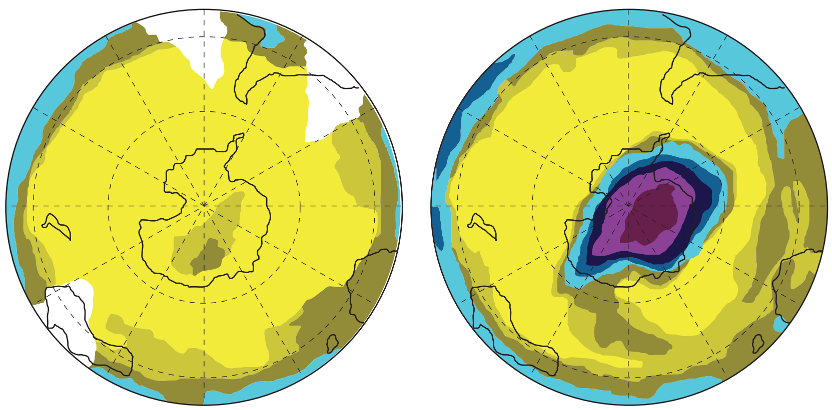


Figure 4.32 Ozone levels reduce over the southern hemisphere every year. The darker colours show where the 'hole' in the ozone layer has grown.

Check your learning 4.9

Remember and understand

1 What is a catalyst?
2 Explain two ways in which catalysts can work.
3 What is a catalytic converter? Why are they used?

Apply and analyse

4 Why is it important that the amount of ozone in the atmosphere remains stable?
5 What has caused a change in the amount of ozone in the atmosphere over time?
6 Which part of the CFC molecule destroys ozone? How does this atom become detached?

//SCIENCE AS
A HUMAN ENDEAVOUR//

4.10 Green chemistry reduces the impact of chemicals on the environment

Being 'green' means doing something positive for the environment. Scientists with special knowledge in ecology, biochemistry, zoology and botany study the environment and how it responds to changes. These scientists detect changes caused by natural events, as well as by human actions. They monitor the environment for changes that may have been caused by the actions of society.

Low-impact chemicals

Some chemicals have a negative impact on the environment and living things. When these substances are identified, scientists act to reduce their use and prevent them from entering the environment. Some substances are banned altogether.

New chemical products and processes are described as 'green' if they have less impact on the environment than the product or process they replace. The study and development of new substances that have a low impact on the environment is called 'green chemistry'.

Some examples of the development of 'green' alternatives are described below.

Pesticides and herbicides

Pesticides and herbicides have been used to kill organisms that eat our food crops and the plants that compete with these crops for sunlight and nutrients. In the past, some of these products killed all living things, not just the target species. Most were non-degradable (did not break down) and remained in the environment long after they were no longer needed. These substances are now banned and have been replaced with **biodegradable** poisons. In many cases, chemical poisons have been replaced with new farming practices, such as crop rotation and planting pest-resistant crop varieties.

Heavy metals

Heavy metals include lead, mercury and cadmium. Heavy metals had many uses, especially in dyes, and were used in chemical processes as catalysts. But these metals accumulated in the bodies of living things, including people.

The most dramatic example is that of Minamata disease, caused when people in Minamata, Japan, in 1956, were poisoned by mercury after eating contaminated seafood. The use of these metals in situations where they could enter the environment has been largely stopped. They have been replaced by different catalysts and even different production processes.

Solvent-based paints

Acrylic paints have replaced solvent-based enamel paints and lacquers. The solvent used in the old paints was a hydrocarbon, such as turpentine, and it evaporated as the paint dried. The hydrocarbon solvents in enamel paint were toxic to aquatic life in waterways and the fumes from the paint caused 'painter's disease' in the workers who inhaled them.

These solvent-based paints have been replaced with acrylic paints, which are water-based and set by polymerisation of the paint, not by evaporation of a solvent.

Green chemistry is sometimes called 'sustainable chemistry'. It is about reducing the impact of chemicals on the environment – chemists produce substances in processes that have less impact on the environment than the substances they replace.

How science can help

You can help protect the environment and the planet by adapting the slogans 'Reduce, Reuse, Recycle' and 'Act Local, Think Global' to reduce your footprint on the environment by:

> using your own shopping bags instead of plastic bags
> composting grass clippings and food scraps and using this compost instead of chemical fertilisers
> using trigger-action spray bottles, not aerosols
> avoiding non-degradable products, such as some biocides
> leaving the car at home for short journeys, and catching public transport or riding a bike instead
> using natural cleaning products and avoiding chlorine-based cleaners.

Figure 4.33 There are many ways in which you can reduce your impact on the environment.

Extend your understanding 4.10

1 How do scientists determine how safe a product is?

2 The 'old masters', the painters of the 1600s to 1800s, used pigments made of compounds of lead, mercury and cadmium. Why are these paints no longer available to today's artists?

3 If you discovered an important new chemical, could you be responsible for any consequences that occurred 30 years in the future? Could the people who are affected in 30 years' time blame you?

4 What other materials can be recycled to reduce the risk of chemical pollution?

5 What are the properties of substances that would make them suitable for recycling?

6 What other actions can you take to reduce your impact on the environment? Your actions will make a small difference, but when others join you, the effect is quite dramatic.

* REVIEW

4

Remember and understand

1 Describe the differences between decomposition reactions and direct synthesis reactions.

2 What types of products are formed when acids react with metals, carbonates or bases?

3 Describe two different types of reactions that produce carbon dioxide.

4 In terms of particles, what is required for a chemical reaction to take place?

5 List four factors that will affect the rate of a chemical reaction.

6 Describe two ways that the rate of chemical reactions can be measured.

7 Describe one situation where it could be dangerous if a reaction occurs too quickly.

8 What is the link between CFCs and the ozone layer?

Apply and analyse

9 Polypropylene is a plastic that can be easily melted and formed into a range of products. Describe the likely structure of polypropylene and explain how its structure allows the plastic to be moulded into a range of shapes.

10 A student mixed the following solutions together in a beaker: ammonium nitrate, sodium chloride, lead(II) nitrate, sodium sulfate. Describe what would be seen in the beaker. Explain your answer using a chemical equation.

11 Sodium metal was used to produce aluminium from purified bauxite (Al_2O_3).

  a What type of reaction would be occurring?

  b Write a chemical equation for the process, ensuring that the law of conservation of mass is applied to the equation.

12 Describe two examples of the use of catalysts in the production of chemical products.

13 In many industrial environments, the presence of a fine dust is regarded as an explosion hazard. Why is coal dust more likely to explode than chunks of coal?

14 What are some examples of green chemistry that you could apply at home?

Evaluate and create

15 How does the particle model of matter help us understand the rate of reactions?

16 The reaction $2SO_2(g) + O_2(g) \rightarrow 2SO_3(g)$ is very slow at room temperature. The reaction occurs in two steps, which are shown below. The reaction occurs more quickly in the presence of nitrogen dioxide gas.

Step 1
$2SO_2(g) + 2NO_2(g) \rightarrow 2SO_3(g) + 2NO(g)$

Step 2
$2NO(g) + O_2(g) \rightarrow 2NO_2(g)$

Explain two reasons why the nitrogen dioxide is regarded as a catalyst.

Ethical understanding

17 In the 1920s, the compound tetraethyl lead was developed to prevent 'knocking' in car engines. ('Knocking' is where the spark plugs fire too early, resulting in loss of power and possible engine damage.) Adding tetraethyl lead saved the cost of additional refining of petrol, which reduced costs for consumers and motorists. However, some people were concerned about the use of a lead compound that was being released from the exhaust of cars. If you had been part of the debate in the 1920s, what arguments would you make against the use of tetraethyl lead?

Critical and creative thinking

18 Some catalysts work by providing a surface on which reactions can occur. These surface catalysts work by allowing the reacting particles to interact together on the surface of the catalyst.

  a Why would attracting particles onto a surface of another chemical encourage a chemical change to occur?

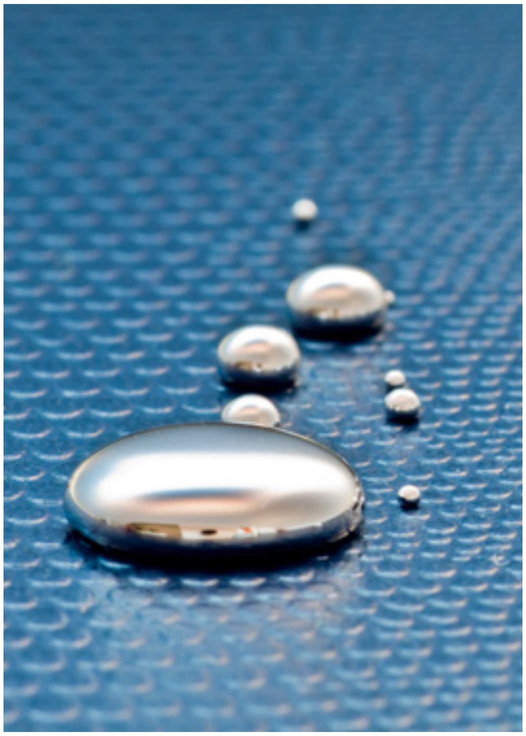
  b Why would a substance that actually bonded chemically to the reacting particles not make a good catalyst?

  c Give an example of the use of a surface catalyst, describing in detail the chemical reaction.

  d Use your knowledge of collision theory to explain why most catalysts are used in the form of a powder or fine mesh.

19 Haemoglobin is responsible for the transport of oxygen in the bloodstream from your lungs to the cells in your body, where respiration takes place. The oxygen molecules interact with the haemoglobin and combine to form oxyhaemoglobin. When the blood reaches the cells (having been pumped through the heart), the oxyhaemoglobin releases the oxygen. If carbon monoxide molecules are breathed into the lungs, they can attach themselves permanently to haemoglobin molecules, thus preventing the essential transfer of oxygen. Carbon monoxide poisoning is a very real danger and many Australians are killed by it each year.

- **a** Use a diagram to represent the transfer of oxygen from the lungs to body cells.
- **b** Explain why the chemical changes occurring between haemoglobin and oxygen need to be reversible.
- **c** Do you think that the reaction between carbon monoxide and haemoglobin is reversible? Explain your answer.
- **d** Suggest two ways that carbon monoxide poisoning can be prevented.



Research

20 Choose one of the following topics for a research project. Present your report in a format of your own choosing.

> **Rare metals**
>
> A range of rare metals is used in microelectronic devices. Many of these metals, such as tantalum and niobium, are sourced from Australia. Find out more about where these metals are found in Australia, in what form they occur naturally and what chemical processes are used to extract the pure metals.

> **Minamata disease**
>
> Minamata disease is caused by people eating seafood contaminated with a compound containing mercury. The condition was called a 'disease' because when it was first described no one knew its cause. Research this disease and present your findings using the following headings.
>
> – Symptoms
> – Cause
> – Action taken
> – Lasting consequences (for the people affected, chemical industry and the world)

> **Ozone and CFCs**
>
> Although governments limited the use of CFCs to reduce the damage to the ozone layer, it took time for many countries to recognise the risks and act on the advice from scientists. Investigate how evidence for ozone depletion was discovered and how countries responded to the evidence, and discuss implications for possible future action (or inaction) of governments based on scientific advice.

KEY WORDS

4

biodegradable
an object or a substance that can be broken down by bacteria, fungi and other living organisms

catalyst
a substance that increases the rate of a reaction but is not used up in the reaction

collision theory
a theory stating that the particles involved in a chemical reaction must collide in order to react

combustion
a reaction that involves oxygen and releases light and heat energy

concentrated acid
this refers to an acid solution with a high concentration of hydrogen ions

concentration
the number of active molecules in a set volume of solution

decomposition
a reaction that involves the breakdown of a compound into simpler substances

dilute
a small number of active molecules (such as acid) in a solution

hydrocarbon
a molecule that contains only carbon and hydrogen atoms

monomer
a small molecule from which polymers are made

neutralisation
a reaction in which an acid and a base combine to produce a metal salt and water

oxidation reaction
a reaction that involves the combination of oxygen with a fuel or metal

polymer
a long-chain molecule formed by the joining of many smaller repeating molecules (monomers)

polymerisation
process of joining of smaller units (monomers) to form a long-chain molecule (polymer)

precipitate
an insoluble compound formed in a precipitation reaction

precipitation reaction
a reaction used to produce solid products from solutions of ionic substances

reaction rate
how fast or slow a reaction proceeds

solution
a mixture of a solute dissolved in a solvent such as water

spectator ion
an ion that does not take part in a chemical reaction

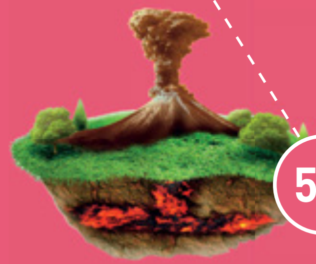
strength
a strong acid readily releases a hydrogen ion in a chemical reaction; can also be used to describe the bond between different atoms

strong acid
an acid which most of its molecules release hydrogen ions into solution

synthesis
a reaction that involves the building up of compounds by combining simpler substances, normally elements

GLOBAL SYSTEMS

5



5.1 The Earth's spheres are balanced

5.2 Matter cycles through the Earth's spheres

5.3 The water cycle is a global cycle

5.4 Human activity affects the carbon cycle

5.5 Evidence supports enhanced global warming

5.6 Enhanced global warming has widespread effects

5.7 Humans can reduce global warming

What if?

What you need:

map of local coastal areas with height above sea level marked or highest astronomical tide marked, map showing local food-growing regions

What to do:

Compare the two maps. What do you notice about the areas that are at risk of current high tides?

What if?

» What if the high-tide line was to increase by 1 metre? (Would your home be at risk?)

» What if the high-tide line was to increase by 5 metres? (Would food-growing regions be at risk?)

5.1 The Earth's spheres are balanced

The solid crust of the Earth (lithosphere) interacts with the **atmosphere** (air) and **hydrosphere** (solid, liquid and gaseous water) to influence temperature and therefore the climate in mountains, deserts and ocean currents. In return, these three spheres affect all the living organisms in the **biosphere**. A balance must be maintained to ensure the survival of all life on this planet.

The lithosphere

The Earth is made up of many different layers. The outermost rocky layer of the Earth is the **lithosphere** and is made up of the upper mantle and the crust (Figure 5.1). Although the crust and upper mantle are only approximately 80 km thick, in terms of the scale of the size of the Earth, it is actually a very thin layer.

The lithosphere is the slowest of Earth's systems to change. Small changes can take thousands, even millions, of years.

Towards the middle of the Earth, it gets hotter and, due to the heat, more molten (melted) and liquid. However, the inner core does not melt or boil because of the intense pressure of the rest of the Earth pushing down on it.

The rocky crust of the Earth is made from magma (molten rock), which cools very slowly and at different times all over the surface of the Earth. The heat from the magma escapes into the air and water surrounding it. The crust settles as uneven giant plates of rock that are mismatched and butt up against their neighbours, covering the entire Earth. The giant pieces are called **tectonic plates**. These plates float on the semiliquid magma at the top of the mantle. The heat in the mantle creates currents that slowly stir through the molten rock, moving the tectonic plates as well. The tectonic plates move about 2–10 cm per year – a similar rate to the growth of your fingernails.

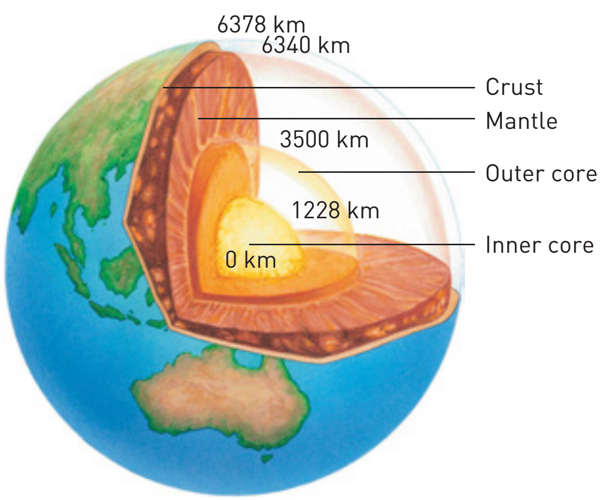


Figure 5.1 The Earth is made up of layers.

The atmosphere

The atmosphere is a layer of gases that we commonly call air (Figure 5.2). The atmosphere is relatively thin compared with the size of the Earth: if the Earth were the size of a party balloon, the atmosphere would only be as thick as the rubber skin of the balloon.

The Earth is the only planet in our solar system that has an atmosphere that sustains life. It helps keep us warm, controls our weather, protects us from the dangers from space and carries sounds.

The most important gas for humans and other animals is oxygen (O_2), which makes up 21% of the atmosphere. Oxygen in the Earth's atmosphere allows organisms to respire; ozone (O_3) offers protection from the Sun's

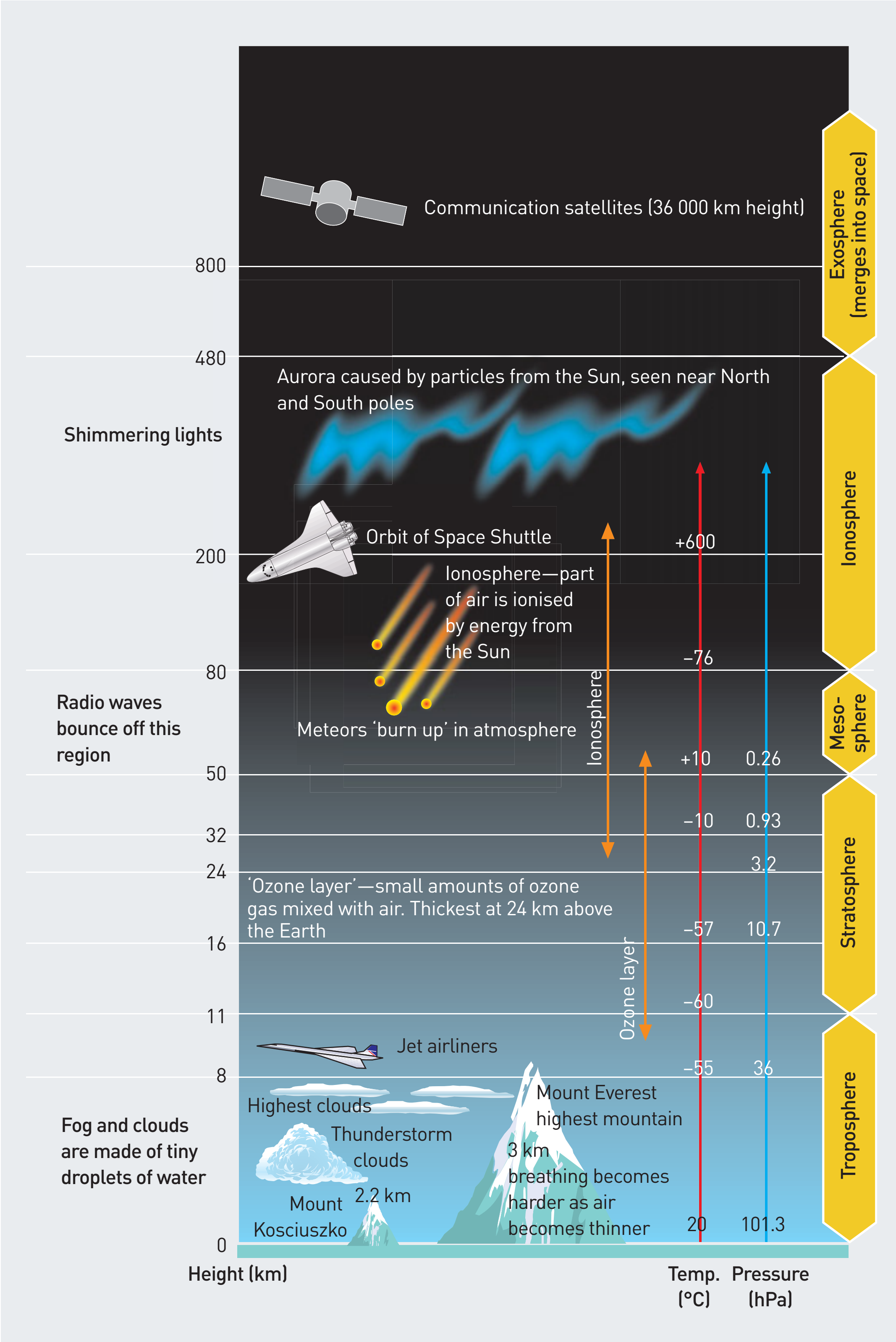


Figure 5.2 Each layer of the Earth's atmosphere has different characteristics.

UV radiation; and carbon dioxide (CO_2), water (H_2O) and other greenhouse gases trap heat to keep us warm. Nitrogen (N_2) makes up 78% of the atmosphere.

Layers in the atmosphere

The atmosphere is more dense at ground level and thins out as you go higher above the Earth's surface: 99% of all the air in the atmosphere is found within 80 km of the Earth's surface. There is not really a top to the atmosphere – the air just thins out, with decreasing pressure, until you reach the relative emptiness of space. These changing conditions are identified as several atmospheric layers.

The hydrosphere

The hydrosphere is made up of all the Earth's water – oceans and lakes, but also the water in glaciers, the soil and even in the air (Figure 5.3). The hydrosphere covers approximately 70% of the Earth's surface, making the Earth the 'blue planet' when viewed from space. The huge amount of water, in all its various forms, is also home to many types of plants and animals. The hydrosphere interacts with and is influenced by each of the other spheres. For example, in the atmosphere you can find water in three different states: liquid, vapour and solid (glaciers and ice).

Hydrosphere influences climate

The part of the hydrosphere that is made up of frozen water is called the **cryosphere**. The cryosphere is very important in regulating the climate on the Earth, and it does this in a number of ways: it influences atmospheric and ocean circulation and currents, as well as the amount of moisture in the atmosphere, and reflects rays from the Sun.

The biosphere

The biosphere is made up of all the living things on the Earth, including plants, animals and bacteria. Within this sphere, there is an enormous degree of organisation and amazing biodiversity. There is also great interdependence between different parts of the living world. From feeding relationships to more obscure dependencies, there is a fine balance between organisms that must be maintained.

The Earth is the only planet in our solar system that is able to support a biosphere. Although life could exist in all spheres on the Earth, most living things can only survive in a fairly narrow range – from deep under the ocean to high mountains. The wide range of conditions that exist in all these habitats accommodates a wide range of organisms – **biodiversity** (*bio* = life; *diversity* = variety).

Figure 5.3 All the Earth's water makes up the hydrosphere.

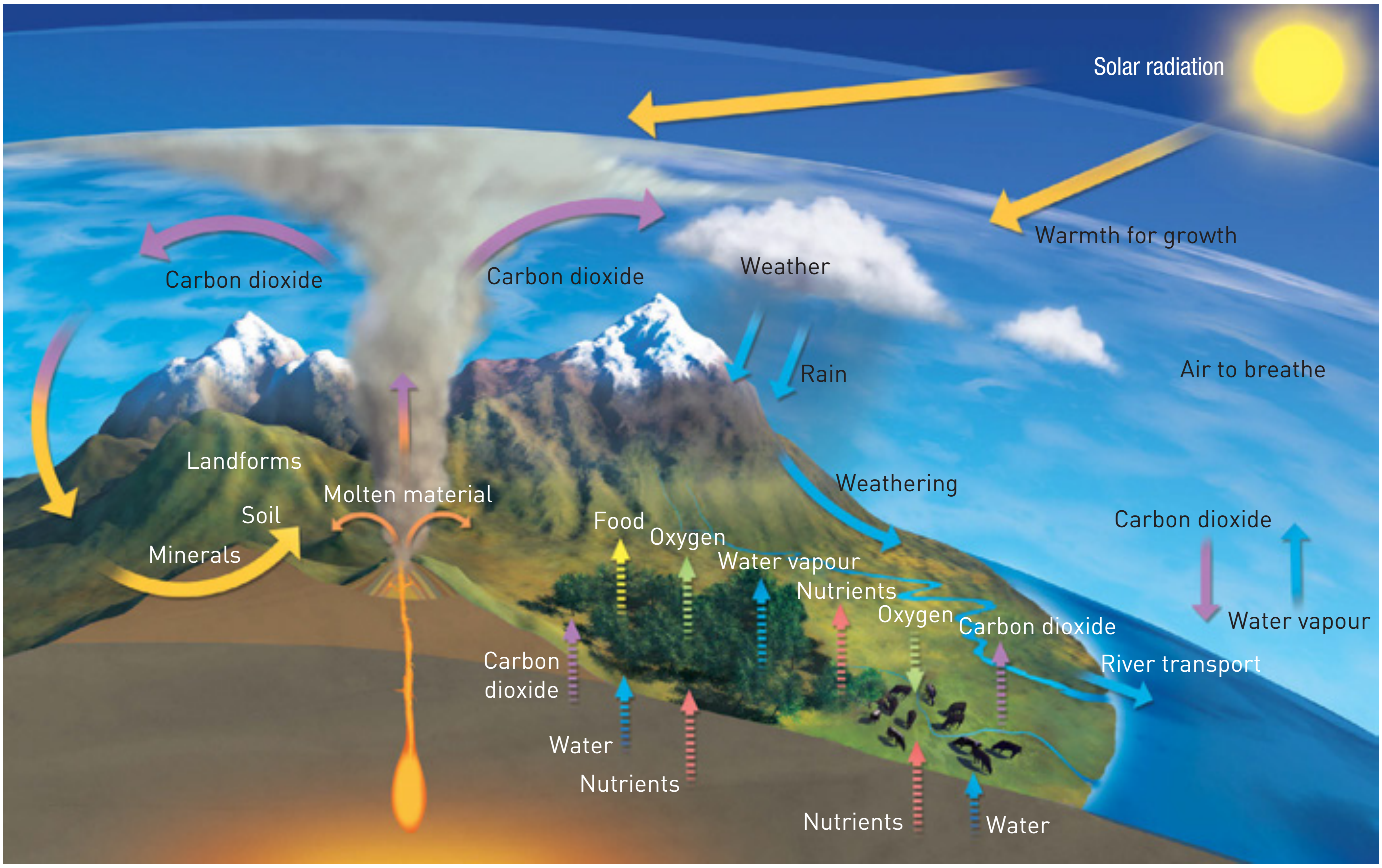


Figure 5.4 The inputs and outputs of the Earth's living and non-living systems.

Check your learning 5.1

Remember and understand

1 What is the lithosphere made up of?
2 What makes up the biosphere?
3 What happens to the amount of air as you go higher into the atmosphere?

Apply and analyse

4 In which layer of the atmosphere do we live?
5 What is the difference between the hydrosphere and the cryosphere?
6 How does the hydrosphere interact with the other spheres?

Evaluate and create

7 Draw a Venn diagram with four interlocking circles, one for each of the spheres studied. Label each sphere and include all the features they share.

5.2 Matter cycles through the Earth's spheres

The cycling of all nutrients through the Earth's spheres is essential to sustaining life. If every time we inhale oxygen it was lost to the atmosphere for good, plants would die out, animals would starve and the biosphere would collapse. We know this is not the case – plants are able to absorb carbon dioxide from the atmosphere and produce more oxygen. Similar interactions between the various spheres enable a flow of matter, including phosphorus and nitrogen.

Figure 5.5 Almost all the oxygen on Earth is locked in the compounds that make up the lithosphere.

Cycling oxygen

Oxygen is the essential ingredient in cellular respiration, the process by which most organisms obtain energy for life. The Earth has a fixed supply of 'useful' oxygen, even though it can be found everywhere. There are three reservoirs of oxygen:

1 the atmosphere (0.49%)
2 the Earth's crust or lithosphere – rocks and the oceans (99.5%) (Figure 5.5)
3 living organisms – the biosphere (0.01%).

In the atmosphere, oxygen exists as the molecules O_2 and O_3 (ozone) and in compounds such as water (H_2O) and carbon dioxide (CO_2). Oxygen can dissolve in the oceans, where it is available for uptake by marine organisms.

The oxygen cycle is influenced heavily by processes in the biosphere and atmosphere (Figure 5.6). In the biosphere, photosynthesis releases oxygen and cellular respiration absorbs oxygen. In the atmosphere, oxygen is formed through UV light converting water to oxygen and hydrogen in a process known as **photolysis**:

$$2H_2O + \text{energy} \rightarrow 2H_2 + O_2$$

EXPERIMENT 5.2: TESTING PHOSPHORUS
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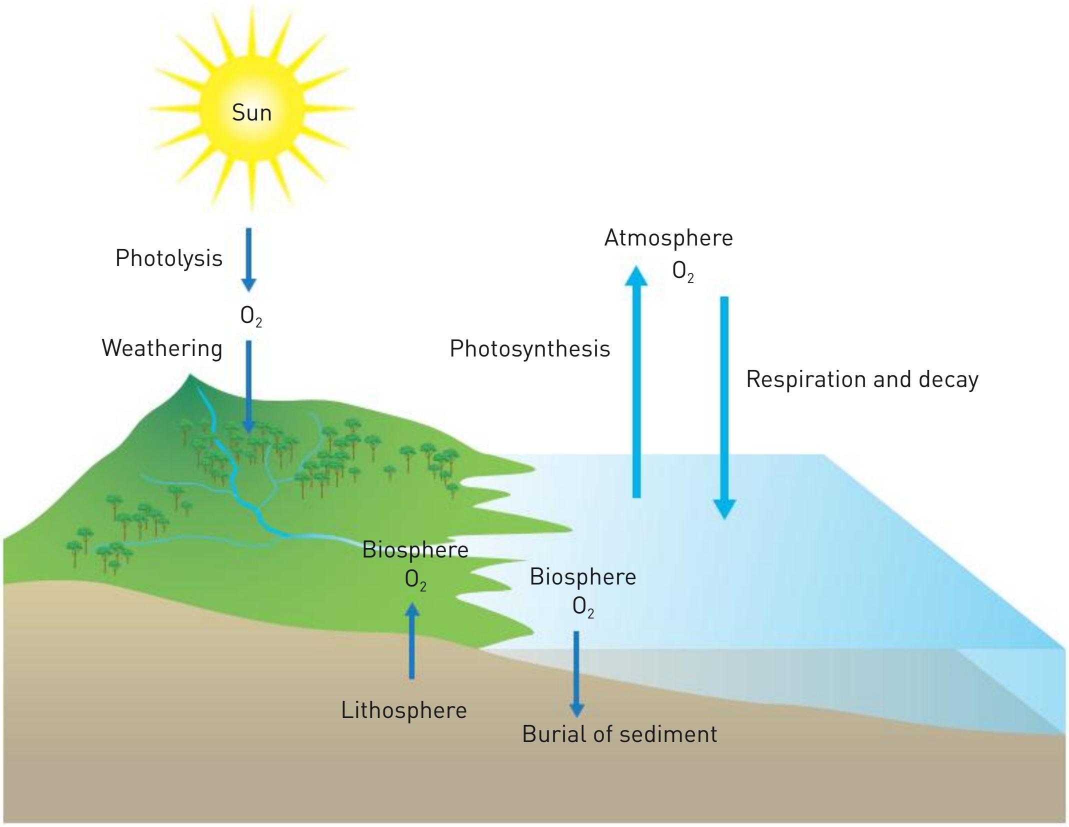


Figure 5.6 The oxygen cycle.

Oxygen is removed from the atmosphere through the process of cellular respiration, the decay of organisms and the weathering of exposed rocks.

Cycling nitrogen

Nitrogen is necessary for the synthesis (to make) of proteins and nucleic acids, vital building blocks for all organisms. Although nitrogen makes up 78% of the gases in the atmosphere, making it the most abundant gas, it is not in a form that can be used by living organisms. Bacteria play an important role in changing nitrogen into usable forms – nitrate, nitrite and ammonium ions – and returning it to the atmosphere.

Nitrogen-fixing bacteria are able to 'fix' or convert nitrogen (N_2) from the atmosphere into nitrate (NO_3^-) ions, nitrite (NO_2^-) ions and ammonium (NH_4^+) ions. Nitrogen-fixing bacteria live in the root nodules of legumes – plants such as peas and beans (Figure 5.7). The nitrogen compounds produced by the bacteria are used by the plant to synthesise proteins. In return, the plant provides protection and other

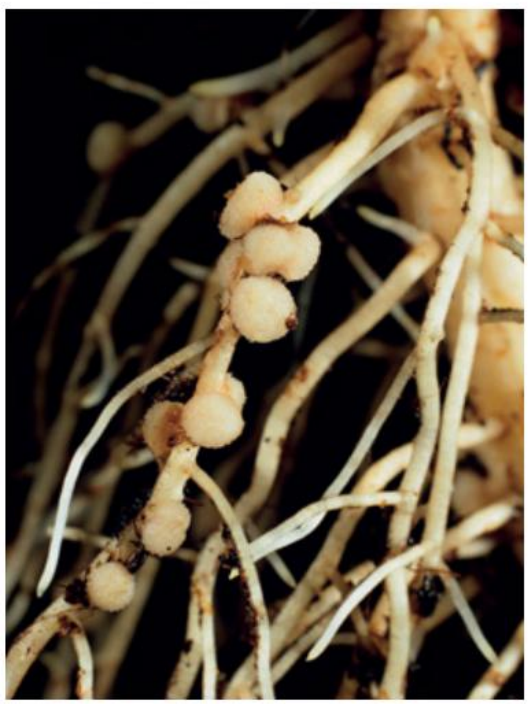


Figure 5.7 Legumes, such as peas and beans, have nitrogen-fixing bacteria living in the nodules on their roots. Consequently, farmers will often plant legumes between crops to maintain nitrogen levels in the soil.

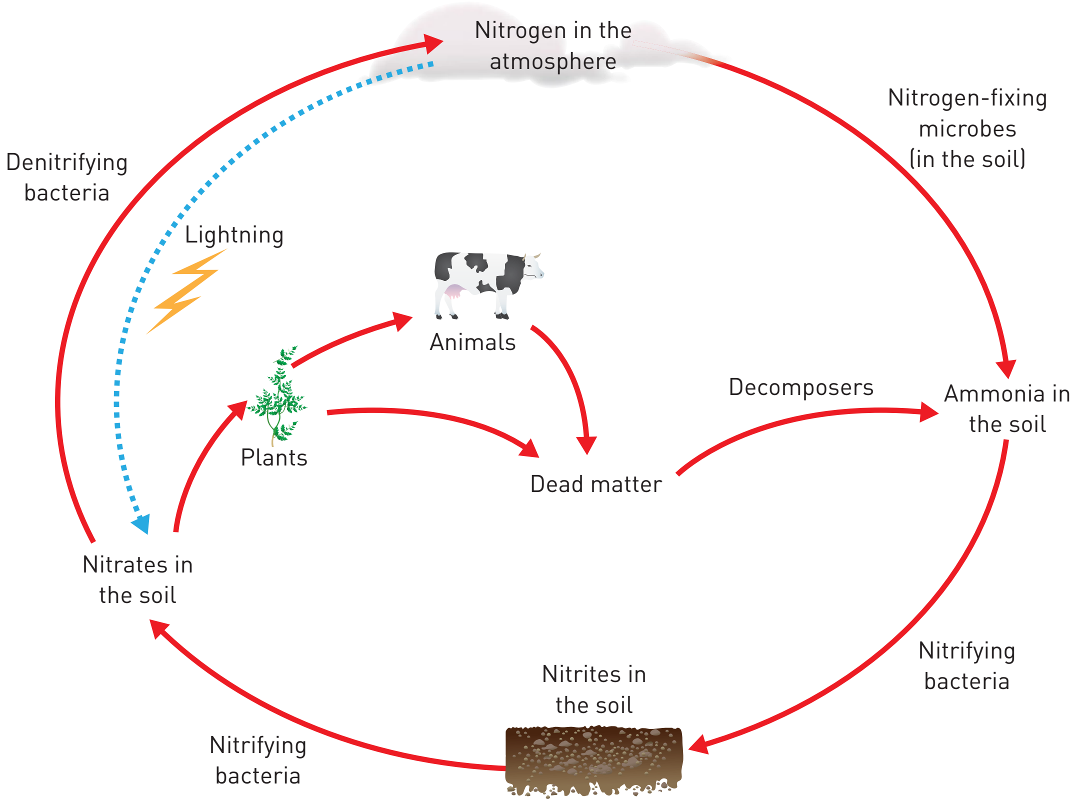


Figure 5.8 The nitrogen cycle.

essential elements to the bacteria. **Denitrifying bacteria** are able to return nitrogen back to the atmosphere.

Many human activities affect the cycle of nitrogen in the atmosphere and lithosphere. These include fossil fuel emissions and run-off from fertilisers. Excessive use of nitrogen fertilisers in areas near coral reefs can result in the nitrogen being dumped on the reefs in times of flooding rains, which can lead to major bleaching of the reefs.

Cycling phosphorus

Phosphorus is an essential component of the energy molecule ATP (adenosine triphosphate), as well as the molecules DNA and RNA (sugar–phosphate backbones) (see Figure 1.7, page 5). Without phosphorus, an organism cannot use available energy-containing molecules.

The phosphorus cycle is the slowest of the biogeochemical cycles (Figure 5.9). Unlike photosynthesis and respiration, for example, weathering and decay are lengthy processes.

Most of the phosphorus available to living organisms comes from sedimentary rocks and soils. Unlike the other biogeochemical cycles, the phosphorus cycle does not have a gaseous phase. Phosphorus is not a common element and its availability is often the limiting factor for plant growth. Farmers will often apply phosphate fertilisers to agricultural land or plant legumes between crops.

In the phosphorus cycle:

- rain weathers rocks, releasing phosphate ions into the soil
- plants absorb phosphate ions via their roots and thus phosphorus enters the food chain
- phosphorus absorbed by organisms returns to the soil through urine, faeces and the decomposition of the organism
- phosphorus is locked in sediments and rocks for millions of years before being released by weathering and erosion, thus completing the cycle.

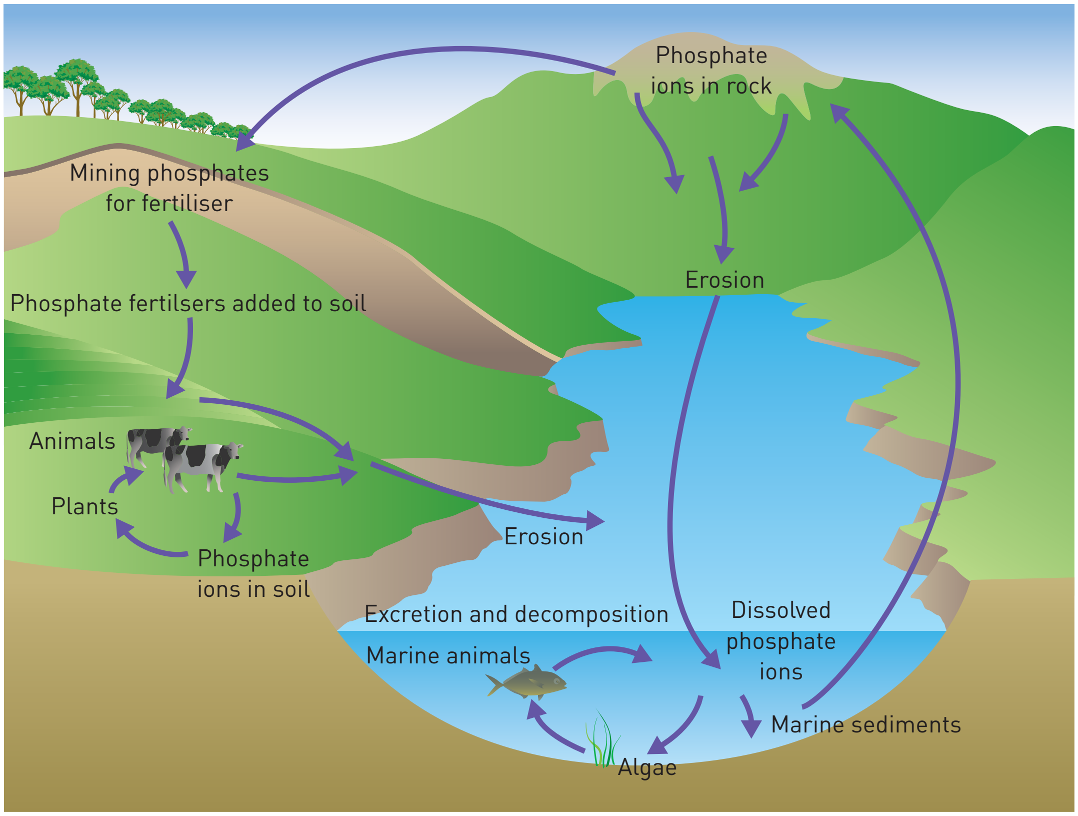


Figure 5.9 The phosphorus cycle.

Phosphorus is mined for use as a fertiliser. Run-off from agricultural land can lead to excessive levels of phosphorus in waterways. Because phosphorus encourages plant growth, excess levels lead to the increased growth of plankton and aquatic plants. This results in an increase in oxygen consumption within this environment, suffocating fish and other aquatic animals, as well as blocking sunlight from bottom-dwelling organisms. This process is known as **eutrophication** (Figure 5.10). To reduce this problem, phosphorus is no longer included in most detergents.

Check your learning 5.2

Remember and understand

1 What are the three reservoirs of oxygen?
2 Name three important molecules in your body that contain phosphorus.

Apply and analyse

3 Why might plants struggle to grow in nitrogen-poor soils?
4 Explain why the cycling of nutrients is referred to as a 'biogeochemical' cycle. Use an example to explain your answer.

Evaluate and create

5 Draw a concept map that shows the contribution of microorganisms to the cycling of nutrients in an ecosystem.

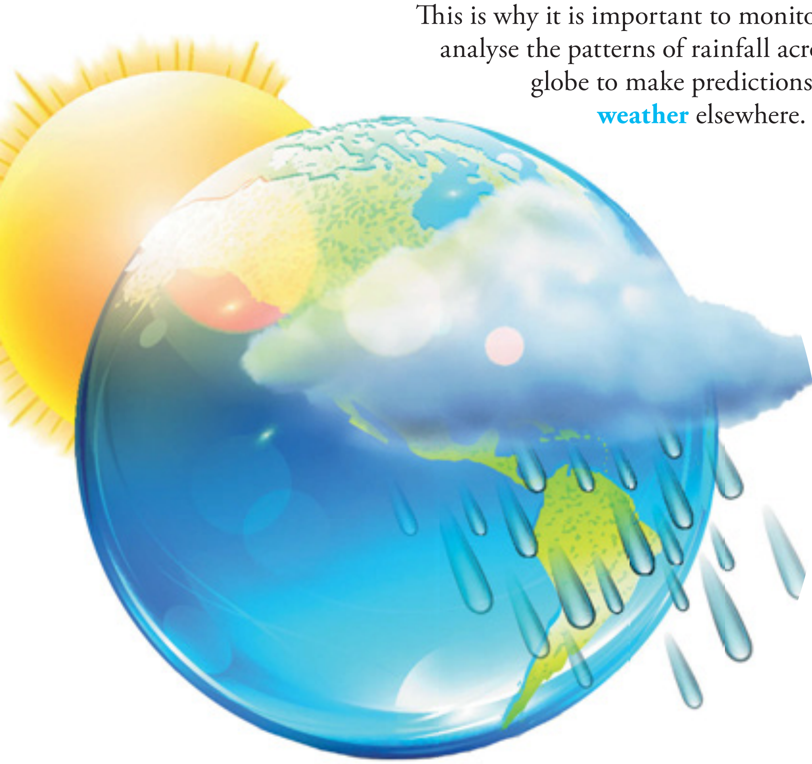
Figure 5.10 The green may be misleading – algal growth is blocking sunlight from all other organisms that live in this irrigation channel.

5.3 The water cycle is a global cycle

The hydrosphere includes all the water on the Earth, including the water in the air, trapped in ice and underground. It includes solid ice, liquid ocean and lakes, and the water vapour in the air. The water continually cycles through the hydrosphere. It evaporates into the air, lowering the air pressure and contributing to the formation of **wind**.

Water cycle

Water is an essential part of life and is important for many metabolic processes in your body. It is continuously cycled through the hydrosphere, moving through the atmosphere and biosphere in the process. However, this does not mean that there is a neverending supply of water. This is because the water cycle (Figure 5.11) is a global cycle. This means that water is not equally available in all ecosystems. For example, water that evaporates from the desert may later fall as rain on a forest thousands of kilometres away. For this reason, an ecosystem may have too little water (drought) or too much water (floods) for the organisms within it to continue to survive. This is why it is important to monitor and analyse the patterns of rainfall across the globe to make predictions about **weather** elsewhere.



Clouds and rain

Water vapour is the source of all **clouds** and **precipitation** and is therefore the most important gas in the atmosphere when it comes to understanding atmospheric processes. Water vapour is evaporated water – water as a gas. Water vapour that has evaporated from oceans and rivers rises until it reaches the cooler parts of the atmosphere. Cold air cannot hold as much moisture as warm air, so the water vapour turns back into liquid water – condensation. These drops of water then form into clouds. The clouds may be carried onto land by winds and may be forced to rise when they reach a mountain barrier or another air mass. The colder air can no longer hold the condensed droplets and they fall as precipitation – rain, hail or snow. The precipitation eventually moves back to the world's lakes and oceans through rivers and streams (collection) and the process begins again.

Weather and climate systems

Weather reports tell you what the weather will be like in terms of temperature, rain and other factors. Therefore, weather is a snapshot of day-to-day changes. **Climate** is more concerned with longer periods of time and involves the collection and analysis of large amounts of data. You can use weather predictions to decide what to wear each day, whereas climate predictions may help farmers plan what types of crops to grow, governments to decide whether to invest in certain technologies or even households to decide whether they'll need to install an air conditioner.

EXPERIMENT 5.3: MAKE YOUR OWN CLOUDS
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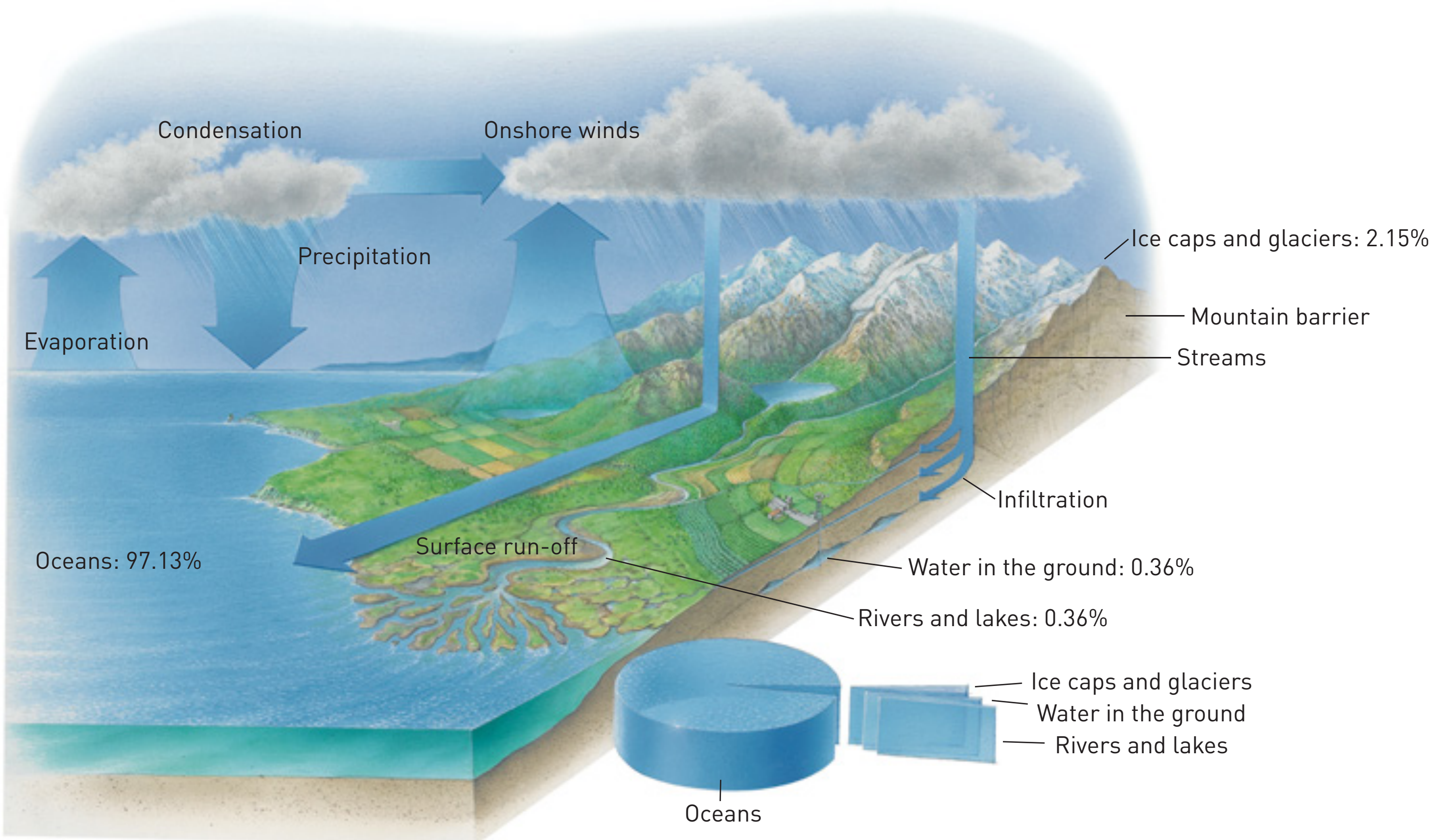

Figure 5.11 The distribution of water on the Earth and the water cycle.

Weather

Regions near the equator are warmer than regions near the poles. Near the equator, the Sun is directly overhead in the middle of the day. Because of this, the energy from the Sun is concentrated, so these regions are heated intensely. Near the poles, the Sun is lower in the sky, shadows are longer and energy from the Sun becomes more spread out. This is because the Earth's surface is curved, so the Sun's rays come in at an angle.

As the air heats up, the particles in the air spread out and become less dense. As a result, the less dense warmer air rises above the more dense cold air. This means the warm air near the equator rises into the atmosphere and colder air near the poles moves towards the equator to fill the space left by the warm air (Figure 5.12). The movement of air is better known as wind. Wind is the result of sideways or horizontal movements of air due to pressure differences.

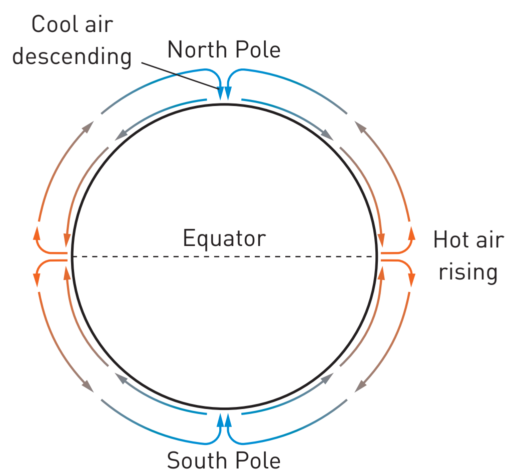

Figure 5.12 Movement of air at the equator and at the poles can result in the circular movements of air called cyclones.

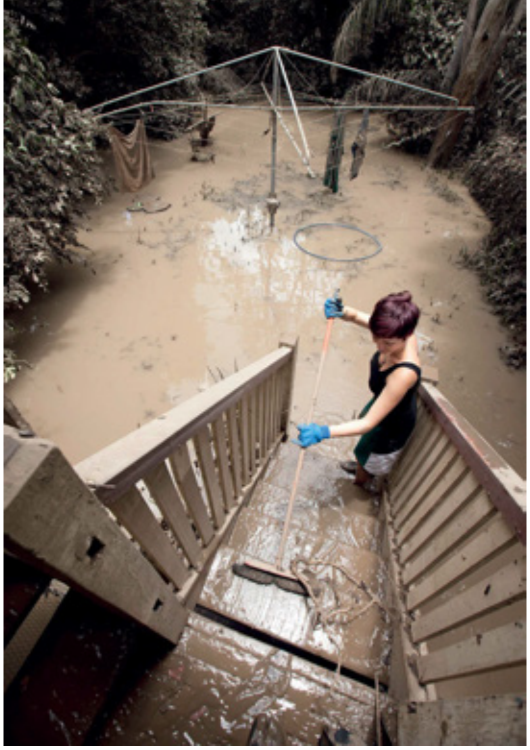

Figure 5.13 Flooding may follow torrential rain during a cyclone.

The **Coriolis effect** is the influence of Earth's rotation on the direction of air or water movement. The Coriolis effect can cause winds to deviate from the path you might expect them to take. The surface of the Earth can also interfere with the speed and direction of wind. Rough and mountainous terrain will slow wind and significantly change the wind's direction.

On a weather map, air pressure differences are shown as **isobars**; the closer the isobars, the greater the difference in pressure and the stronger the wind. Regions of high and low pressure are also shown on a weather map (Figure 5.16b). Low-pressure areas are frequently associated with clouds and precipitation, whereas high-pressure systems bring clear blue skies.

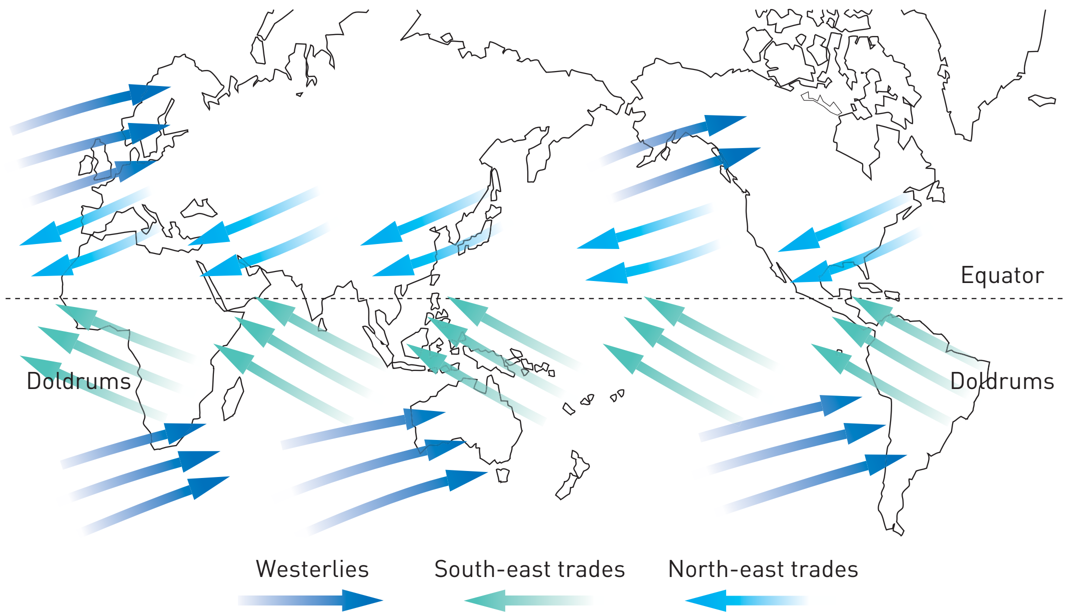

Figure 5.14 Wind patterns over the Earth. The Doldrums are areas of low pressure where winds tend to be very calm.

Figure 5.15 An anemometer measures wind speed.

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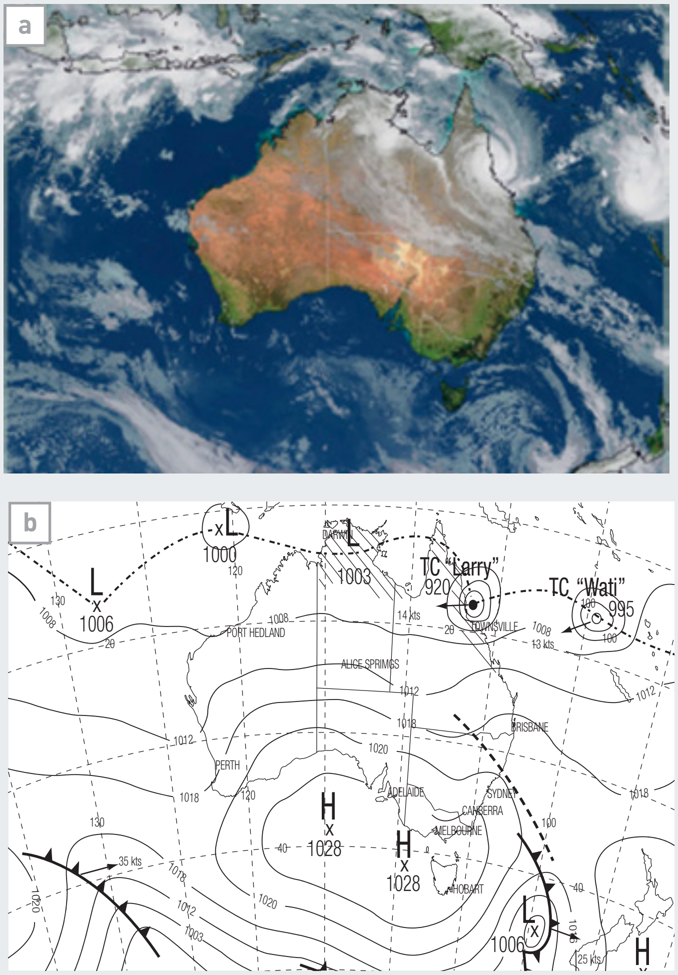


Figure 5.16 A (a) satellite image and (b) weather map showing tropical Cyclone Larry as it crosses the Australian coast at Innisfail, just south of Cairns, in 2006.

Check your learning 5.3

Remember and understand

1 What is the difference between weather and climate?

2 What is meant by 'air pressure'?

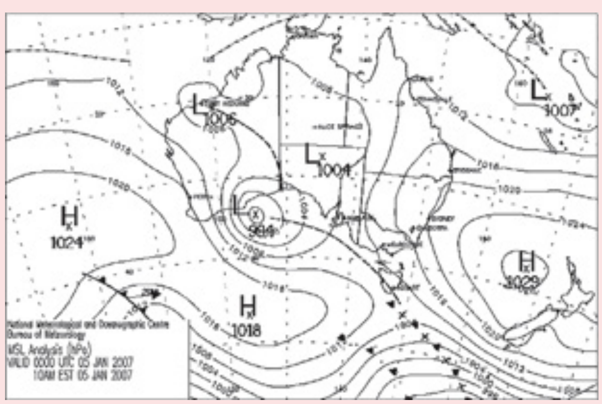
3 What happens to the pressure of the air when it is heated?

Apply and analyse

4 How are winds related to rising air?

5 What conditions must occur for water vapour in clouds to fall as precipitation?

6 Print out and label this weather map with as many of the terms listed in this section as you can.



5.4 Human activity affects the carbon cycle

*

Like all matter, carbon cycles through all the Earth's spheres. Carbon trapped in the lithosphere cycles very slowly, while carbon in the biosphere and atmosphere cycles much faster. Carbon can be stored for a long time in **carbon sinks** such as fossil fuels and the ocean. Human activity can cause the carbon sinks to release carbon into the atmosphere as carbon dioxide.

Cycling carbon

Carbon is the fourth most abundant element on Earth and is the basic component of all living organisms. It is the basis of carbohydrates, proteins and lipids. Carbon can cycle through the land, oceans and atmosphere over both the short and long term (Figure 5.17).

> The geological carbon cycle is a long-term cycle that occurs over hundreds to millions of years and has resulted in the bulk of carbon being locked in rocks or in sediments as fossil fuels.
> The biological/physical carbon cycle is a short-term cycle that occurs over days, weeks, months and years and involves the cycling of carbon through photosynthesis and cellular respiration.

Humans tap into the geological carbon cycle by extracting oil, natural gas and coal, all of which are hydrocarbons, for use in cars and energy production. Large-scale extraction and the use of these fossil fuels has resulted in increased levels of carbon dioxide in the atmosphere. Coupled with an increase in deforestation, this increase in carbon dioxide has led to an enhanced greenhouse effect, altering temperature and rainfall patterns significantly.

Fire plays an important role in transferring carbon dioxide from the land to the atmosphere (Figure 5.18). Fires consume biomass and organic matter, producing carbon dioxide as well as methane, carbon monoxide and smoke (solid carbon particles).

Carbon is stored over the long term in the trunks and branches of trees. It is also temporarily stored in the bodies of other organisms, such as herbivores and carnivores. When these organisms die, carbon is returned to the atmosphere as carbon dioxide by decomposers.

Carbon sinks

A carbon sink is any feature of the environment that absorbs and/or stores carbon, keeping it from the atmosphere. Forests take in carbon dioxide, so they are a very significant carbon sink. However, the ability of forests to absorb carbon has been reduced as a result of the large-scale clearing of forests throughout the world.

The ocean is another important carbon sink, absorbing atmospheric carbon dioxide and consequently becoming more acidic.

Carbon is also stored in:

> decomposed organic matter, such as coal, natural gas, petroleum and shale oil
> rocks, such as limestone, marble, dolomite, chalk and other carbonates
> organic matter in the soil
> dissolved carbon dioxide in the oceans and other waters
> the shells of marine organisms and some terrestrial organisms.

CHALLENGE 5.4: MODELLING A CARBON SINK
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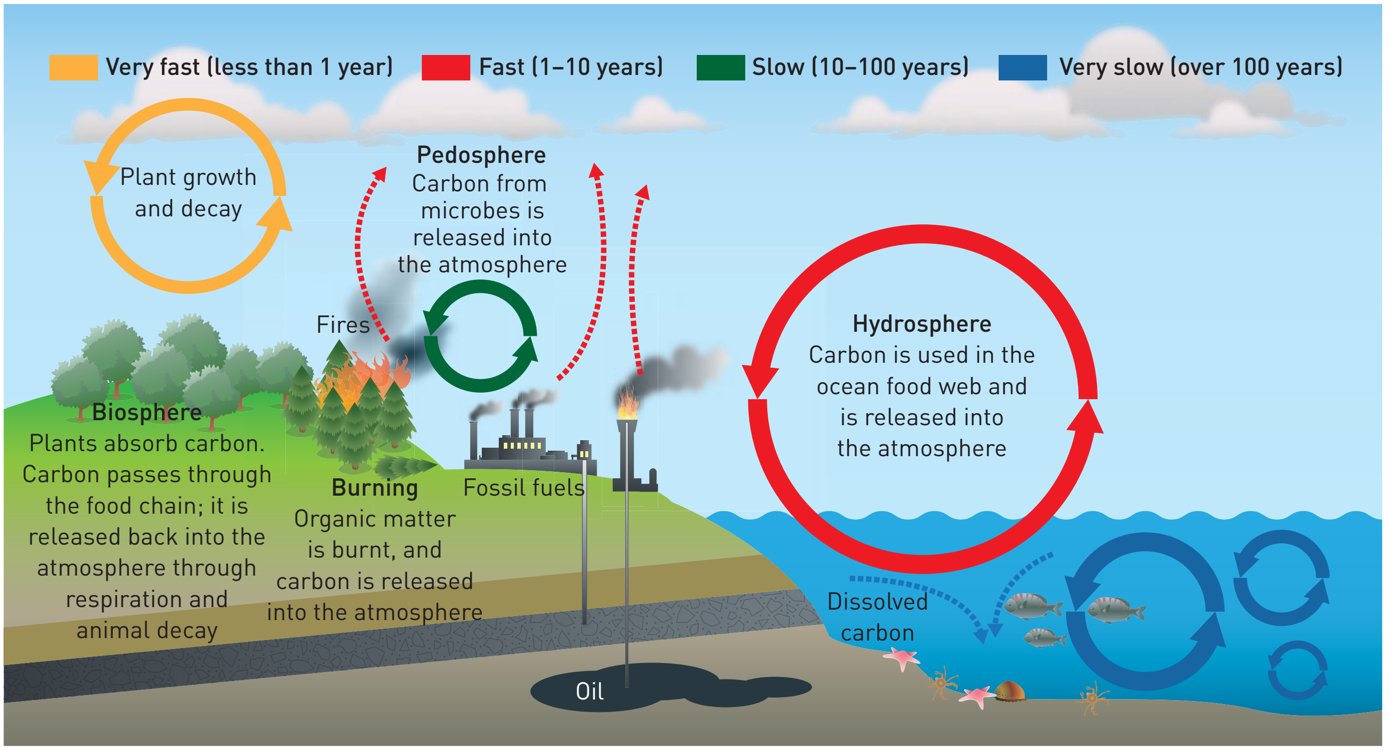

Figure 5.17 The carbon cycle.

Human impact

Ecosystems depend on the biogeochemical cycling of water, carbon dioxide and other nutrients. Human activities have affected these cycles in many ways. For example:

> we have reduced the total mass of fished species by as much as 90% in much of the world
> freshwater ecosystems have been altered through the building of dams for irrigation and hydroelectric power production, resulting in changed river flows
> agriculture and farming have converted more than half the world's many grasslands for human use.

Human activity has diverted or prevented 20–30% of the flow of energy that is fixed by natural ecosystems (e.g. carbon fixation). This is due to:

> maintaining crops (15%)
> establishing urban areas (1.8%)
> grazing livestock (2.3%)
> habitat degradation (e.g. desertification) (4%).

Figure 5.18 Bushfires are an important part of the carbon cycle, releasing carbon back into the atmosphere.

Check your learning 5.4

Remember and understand

1 What is a carbon sink? Give two examples of carbon sinks.
2 Explain how you are part of the carbon cycle.

Apply and analyse

3 What is the difference between the geological carbon cycle and the biological/physical carbon cycle?
4 List two ways human activity affects the carbon cycle.
5 Compare the speed at which carbon is released into the atmosphere through the biosphere and burning. How does this compare with carbon being released from the hydrosphere?

5.5 Evidence supports enhanced global warming

The Earth is surrounded by an atmosphere of **natural greenhouse gases** including carbon dioxide, methane and water vapour. These gases reflect **radiation** from the Sun and retain the warmth from the Earth, preventing extreme temperature changes. The average global temperature of the Earth has increased 0.8°C over the last 100 years. Evidence for **enhanced global warming** can be found in the melting of sea ice and **permafrost** and increasing sea levels.

Climate change

Climate change is being talked about nearly everywhere we go: from dusty farms experiencing drought in the outback to families fleeing their homes in the worst flooding we have ever seen. Changes to the climate as a result of natural and human influences are having many different effects on the Earth.

The greenhouse effect

The **natural greenhouse effect** is critical for maintaining life on the Earth. Solar energy passes through the atmosphere and warms the Earth's surface. Heat gradually leaves the Earth's surface and is radiated back into space. Some heat is trapped by the gases in the atmosphere. These gases act like a giant greenhouse of warm air, keeping the Earth warm. If heat were not trapped, the temperature would drop to –100°C each night and, rise to 80°C in the day. The gases that contribute to the greenhouse effect include carbon dioxide, water vapour, methane, nitrous oxide and ozone.

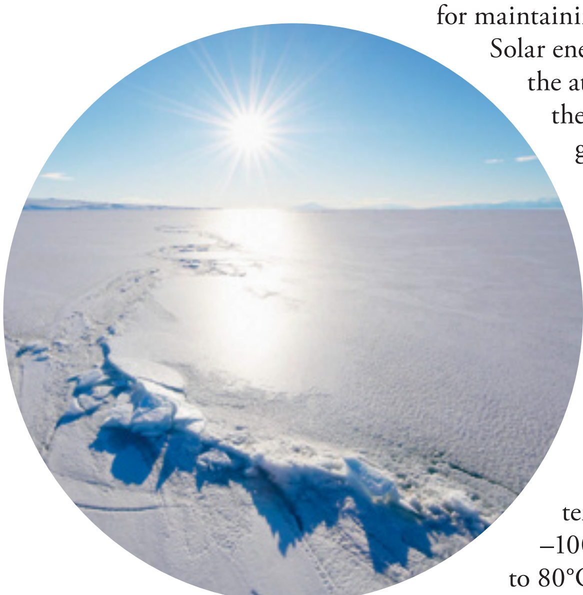

Figure 5.19 Arctic sea ice reflects heat from the Earth.

Since the Industrial Revolution of the 18th and 19th centuries, the level of greenhouse gases has been increasing, causing an **enhanced greenhouse effect**.

Increased levels of greenhouse gases

The concentration of carbon dioxide in the air has changed significantly, by approximately 34%, since 1750. The bulk of that increase has happened since 1959. The concentration of methane in the atmosphere has also risen dramatically over the past century, more than doubling (Figure 5.20).

The main greenhouse gas is carbon dioxide. It is formed by the burning of fossil fuels, such as coal, petrol, oil and gas. We all use energy for heating, lighting, transport, industry and communications. Burning carbon-based fossil fuels releases energy, usually as heat, and produces carbon in the form of carbon dioxide, and sometimes carbon monoxide or solid particulate carbon.

Forests consume carbon dioxide in the process of photosynthesis. Massive deforestation for farming and urban land has also led to an increase in carbon dioxide levels because these forests are no longer available to absorb excess carbon dioxide. This increase in production and decrease in absorption has resulted in an increase in the amount of carbon dioxide present in the atmosphere (Figure 5.20). Figure 5.21 shows which parts of the world emit the highest amounts of carbon dioxide.

Natural sources of methane in the Earth's atmosphere include the decay of organic materials in wetlands, termites, emissions from the oceans and the melting of methane hydrates, which are frozen forms of methane

EXPERIMENT 5.5A: WHAT FACTORS AFFECT A GREENHOUSE?
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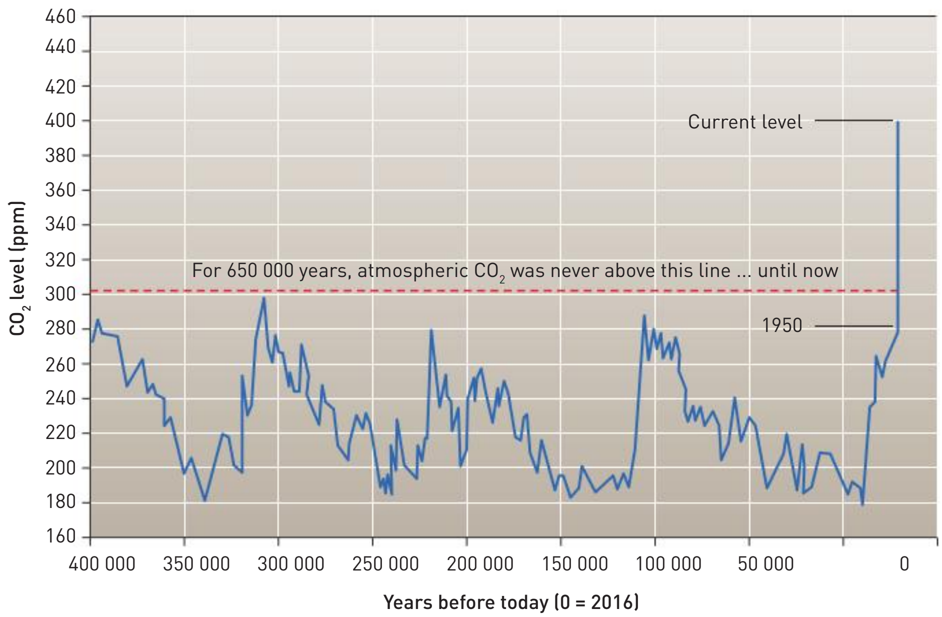

Figure 5.20 Carbon dioxide levels in the atmosphere have increased significantly since 1750.

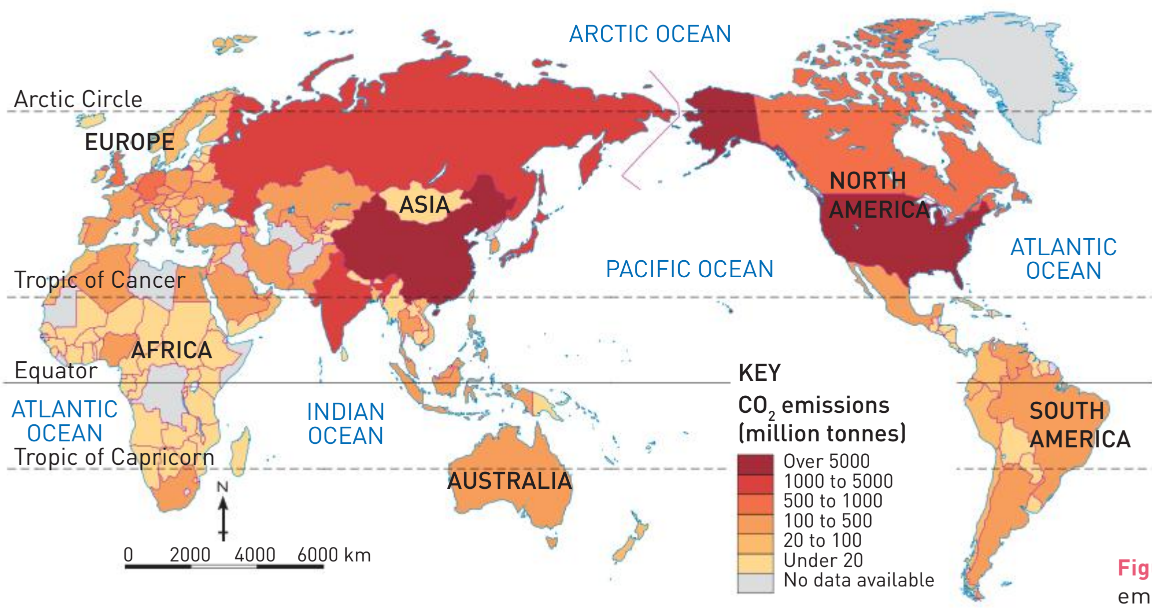

Figure 5.21 Global CO_2 emissions by area.

found in the ocean floor. Human activity also produces methane through energy production, increased emissions from livestock (e.g. cattle), landfill, biomass burning and waste treatment. The increase in these greenhouse gases has resulted in trapping more heat in the atmosphere (Figure 5.22). Figure 5.23 shows how global temperatures have changed since 1900.

Melting sea ice

The ocean is very important in the regulation of global temperatures. It is a carbon sink, absorbing carbon, but it also absorbs up to 90% of the solar radiation that hits the ocean.

Warmer water in the ocean reduces the ocean's ability to absorb solar radiation. The warmer water also causes sea ice to melt. Sea ice is vast, shiny and bright white – it acts as a big mirror that reflects the Sun's radiation back out to space, once again keeping the Earth cooler (Figure 5.23). When this ice melts, more heat is absorbed by the water, increasing its temperature. The warmer water heats the atmosphere above it, and so a cycle has begun that increases global temperature.

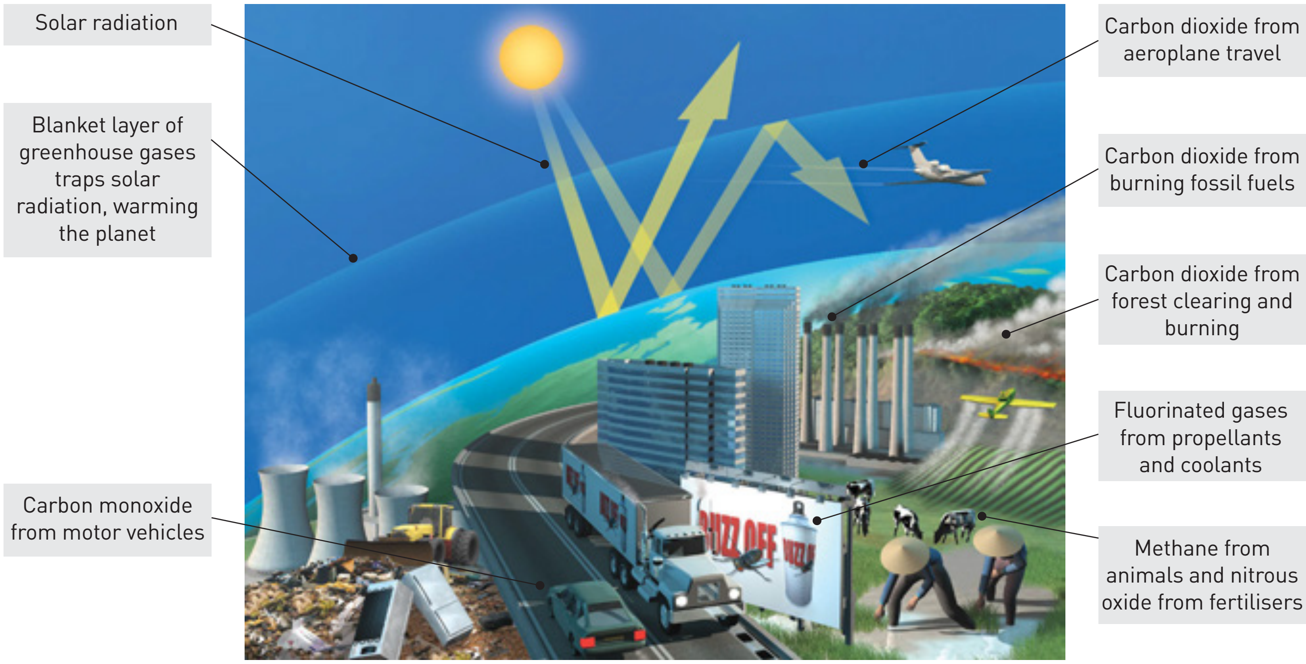

Figure 5.22 Factors contributing to human-induced climate change.

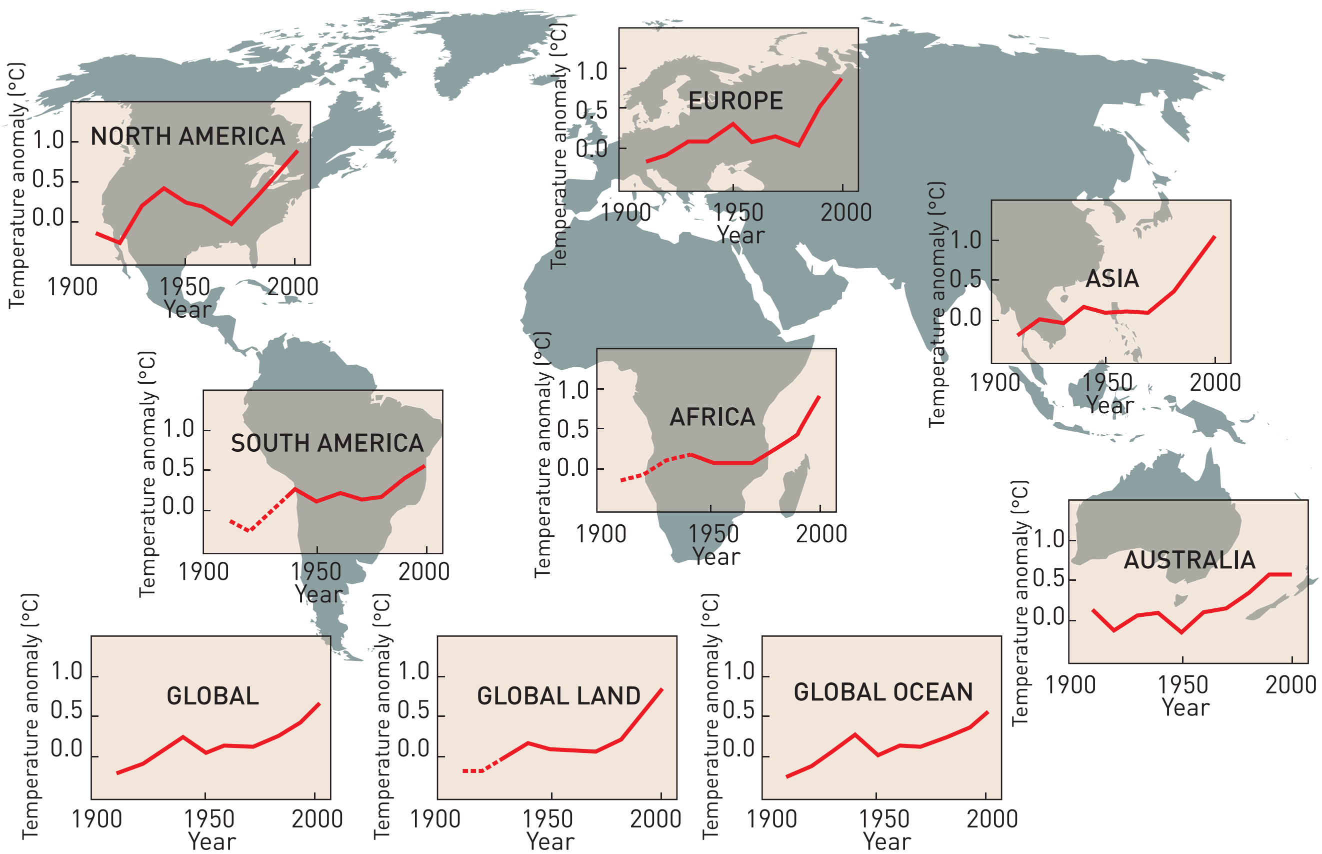

Figure 5.23 Global changes in temperature since 1900.

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Melting permafrost

Permafrost is permanently frozen ground that stores carbon from plant material frozen during the last Ice Age. Scientists have been measuring the temperature of the permafrost in Siberia for over 150 years and they have noticed an upwards trend. This means the ice is getting close to melting temperature (0°C) (Figure 5.24). Scientists believe that as much as two-thirds of the Earth's permafrost could disappear by 2200.

If the Earth's permafrost does melt, it will release thousands of years' worth of carbon into the atmosphere. This would equate to roughly as much as half of all fossil fuel emissions to date from when the world became industrialised.

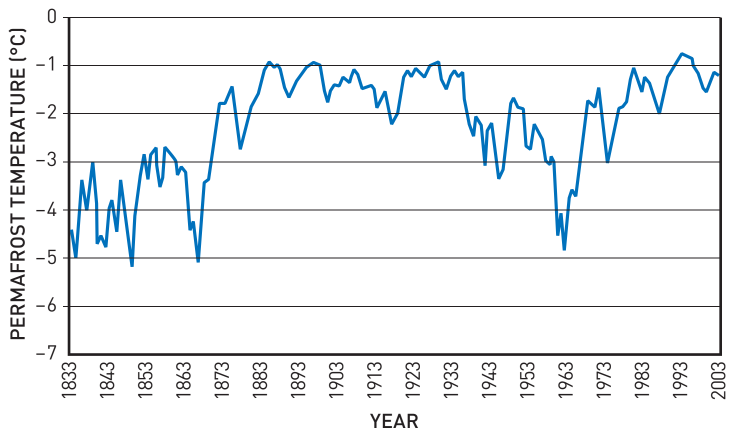

Figure 5.24 Historical measurements of Siberian permafrost temperatures at 5 m depth suggest that the permafrost is becoming warmer.

Rising sea levels

The gravitational pull of the Moon (and Sun), together with the rotation of the Earth, mean there is a high tide approximately every 11 hours. Over many centuries, average water levels have varied. An Ice Age traps water in glaciers and sea ice, exposing land bridges for animals to migrate. These changes are very slow, taking thousands of years to affect sea levels. Over the last 100 years, there has been a dramatic change in sea levels as a result of enhanced global warming melting ice at the polar ice caps (Figure 5.25).

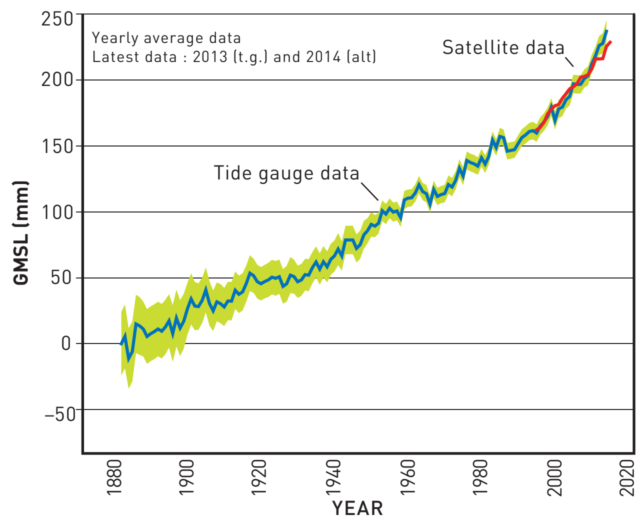

Figure 5.25 The CSIRO measured the Global Mean Sea Level (GMSL) from coastal tidal gauges and satellite data from 1880 to 2014. The overall trend indicates a consistent rise in sea levels.

Check your learning 5.5

Remember and understand

1 Name the two most significant carbon-containing greenhouse gases.
2 Explain why the natural greenhouse effect is actually good for life on Earth.
3 By how much has the temperature on Earth risen over the past century?
4 What is permafrost and why does it add to emissions if it melts?

Apply and analyse

5 Global warming scientists compare trends over many decades rather than data for one or two years. Explain why.
6 Climate-change deniers suggest that the increase in sea levels is part of a normal cycle. Compare the time scale of previous global warming events to current climate changes.

Evaluate and create

7 Examine the data shown in this section. Use the data to support your opinion of the validity of enhanced global warming.

5.6 Enhanced global warming has widespread effects

It is difficult to separate the impacts that humans have on the natural environment. This is because all the systems and cycles of the Earth are connected in some way. Small increases in global temperatures are expected to cause an increase in the number of extreme weather events, and some mosquito-borne diseases. The survival of many organisms may also be affected and as a result biodiversity is expected to decrease.

Extreme weather events

The number of extreme weather events around the world is increasing. Scientists predict that storms will have greater maximum wind speeds and more sudden and extreme rainfall. More intense tropical cyclones will cause flooding, landslides and damage to buildings. Worldwide, the number of cyclones reaching category 4 or 5 has risen by 15% over the past 20 years (Figure 5.26). Cyclones intensify over warm ocean waters, another consequence of increasing global and ocean temperatures. We can also expect to see an increase in the loss of human lives as a result.

Health and disease

Higher temperatures in summer have increased heat-related deaths. A heat wave in Europe in 2003 was estimated to have killed between 22 000 and 35 000 people. Global warming is also thought to extend the zones for infectious diseases, such as dengue fever and malaria, which thrive in warm, moist conditions (Figure 5.27). In cities such as Beijing, China, stagnant weather conditions can trap both warm air and pollutants, leading to smog, which results in serious respiratory problems.

Figure 5.26 The aftermath of a cyclone: the number of severe cyclones is increasing.

CHALLENGE 5.6: SALT WATER DENSITY
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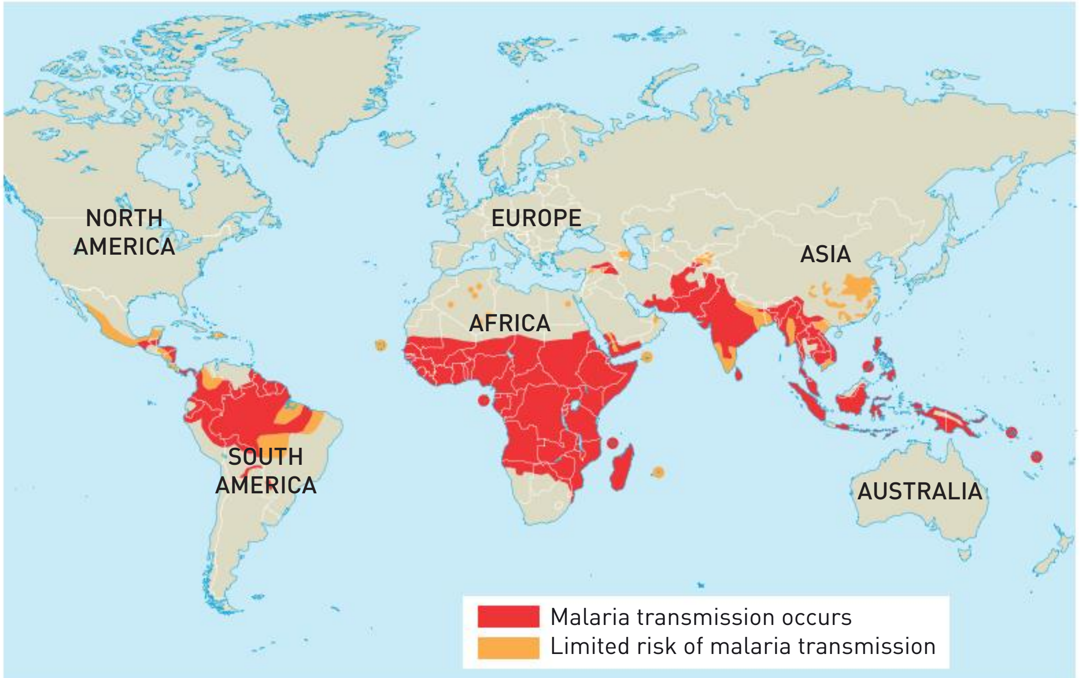


Figure 5.27 Countries or areas at risk of transmission of malaria, 2010.

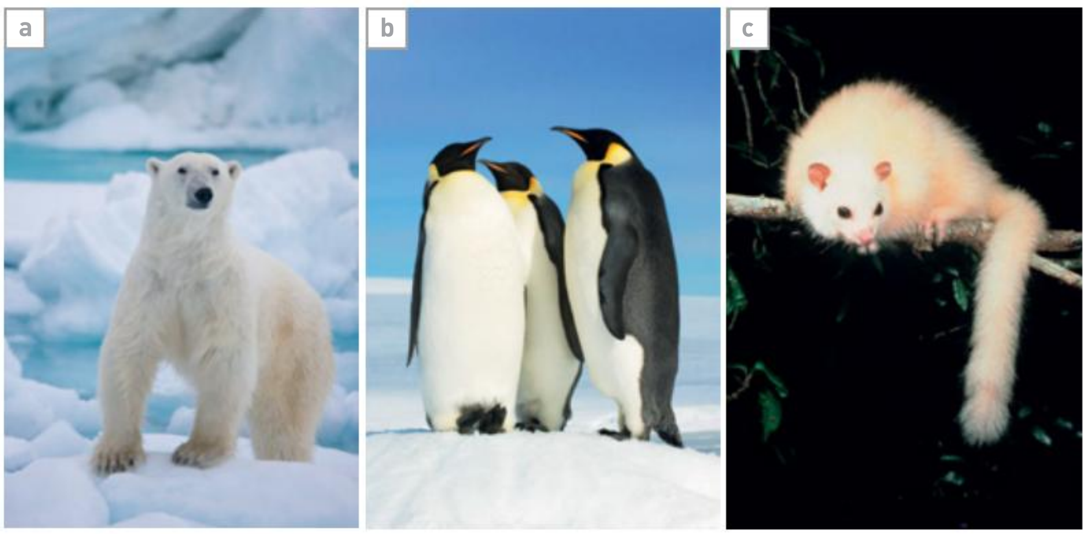


Figure 5.28 Many animals are at risk of extinction as a result of climate change, including (a) polar bears and (b) emperor penguins, which live in cold climates, and (c) lemuroid possums, which can only live within a certain temperature range.

Loss of biodiversity

Climate change over the past 30 years has resulted in many changes to the distribution and numbers of species, and is thought to have caused extinctions. Many of the species at risk are Arctic and Antarctic animals, such as polar bears and emperor penguins, which live on the ice (Figure 5.28). Other species, such as the white lemuroid possum, which is only found in high-altitude areas in north Queensland, can only live within certain temperature ranges. The white lemuroid possum has been named as the first mammal species to have possibly been made extinct as a result of global warming (Figure 5.28). These possums cannot survive extended temperatures over 30°C, which occurred in 2005. The possum has not been seen for over 3 years.

Australian native plants and animals are well adapted to year-to-year climate fluctuations, such as floods and droughts, but often they can only survive within a narrow range of temperatures. This means that many species and ecosystems could be highly vulnerable to the rapid and sustained increase in long-term average temperatures of 1–2°C that are expected as a result of global warming.

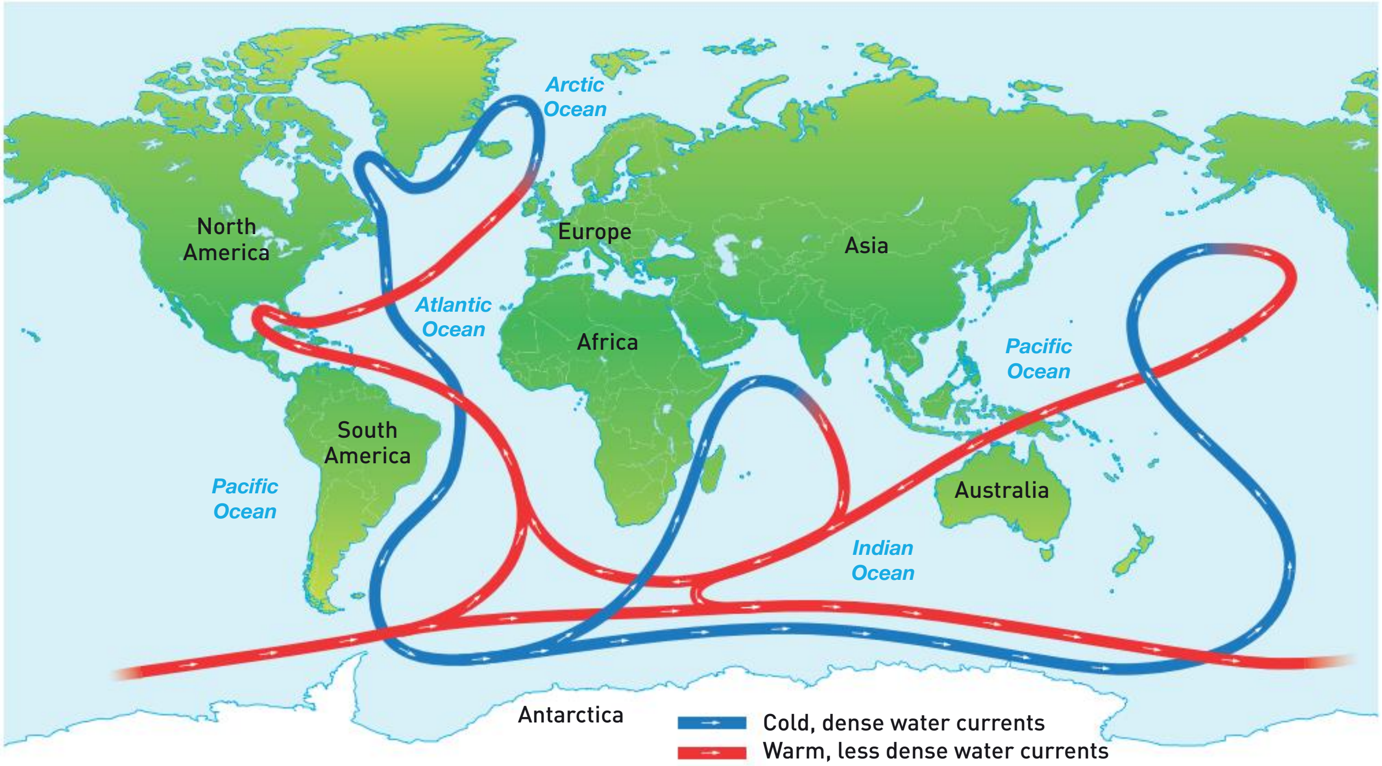


Figure 5.29 The path of the ocean 'conveyor belt', in which differences in temperature and salinity drive the movement of large currents of water.

For example, climate change modelling indicates that the extent of highland rainforest ecosystems of tropical north Queensland may decrease by up to 50% with a 1°C increase in temperature. These changes mean some species may become extinct. As all organisms in the biosphere are interlinked, the loss of one species will affect the survival of other organisms. Even a small decrease in a population may cause a decrease in the number of alleles in the gene pool, making the species more vulnerable to disease in the future.

Deep ocean currents and climate control

Within the oceans are large deep ocean currents that act like conveyor belts to churn heat through various parts of the world and regulate temperature (Figure 5.29).

Ocean currents have the important job of moving warm water from equatorial regions towards the poles; the water then cools and this colder water travels from the poles back to the warmer areas of the Earth. These large conveyer belts of water are driven by the differences in temperature and salinity. Colder water is dense and heavy, and moves towards the ocean floor; warmer water is less dense and moves up towards the surface, completing the up and down conveyer belt-like movement. Less salty water is also less dense and rises to the surface, whereas salty water is denser and sinks. Heat from the Sun evaporates the top layer of the ocean. Therefore, the remaining water is more concentrated in salt and sinks once again. This cycle of warm water and cold water is disrupted by the melting of the fresh water in ice caps. This in turn can affect the ocean conveyor belt that controls climate.

Small changes in these large ocean currents can produce large climate changes. El Niño events occur when the waters of the Pacific Ocean are warmer than normal. This in turn causes more rain to fall in the Pacific Basin instead of northern Australia. A La Niña event occurs when the Pacific Ocean is cooler than normal, causing increased rainfall and possible flooding in Australia.

Figure 5.30 Coral bleaching along the Great Barrier Reef may be the result of rising sea temperatures, which block the photosynthetic reactions corals need to stay alive.

Check your learning 5.6

Remember and understand

1 Why is a change of only 1–2°C sometimes enough to cause problems to species on Earth?

2 Explain why an increase in the number of cases of malaria is expected as a result of enhanced global warming.

3 Why is loss of biodiversity a problem?

Apply and analyse

4 Why are ocean currents responsible, in part, for global temperature?

5 How does the temperature of the Pacific Ocean affect Australia's climate?

//SCIENCE AS A HUMAN ENDEAVOUR//

5.7 Humans can reduce global warming

* The idea of the enhanced greenhouse effect or **global warming** was first raised by the scientific community in 1977. As a result, scientists around the world began to coordinate their research in the World Climate Research Program. By 1983, the enhanced greenhouse effect was becoming a political issue. Currently, global warming is seen as a worldwide problem and this has influenced the focus of scientific research.

Figure 5.31 The use of renewable energy, such as wind power, is one way to reduce carbon emissions.

Kyoto Protocol

In 1997, an international treaty called the Kyoto Protocol was signed by many of the countries that are part of the United Nations. This document stated that global warming exists and that it is a result of carbon dioxide emissions arising from human activity. The countries that signed the protocol agreed to start working to reducing carbon emissions by 5% of the 1990 emissions. Australia ratified the agreement in 2007. This required the Australian Government to limit its average annual greenhouse gas emissions during 2008–2012 to 108% of its emissions in 1990. In 2012, the Protocol was amended to allow countries to commit to reducing carbon emissions by 2020.

Reducing carbon emissions

Many governments are encouraging industries in their countries to reduce carbon emissions. Some governments are charging a fee for each tonne of carbon a business emits. This is often called a **carbon tax**. Other governments have instigated a **carbon trading scheme** where each business is allowed to release a predetermined amount of carbon emissions. If a company needs to release more carbon dioxide or methane as part of their production process, then they must buy an allocation from another company. This also allows other industries to actively extract carbon dioxide from the atmosphere in order to sell 'carbon credits'. One carbon credit is often equivalent to 1 tonne of carbon dioxide.

Geosequestration

The capture and storage of carbon dioxide underground is called geosequestration. This process, often employed by oil companies, involves capturing carbon dioxide from power station chimneys, separating it and compressing it into a liquid. The liquid is then pumped into depleted oil or gas wells and sealed with a solid plug of thick clay.

Carbon farming

Plants remove carbon dioxide from the air as part of photosynthesis. This carbon dioxide is converted into sugars and proteins that are then used by the plant to grow. Therefore, the greenhouse gas becomes part of the plant's structure. The carbon is considered to be locked in the plant for as long as it lives. For some trees this can be hundreds of years. Carbon farming is the process of growing plants that are not harvested for firewood, building or any other purpose (Figure 5.32).

Reducing methane production

Methane, another greenhouse gas, is often produced as a result of grass fermenting in a cow's stomach. The increase in our populations has meant more food (including meat) is needed. This has resulted in more cattle, and therefore more methane being released into the atmosphere. Microbiologists at the University of Queensland are studying ways to modify the bacteria present in the stomachs of cows so that they do not produce as methane. Their model is the bacteria found in the foregut of kangaroos. This particular species of bacteria produces mainly acetic acid as a waste product. This acetic acid is then digested further by the kangaroo. It is hoped that the way these bacteria digest grasses can be mimicked by the bacteria in a cow, thereby reducing the emission of the greenhouse gas.

Extend your understanding 5.7

1. What is the Kyoto Protocol?
2. What is the difference between a carbon tax and a carbon trading scheme?
3. What is a carbon credit?
4. Explain two ways carbon dioxide can be removed from the atmosphere.
5. How have the values and needs of contemporary society influenced research on global warming?

Figure 5.32 Carbon farming removes carbon from the atmosphere and locks it away for hundreds of years.

Small changes, big differences

There are many ways each person can contribute to slowing global warming. These include:

> using public transport or car pooling
> switching off electrical appliances
> using renewable energy such as solar panels
> buying local produce, which prevents fossil fuels being used to transport food long distances
> reducing, reusing and recycling items to prevent them going into landfill and generating methane.

Many of these factors are affected by social factors. A country with a low socioeconomic population will consider increasing wealth to be more important than future environmental concerns. The challenge is to support these countries in considering larger global issues as well as local issues.

* REVIEW

5

Remember and understand

1 Name the three different layers of the Earth.

2 In which layer of the Earth are the tectonic plates found?

3 What gases are found in our atmosphere and why are they important to life on the Earth?

4 What is a drought and which sphere does it relate to?

5 Even though the Earth's inner core is hotter than its molten outer core, it is thought to be solid. How can this be the case?

6 What input from the solar system has the greatest influence on our weather?

7 Will salty water sink to the bottom or rise to the top of the ocean?

8 Make a list of three ways that increasing industrialisation, particularly since the 19th century, has affected ecosystems.

9 Describe the most significant way in which humans have affected ecosystems.

10 List some of the predicted outcomes of climate change.

11 Explain how humans are shifting the distribution of energy in an ecosystem.

Apply and analyse

12 The hydrosphere can have a huge effect on the other spheres. Australia is prone to devastating droughts when there is not enough water available for the needs of Australians.

   a How could drought affect the biosphere?

   b How would this affect the atmosphere?

13 What is the difference between water and water vapour? Would you find both in the air?

14 Why is it warmer near the equator than elsewhere on the Earth?

15 The northern bettong is a very small, endangered nocturnal marsupial (Figure 5.33). It is an omnivore that eats small invertebrates, herbs, grasses and a species of fungus that makes up approximately 45% of its diet. Northern bettongs were once widely distributed throughout Queensland. However, there are now only three populations left along the western edges of the wet tropics of north Queensland.

Research the northern bettong on the Internet. What human activities do you think are contributing to the northern bettong being listed as endangered?

Figure 5.33 The northern bettong is an endangered species.

16 The glaciers on Mount Kilimanjaro in Tanzania are disappearing eight times faster than 20 years ago due to global warming. Explain how cloud cover can affect the atmospheric temperature and hence the melting of glaciers.

Evaluate and create

17 The biosphere includes parts of the lithosphere, the troposphere (the lowest part of the atmosphere) and the hydrosphere. Create a list of the parts of the biosphere you may find in each of these three spheres.

18 How are water currents similar to air currents? How are they different?

19 What do 'H' and 'L' represent on a weather map? How are they formed and what type of weather are they associated with?

20 The human population was fairly stable until about 1 CE. Then it started to grow, and its growth accelerated until it almost reached an exponential rate. In the past century, the human population has almost quadrupled. What are the likely effects of the population increase on world ecosystems?

Critical and creative thinking

21 Construct a chart or table that describes environmental carbon sinks and carbon producers.

22 Draw a mind map showing the potential connections and dependencies between the four spheres of the Earth and their components. Challenge yourself to find as many links as possible.

23 Imagine you had to reduce your energy impact on the environment. Look at all the appliances and gadgets you use in your home. Which one of these could you absolutely not bear to give up? Create an A4 page outlining why this one item is 'essential' to you and then make a list of appliances and gadgets that you could live without.

24 The Earth's climate and weather are the result of global interactions between systems and cycles. How does this support the argument that logging in any country affects everyone else on the planet? What other human activities fit into a similar category? Discuss your thoughts with the class.

25 Over 80% of the Earth's energy resources are non-renewable and declining. In the 20th century, most energy use was concentrated in a few nations that make up only a small proportion of the Earth's population. The seven largest economies at the beginning of the 21st century (with 10% of the global population) used approximately 45% of the total primary energy supply. Yet, approximately 2 billion people on Earth do not have access to electricity. In a group, discuss this concept and form an opinion. What actions could you take to improve this situation?

Research

26 Choose one of the following topics for a research project. Some questions have been included to help you begin your research. Present your report in a format of your own choosing.

> **Peak oil**
>
> Our society runs on fossil fuels. Find out about the concept of peak oil and what implications it will have for our lives in the not-too-distant future.

> **Responding to climate change**
>
> The Kyoto Protocol is an agreement between 181 countries that aims to stabilise greenhouse gas emissions in the atmosphere at a level that would prevent danger to the Earth's climate system. However, to date, the USA, the world's largest emitter of greenhouse gases, has not ratified the agreement. What does this mean for the effectiveness of the agreement? Which other countries are also not assisting and what might their motives be?

> **Global warming or Ice Age?**
>
> Like the Earth, the Sun demonstrates cycles of behaviour. One such pattern that has been identified is a period during which sunspots are absent. The next predicted period of sunspot absence is around 2020 and could last a couple of decades. The lack of sunspots would likely result in a global temperature decrease for the Earth, potentially sending us into an Ice Age. Find out more about the potential impact of this solar cycle on the Earth's future climate.

KEY WORDS

5

carbon sink
any feature of the environment that absorbs and/or stores carbon

carbon tax
a tax levied on the carbon content of fuels used by businesses or homes

carbon trading scheme
the process of allocating a set limit of carbon credits to businesses that can then be traded

climate
the weather conditions at a particular place over a long period of time based on the collection and analysis of large amounts of data

cloud
a visible mass of condensed water in the atmosphere

Coriolis effect
the influence of the Earth's rotation on the direction of air or water movement

denitrifying bacteria
bacteria that return nitrogen to the atmosphere

enhanced global warming
the effect on the climate due to additional heat retained as a result of increased amounts of carbon dioxide and greenhouse gases released into the Earth's atmosphere by human activity

enhanced greenhouse effect
an increased level of global warming caused by the greenhouse effect of the atmosphere

eutrophication
a process whereby excessive levels of phosphorus in our waterways lead to the excess growth of algae and bacteria and an increased consumption of oxygen, suffocating fish and other aquatic animals

isobar
a line drawn on a weather map that joins places of equal air pressure

natural greenhouse effect
the effect on the Earth's temperature due to water vapour and other gases being present in small amounts in the atmosphere and affecting the Earth's radiation balance, resulting in a higher surface temperature

natural greenhouse gases
gases such as water vapour, carbon dioxide, methane, nitrous oxide and others that contribute to the greenhouse effect by affecting the radiation transfer through the atmosphere

nitrogen-fixing bacteria
bacteria that convert nitrogen from the atmosphere into various nitrogen compounds

permafrost
permanently frozen ground

photolysis
the breakdown of a chemical substance by light, for example, the breakdown of water into oxygen and hydrogen

precipitation
the process of condensed water droplets falling as rain

water vapour
a gaseous form of water

weather
a snapshot of what the air and conditions are like in any one place on the Earth at any one time

wind
the sideways movement of air as a result of lower density warm air rising through the atmosphere

THE UNIVERSE

6

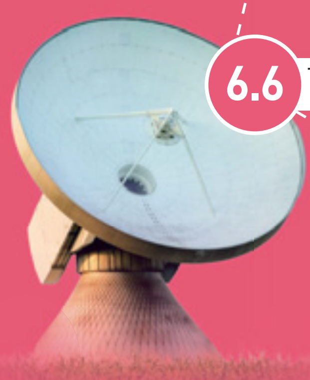
6.1 The universe was studied by early Australians

6.2 The Earth is in the Milky Way

6.3 Stars have a life cycle

6.4 The galaxies are moving apart

6.5 The Big Bang theory is supported by evidence



6.6 Technology aids cosmological research

What if?

What you need:

stopwatch, large open space (basketball court), long tape measures

What to do:

1 Mark a starting point on the basketball court.
2 Walk heel to toe in a straight line, carefully touching the heel of one foot to the toe of the previous foot for exactly one minute.
3 Measure the distance you walked in one minute.

What if?

» What if you walked heel to toe for 1 hour? (How far would you walk?)
» What if you walked heel to toe for 1 day (24 hours)?
» What if you walked heel to toe for 1 year (365.25 days)?
» What if you travelled at the speed of light? (How far would you travel?)

//SCIENCE AS A HUMAN ENDEAVOUR//

6.1 The universe was studied by early Australians

While many people consider the ancient Greeks (400 BCE) to be the first astronomers, there is increasing recognition of early Indigenous astronomers. Indigenous Australians had a very practical use for the night sky. It was part of their culture, spirituality and calendar.

Aboriginal calendar

Constellations are groups of stars that form a picture in the night sky. To Indigenous Australians, the appearance of certain constellations at sunrise or sunset told them when and what to hunt.

Many people in Australia are familiar with the whitish hazy band that appears across the sky. This is the Milky Way, which is our galaxy (a group of stars held together by their own gravity). Deep within the Milky Way is a dark patch that looks like an emu (Figure 6.1). There are many Indigenous stories about the emu in the sky. However, to the people living in the western desert it was part of their calendar. If the emu appeared to be running when it appeared on the horizon, then it was time to hunt emus. If the emu appeared to be sitting down, then it was time to collect the emu's eggs.

To the Boorong people who lived at Lake Tyrrell in Victoria, the appearance of the ancestral malleefowl called Neilloan during March and October signalled that the bird was building its nest mounds. When the constellation disappeared in late September, early October, it was time to gather the eggs.

To the people living in the Gulf of Carpentaria, a group of stars (called Scorpius by Europeans) appearing in the night sky in April meant the wet season was over and soon the dry southeasterly wind would start.

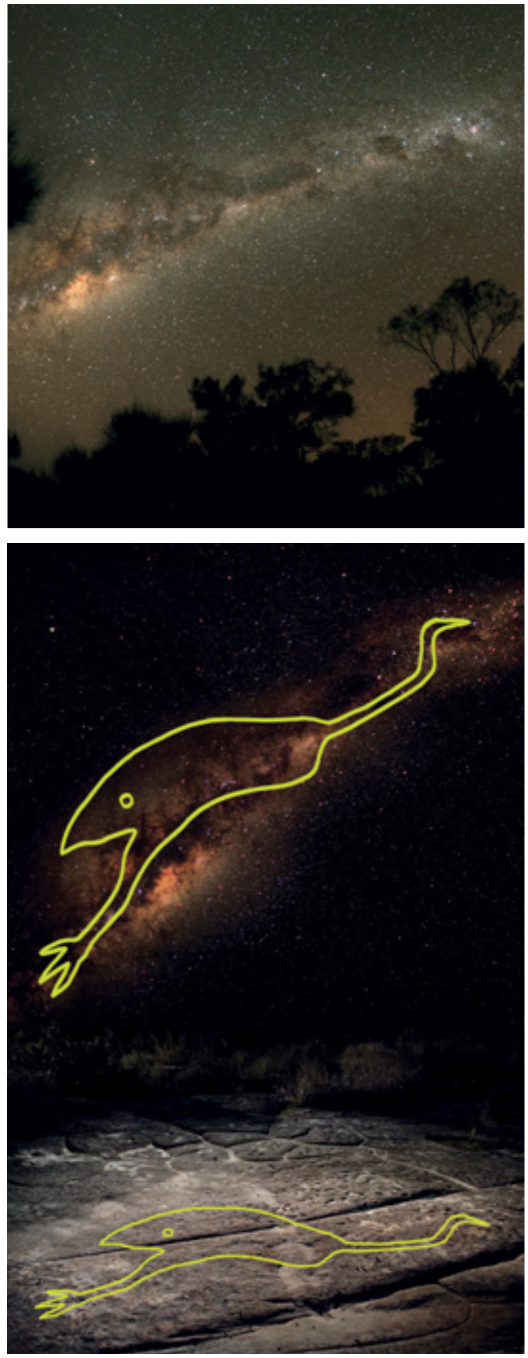


Figure 6.1 The emu-shaped dark patch in the Milky Way told Indigenous Australians when it was time to hunt.

SKILLS LAB 6.1: USING A STAR CHART
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CHALLENGE 6.1: MODERN-DAY AUSTRALIAN ASTRONOMERS
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Stories in the stars

Indigenous Australians are a diverse group of people who live in all parts of Australia. Each tribal or national group has its own language and stories of the stars.

The constellation of stars called Orion by Europeans has different stories told about it by the different peoples. The Yolngu people of the Northern Territory call this constellation Djulpan. They tell of three brothers of the king-fish (Nulkal) clan sitting side by side in a canoe. The cloud of stars in the nearby nebula are the fish and the stars marking Orion's sword mark the fishing line. The three brothers were forbidden to eat any king-fish. The brothers caught king-fish after king-fish, but had to throw them all back. Eventually one of the brothers became so hungry he ate the king-fish. The Sun-woman (Walu) saw him and in anger, created a water spout that lifted the brothers up into the sky.

To the people of Central Australia, this same group of three stars are a man chasing seven young women across the sky. The fleeing women can be found in a cluster of stars always ahead of the man in the sky.

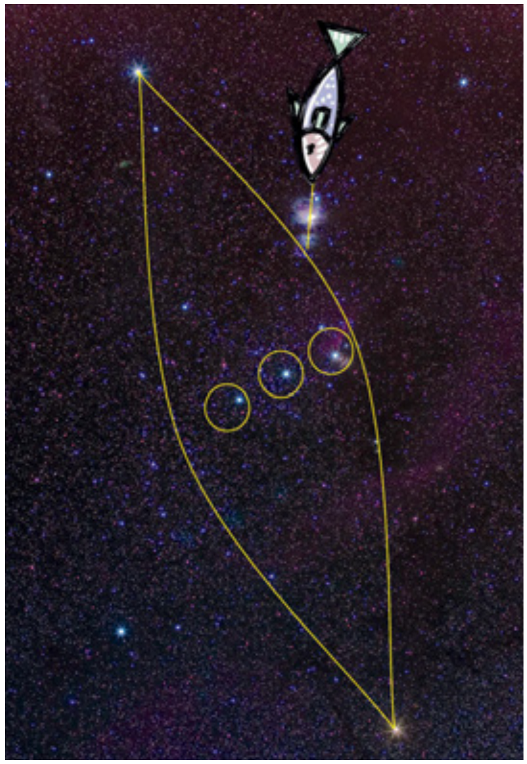

Figure 6.2 Different stories are used by Indigenous Australians to explain the same constellation. The Yolngu people call the Orion constellation Djulpan.

Extend your understanding 6.1

1. What is the difference between a galaxy and a constellation?
2. How could the Indigenous people use the sky as a calendar? Provide two examples to support your answer.
3. What is our galaxy? What does it look like in the night sky?
4. Is Orion a galaxy or a constellation? What features help you to find Orion in the night sky?
5. Why might there be different stories about Orion from the Indigenous peoples across Australia?
6. Why can't we see individual stars from other galaxies at night?

6.2 The Earth is in the Milky Way

Stars are large balls of gas that undergo **nuclear fusion**. They can vary in size, mass, temperature and brightness. Stars that appear brighter are described as having a high apparent magnitude. Larger, hotter stars that are further away will have a higher absolute magnitude. Stars appear to move in the sky. This is largely due to **stellar parallax**. Distances in space are measured in **light-years**.

Stars

A star is a giant ball of hot glowing gases. Most stars are made almost entirely of hydrogen and helium. These gases are constantly reacting at the core (centre) of the star and provide energy to the star through nuclear fusion (when atomic nuclei join). This energy is emitted as light (and other forms of electromagnetic radiation) and is what we see when we look at the stars at night. Stars can vary in size, mass, temperature and brightness.

What does a star's brightness mean?

The brightness of a star viewed from the Earth is measured on a scale called the **apparent magnitude scale** – a measure of how bright it 'appears' to be. The Sun is the brightest object in the sky and has an apparent magnitude of –27. In comparison, a full Moon has an apparent magnitude of –13. So, the more positive (and the less negative) the number, the dimmer the star.

A star may appear to be quite bright because it is close to the Earth, but it may not actually be very bright (Figure 6.3). For example, the Sun is not a very bright star compared with other stars, but it is the closest star to the Earth.

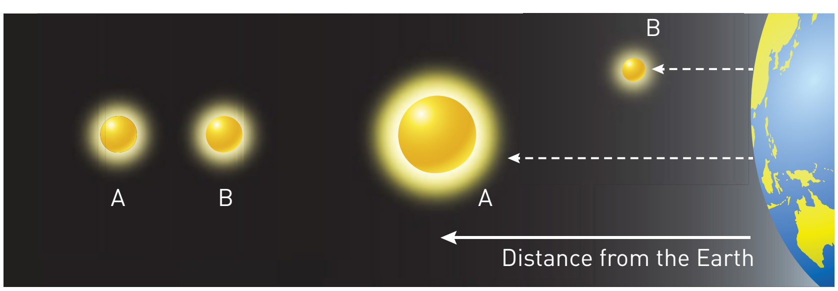

Figure 6.3 Although both stars A and B have the same apparent magnitude, A is more luminous and has a higher absolute magnitude than B.

The **absolute magnitude scale** measures a star's brightness as if all stars are the same distance from the Earth – its actual brightness or **luminosity**. Therefore, a star may have a higher absolute magnitude but appear less bright because it is a long way from the Earth.

What does a star's colour mean?

Another way of comparing stars is to analyse their colour. The colour of a star depends on its surface temperature. Blue stars are the hottest and red stars are the coolest.

A method of displaying star data is a **Hertzsprung–Russell diagram** (Figure 6.4). This shows a plot of the star's temperature on the *x*-axis and the star's absolute magnitude on the *y*-axis. When plotted this way, most stars, including our Sun, fall into a narrow diagonal band called the main sequence.

Light-year

The universe that we can observe consists of all the stars, galaxies and other objects that we can see from the Earth – it is enormous. We can only see these objects because light, or another type of signal, from these objects has had time to reach the Earth and we can detect the signal.

Light travels very fast – at 300 000 km/s. The distance that light travels in 1 year is called a light-year (9 500 000 000 000 km). Light-years are used to measure the distance of stars from the Earth. The nearest star to the Earth is our Sun, which is only 500 light-seconds from

CHALLENGE 6.2: UNDERSTANDING PARALLAX
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EXPERIMENT 6.2: CALCULATING THE DISTANCE TO THE SUN
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the Earth. This means it takes 500 seconds (approximately 8 minutes) for the light from the Sun to reach the Earth. The next closest star to the Earth is Proxima Centauri, which is 4.2 light-years away. This means if Proxima Centauri was to explode, it would take 4.2 years for the light to reach the Earth and for you to see the explosion!

Stellar parallax

Every night, the stars and planets appear to move across the night sky. During the night we can observe the 'movement' of our Moon through the sky as it rises and, much later, as it sets. All stars 'move' in the sky, although, because they are so far away, their movement is much less noticeable than that of the Moon.

This effect, known as stellar parallax, is used by astronomers to calculate the distance to nearby stars (i.e. those stars closer than 100 light-years). Beyond this distance, spacecraft are needed to calculate the distance accurately. When a star is observed from two different positions (e.g. in January and then 6 months later in July), its position relative to other stars may appear to be different (Figure 6.5).

Galaxies

Some stars are held together by gravity. These groups of stars are called galaxies. Our Sun is part of a spiral-shaped galaxy called the Milky Way. Galaxies are classified according to their shapes: elliptical, spiral or irregular (Figures 6.6 and 6.7).

Check your learning 6.2

Remember and understand

1 What is a:
   a star
   b galaxy
   c light-year?
2 What is a main sequence star?
3 What is meant by the term 'parallax'?

Apply and analyse

4 Why does the Milky Way galaxy appear so large in the night sky compared with other galaxies?
5 If a star that was 20 light-years away exploded right now, when would we see it exploding?

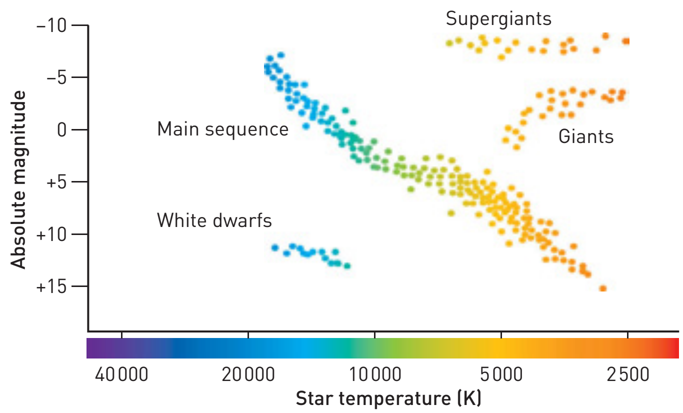

Figure 6.4 A Hertzsprung–Russell diagram.

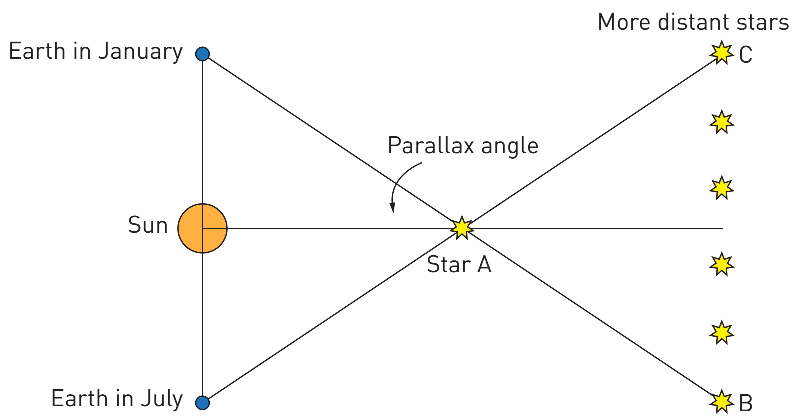

Figure 6.5 Measuring the distance to stars using stellar parallax. In January, star A, a close star, is in line with a more distant star, star B, but in July it is in line with star C. By measuring the parallax angle and knowing the radius of the Earth's orbit, the distance to star A can be calculated.

Figure 6.6 Our solar system (a group of planets that orbit the Sun) can be found on one of the arms of the Milky Way.

Figure 6.7 An elliptical galaxy.

6.3 Stars have a life cycle

Throughout the universe, stars are born in large clouds of gas called **nebulae**. Each star exists in a **hydrostatic equilibrium** between the gravitational pull to the centre and the push release of energy from nuclear fusion. As the nuclear fuel is depleted, the star collapses, creating more pressure and higher temperatures. Small stars will cool and die, forming **white dwarfs** and **black dwarfs**. Large stars explode in **novas** and **supernovas**, releasing large amounts of light and energy. The remaining core forms a **neutron star**.

In the constellation of Orion lies a group of stars informally known as the Saucepan. A misty patch, just visible to the naked eye, is the M42, or Orion Nebula. This region of gas and dust also has new stars just as they begin to emit light. It is a stellar nursery, with stars being born all the time. Our own Sun would have been born in a similar region. Throughout the universe, the stars are at various stages of their lives. Young, medium, old and dying stars can be found, as well as exploded stars.

Figure 6.8 This image of Kn 61, a newly confirmed planetary nebula, was taken by Professor Travis Rector, University of Alaska, Anchorage, using the 8.1-metre Gemini Telescope. The nebula appears as a blue bubble, and a bright star and spiral galaxy can also be seen.

Birth of a star

Across the universe are large clouds of hydrogen gas called nebulae. Even though these hydrogen atoms are very small, they are attracted to each other by gravity. The more the hydrogen atoms gather together, the greater the attractive force. The hydrogen atoms in the centre of the cloud are under a great deal of pressure, causing the centre of the gas cloud to heat up. Eventually there is enough heat and pressure to fuse two hydrogen atoms together, forming helium. This nuclear fusion releases large amounts of energy in the form of heat and light. A star is born. You can see a nebula in Figure 6.8.

Adult stars

The release of energy from the nuclear fusion of hydrogen atoms forces the gas particles out, while the force of gravity pulls the atoms in. These two forces become balanced so that the star stabilises to a consistent size. This balance of forces is called a hydrostatic equilibrium. A main sequence star can maintain this balance between the forces for millions of years.

Older stars

Eventually the hydrogen available for nuclear fusion starts to decrease. When this occurs, the gravity force becomes stronger than the force pushing the hydrogen atoms out. The gas particles are pulled closer to the centre of the star, producing even greater pressure (and higher temperatures). Eventually the helium atoms start to fuse, forming carbon atoms. This form of nuclear fusion releases even more energy than hydrogen fusion. The star grows larger as the forces reach a new hydrostatic equilibrium. This cooling and expansion results in the formation of a **red giant** star (Figure 6.9). Our Sun will do this in about 5 billion years from now. Because of its size, the Sun will swallow up the inner planets of the solar system – Mercury, Venus, Mars and the Earth.

Death of a star

Eventually the amount of helium available decreases as well. As the outer regions of lighter red giants fade away, the shell is called a **planetary nebula**, although it has nothing to do with planets (Figure 6.10). Only the core remains at the centre. Further nuclear reactions occur, increasing the rate of energy release and therefore the temperature. The core becomes white hot and the star is called a white dwarf. As this mass cools, the star gradually fades away to become a black dwarf.

Heavier red giants seem to have a different fate. The nuclear fusion process continues through various elements until iron is formed. Eventually, the star runs out of energy for fusion reactions and collapses. This increases the pressure and temperature to extreme levels. The resulting explosion is the largest explosion in the universe – a supernova.

After the supernova, the remaining core is amazingly dense and electrons and protons collide to form neutrons, creating a neutron star. Neutron stars are only tens of kilometres in diameter and are remarkably dense. A teaspoonful of neutron star material would have the same mass as 100 000 cars!

If a neutron star collapses further, its gravitational pull and density become so huge that not even light can escape. These are **black holes**. As matter falls towards a black hole, X-rays are emitted and this is how possible black holes are detected in space, although their existence is still to be determined absolutely.

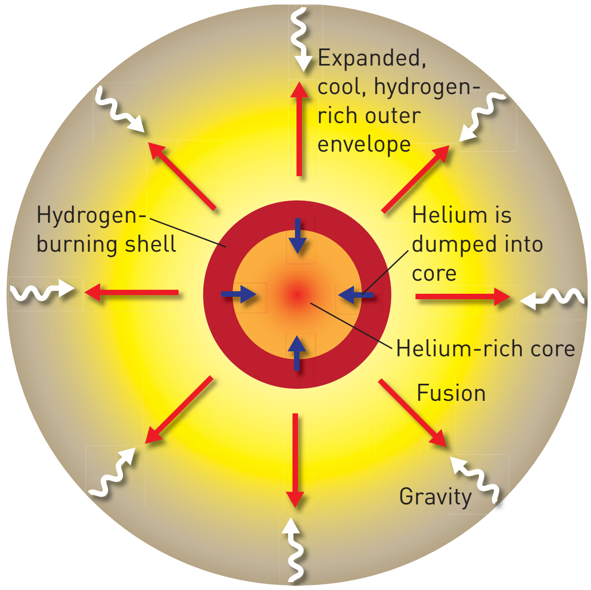

Figure 6.9 How a red giant star forms.

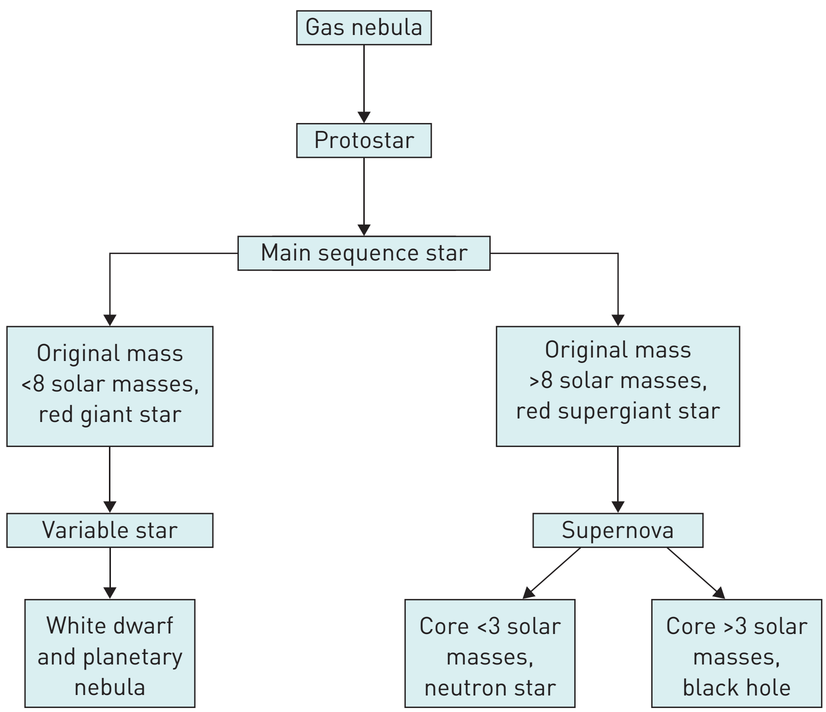

Figure 6.10 The life cycle of a star.

Check your learning 6.3

Remember and understand

1 What event marks the birth of a star?

2 Why are most stars 'main sequence' stars?

3 What is left after a supernova?

Apply and analyse

4 Draw a flow chart to show the life cycle of a star the size of our Sun.

5 Blue stars are much larger than our Sun. However, they do not have enough energy to explode. Draw a flow chart to show the life cycle of a blue star.

6.4 The galaxies are moving apart

*

Elements will absorb light energy in specific wavelengths, creating an **absorption spectrum**. When the same elements return to a stable state, they will release the same wavelengths of energy as an **emission spectrum**. These two spectra allow scientists to determine the elements that are present in different parts of the universe. The **Doppler effect** describes that change in a frequency of a wave as an object moves towards or away from an observer. A **red shift** in the emission or absorption spectrum of a galaxy indicates that the galaxy is moving away from the observer.

Measuring the movement of galaxies

As a star undergoes nuclear fusion, it releases energy in the form of light. The outer layers of gas surrounding the star contain elements that will absorb specific wavelengths of light energy. This causes dark lines in the spectrum of light that leaves the star. This is called the absorption spectrum of a star. The set of dark bands in the light spectrum is unique to the element contained in the star.

Alternatively, if there is a nebula or gas cloud near a star, the elements in the gas will also absorb some of the energy from the star and become excited. Eventually the elements will return to their stable state and emit (release) the unique bands of light energy they absorbed. This is called the emission spectrum.

Compare the emission spectrum and the absorption spectrum of helium in Figure 6.11. The absorption spectrum contains lines in exactly the same positions as in the emission spectrum.

In the 1920s, using the most powerful telescope in the world at the time, Edwin Hubble examined the spectra of light absorbed and emitted by the galaxies.

Absorption spectra can also reveal another important aspect of a distant star – its velocity – which is what Hubble discovered.

Figure 6.12 Edwin Hubble made his observations from the Hooker Telescope – an older, less powerful telescope than the Hubble Telescope shown here, which was named in his honour.

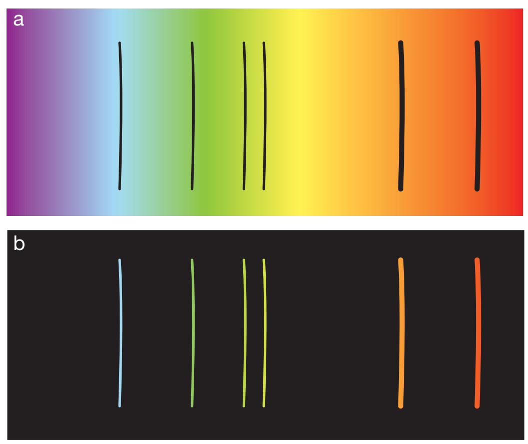

Figure 6.11 (a) Absorption spectrum and (b) emission spectrum of helium.

Doppler effect

When a racing car races past you, the pitch of its sound appears to change. This can be modelled by making a 'yeee … owww' sound with your voice. The 'yeee' is the high pitch from the car's engine as it approaches you: its sound waves are being bunched up as the car speeds in your direction. This causes the lengths between the waves to be shorter, increasing the pitch, or frequency, of the sound. As the racing car passes you, the pitch you hear drops – that's the 'owww' part. The car is now speeding away from you and sending the sound waves back to you, lengthening their wavelength and lowering the pitch. The faster the car goes, the more pronounced the effect.

CHALLENGE 6.4: EXPLORING THE DOPPLER EFFECT
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EXPERIMENT 6.4: INVESTIGATING EMISSION SPECTRA
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This is known as the Doppler effect, after its discoverer, Christian Doppler. The Doppler effect happens with ambulance and police car sirens, trains, fast noisy objects and light (Figure 6.13).

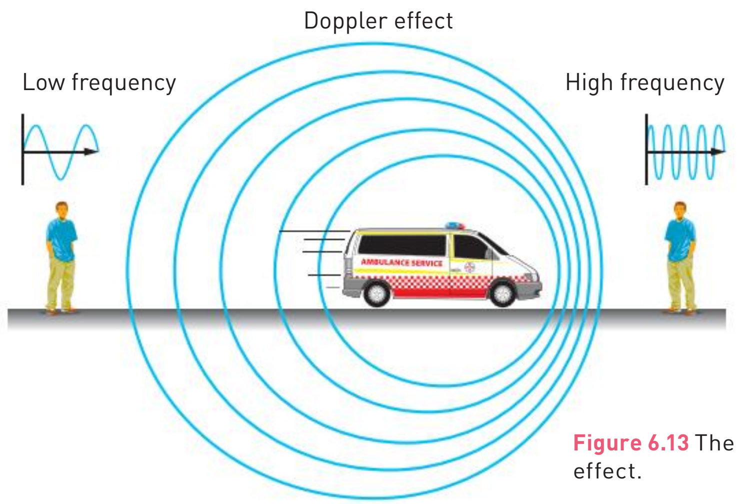

Figure 6.13 The Doppler effect.

Red shift, blue shift

When Hubble looked at the absorption spectra of distant galaxies, he saw that the lines were shifted in the red direction of the spectrum. Red light has a long wavelength; blue light, at the other end of the visible spectrum, has a shorter wavelength. A shift in the red direction, which is known as a red shift, indicates that the galaxy is moving away from the Earth. The greater the shift of the emission light bands towards the red spectrum, the faster the galaxy is moving. A shift in the blue direction, a **blue shift**, indicates that the star is moving towards the Earth. The greater the shift towards the blue spectrum, the faster the galaxy is moving.

Edwin Hubble's big discovery was that the more distant galaxies tended to have more red-shifted spectra and, hence, were travelling faster away from the Earth. This discovery became known as Hubble's law and provides compelling evidence for the **Big Bang theory**.

Hubble's law was followed up by a group of scientists including US-born Australian Brian Schmitt. Their research determined the expansion of the universe is accelerating. As a result, Brian Schmidt was awarded a Nobel Prize in 2011.

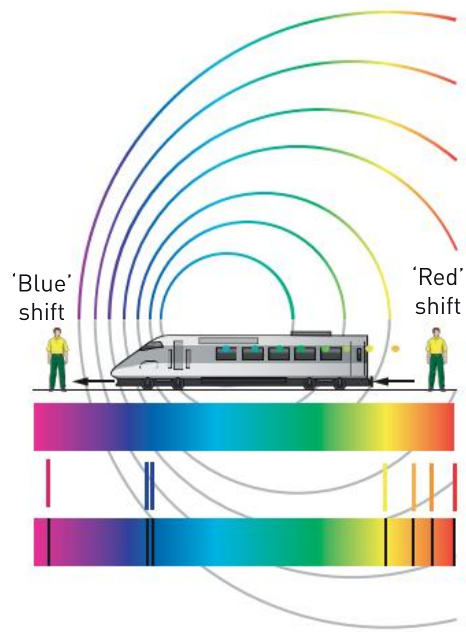

Figure 6.14 Red shift and blue shift.

Check your learning 6.4

Remember and understand

1 How would you know you were looking at an absorption spectrum?

Apply and understand

2 How are the emission and absorption spectra for helium similar?

3 How does red-shifted light show that a galaxy is moving away from us?

4 Figure 6.15 shows the spectra observed from three stars. Star A is at a fixed distance from the Earth, whereas stars B and C are moving.

   a What produces the dark lines on each spectrum?

   b Which star, B or C, is moving towards the Earth? Explain your answer.

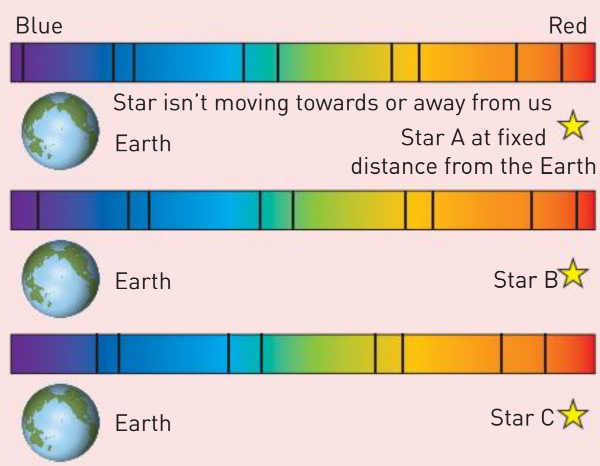

Figure 6.15

6.5 The Big Bang theory is supported by evidence

The Big Bang is a theory that describes how the universe developed from a small dense **singularity** into the massively expanded space it is today. This theory, like all theories, is supported by large amounts of reproducible evidence. It includes the presence of **cosmic microwave background radiation**, the proportion of lighter mass elements such as hydrogen and the observations of distant galaxies that provide a glimpse into the past.

How the universe began has been much debated and studied. In ancient civilisations, people believed that the Earth was at the centre of the universe. Astronomers today theorise that the universe came into existence from a single dense hot point called a singularity. From this point, space expanded rapidly and silently – it wasn't really a bang at all. Over time, the universe cooled and matter (atoms) was formed.

Big Bang theory

The concept of the Big Bang was originally proposed in the 1920s, although it wasn't called this then. In 1929, the US astronomer Edwin Hubble discovered that the spectra of light from galaxies implied that they were moving away from the Earth. Hubble also found one of the most significant results in the history of the origin of the universe: that the further away galaxies were from the Earth, the faster they were moving. The speeds were enormous. In fact, it is not the galaxies themselves that are moving away; rather, space is expanding and taking the galaxies with it (Figure 6.16).

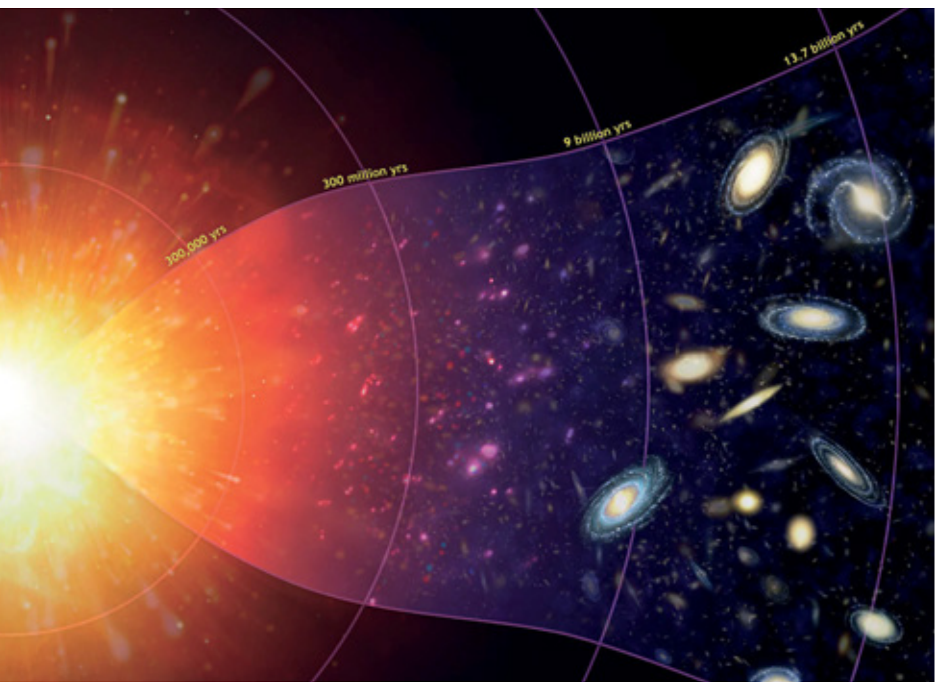

Figure 6.16 According to the Big Bang theory, the universe began from a rapid expansion from a hot dense state.

But what is the universe expanding into? Based on Hubble's observations that the galaxies are racing away from each other, the obvious conclusion is that if you run things in reverse, everything must have come from the same spot. This idea led to the development of the Big Bang theory. As with all science, this theory is supported by many forms of evidence.

Microwave background

The concept of the Big Bang relied on the idea of the existence of some sort of radiation. It was hypothesised that the enormous amounts of heat released as part of the Big Bang would still exist in a much cooler form. In 1965, two US scientists, Arno Penzias and Robert Wilson (Figure 6.18), found evidence that the leftover energy existed as background radiation.

While testing a new, sensitive horn-shaped radio telescope antenna, Penzias and Wilson found a strong background noise that was interfering with transmission. They weren't trying to find it, they just happened to notice it. This background noise was a form of electromagnetic radiation known as cosmic microwave background radiation (Figure 6.17).

CHALLENGE 6.5: THE EXPANDING UNIVERSE
GO TO PAGE 235

The existence of cosmic microwave background radiation was one of the greatest discoveries of all time, so important that Penzias and Wilson were awarded a Nobel Prize in 1978 for their discovery.

Mixtures of elements

As shown by cosmic microwave background radiation, the universe has cooled since the Big Bang. As energy cannot be created or destroyed, the energy must have been converted into elementary matter. The simplest element that could have been made is hydrogen. The amount of hydrogen (and subsequent heavier elements) formed should be proportional to the amount of energy available. This would leave cools spots in the universe that are directly related to the mass of elements present. In 1992, the Cosmic Background Explorer (COBE) satellite detected these ripples in temperature fluctuations that are consistent with the formation of distant galaxies and old stars.

The universe is changing

When we examine distant galaxies, we are also looking back in time. The light from these galaxies take many years to arrive on the Earth. As a result, scientists can see old galaxies that developed millions of years before our own Milky Way. This has provided a timeline of galaxy formation that is consistent with the Big Bang.

All these observations have allowed astrophysicists to estimate that the universe is 13.7 billion years old.

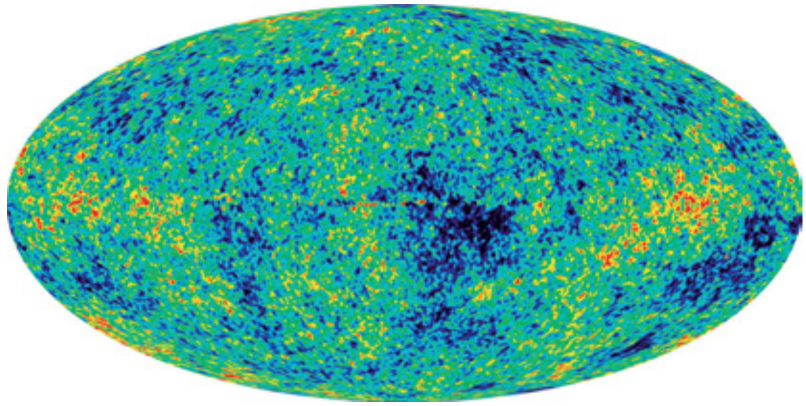

Figure 6.17 Fluctuations in the cosmic microwave background radiation are shown as temperature fluctuations over the sky. These fluctuations correlate with the formation of nearby matter.

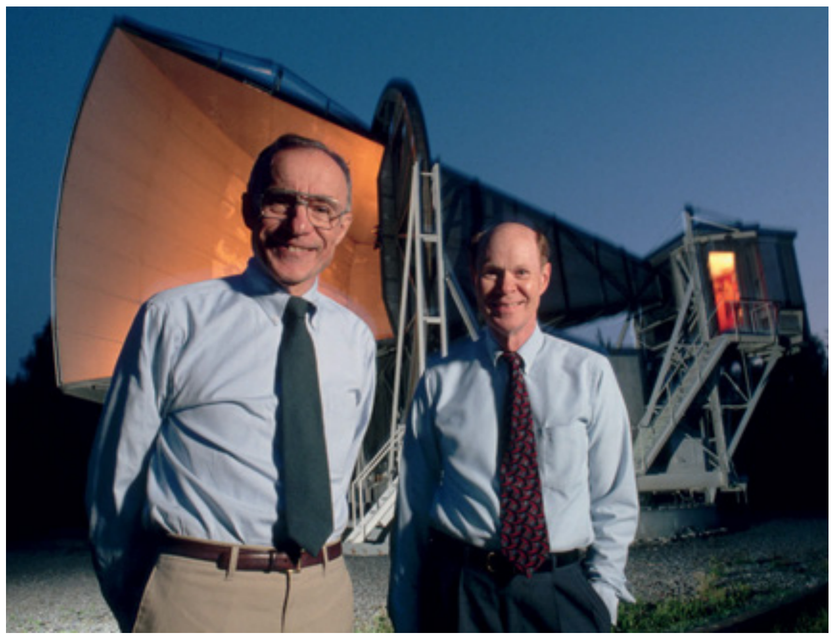

Figure 6.18 Arno Penzias (left) and Robert Wilson (right) in front of their horn antenna with which they discovered cosmic microwave background radiation.

Check your learning 6.5

Remember and understand

1 Why is the Big Bang not a bang at all?
2 Write a description of the Big Bang theory.

Apply and analyse

3 A theory is never final. Evidence is always needed to reinforce a theory. The Planck satellite was designed to examine cosmic microwave background radiation. How do you think evidence obtained from the Planck satellite will help support the Big Bang theory?
4 What is cosmic microwave background radiation? Why is its existence important?
5 Cosmic microwave background radiation has been called ‘ancient whispers’. Why is this name appropriate?
6 What other evidence supports the Big Bang theory?

//SCIENCE AS A HUMAN ENDEAVOUR//

6.6 Technology aids cosmological research

Australian Square Kilometre Array telescope takes shape in WA outback

by Gian De Poloni

13 October 2014

A project to build one of the world's most powerful radio astronomy telescopes is taking shape in Western Australia's outback.

The $160 million Australian Square Kilometre Array Pathfinder (ASKAP) is being built in a radio quiet area of WA's Murchison region, about a four-hour drive from the port city of Geraldton.

The project has seen the installation of 36 huge antenna dishes on Boolardy Station, which will eventually work together to survey large areas of sky to help scientists understand how galaxies have formed and evolved.

CSIRO scientist Lisa Harvey-Smith said although only six of the dishes were active, the images that had been taken so far were remarkable.

'The latest picture we've taken has almost 2000 galaxies in it, which is incredible,' she said.

'It's kind of a wide field image of the sky.

'Once we've got 36 telescopes, we'll be able to do a huge survey of the entire night's sky and see millions of new galaxies, black holes and things in the very distant universe that no one's ever seen before.'

She said the question of what exactly the telescope will be able to see in distant space was a complete mystery.

'The discovery potential of this telescope is quite amazing,' she said.

'Even now, we've been able to look at galaxies that are actually older than our Earth – which is a pretty incredible thing – and look into the distant universe to search

Three ASKAP telescopes are trained towards the sky east of Geraldton. (Alex Cherney)

for galaxies that were actually around billions of years ago and may not exist anymore.'

Dr Harvey-Smith said the giant dishes were picking up radio waves being emitted from objects in space.

'Our eyes can't see radio waves, so the data that we get is just boring ones and zeros, but we actually use clever computer algorithms and a super computer that's based in Perth to make the images into real optical type images that we can see,' she said.

Telescope will view area 200 times size of moon

Project director Antony Schinckel said images produced so far were stunning.

'The thing about ASKAP is it's a completely new type of telescope – it's never been built before – so a lot of this very early work is simply understanding exactly how to use it,' he said.

'Many of our staff said "look, it's not worth trying to do much with just the six dishes because we won't be able to see much", but they've been completely shown to be wrong.

'Trying to predict ahead to what we're going to see with 36 at the full capability is really hard but we'll be able to very quickly map really big areas of the sky and by really big, I mean in a single snapshot we'll be able to see an area around about 200 times the size of the full moon.

'There are still huge holes in our knowledge of how our universe evolved, where galaxies come from, how planets form and we expect ASKAP will be able to really help us answer a lot of that.'

Dr Schinckel estimated it would cost about $10 million a year to keep the project going.

'We've had good support from the Government over the last few years and we believe the Government does see the positive impacts of these sorts of projects,' he said.

'There's the pure science side, there's the very tight international collaboration aspect, there's the technology spin off, there's training of engineers and scientists who may or may not stay on in astronomy but may go on to work in other fields.'

ASKAP is viewed as a precursor to the future $1.9 billion Square Kilometre Array, which will be built in both the Murchison and South Africa in 2018, with input in design and funding coming from 11 countries.

The SKA is expected to be the largest and most capable radio telescope.

Murchison ideal location for project

Dr Harvey-Smith said the isolation of the Murchison region made it the perfect place for the project.

'If you could imagine trying to listen for a mouse under your floorboards hearing tiny scratching noises, you don't want to be playing the radio very loudly in the background,' she said.

'It's the same type of thing with the radio telescopes.

'We're looking for tiny, tiny signals incredibly weak from galaxies billions of light years away.

'They're so weak we have to amplify them millions of times with specialist electronic equipment.'

This wide shot image taken from the ASKAP telescope over 12 hours shows distant galaxies. (CSIRO)

Dr Schinckel said the communications infrastructure in place to support the telescope was unfathomable.

'The raw data rate we get from the telescopes is about 100 terabytes per second,' he said.

'To put that in context, that's about the entire traffic of the internet all around the world in one second.

'Luckily the super computers we have on site can very quickly reduce the data back to a more manageable volume of around about 10 gigabytes per second.

'The sheer volume of that and the speed of which that raw data comes in is truly astounding.'

Dr Harvey-Smith said she could control the telescope from the comfort of her lounge room.

'As one of the research scientists, I can access the telescope from Sydney – from my house, on my laptop,' she said.

'We just send signals through the internet and tell the telescope what to do.

'It's pretty amazing that we can have a giant international scientific facility with very few people actually out there on the site.'

It is hoped the entire network of dishes will be fully operational by March 2016.

Extend your understanding 6.6

1 Why was ASKAP built in Murchison, Western Australia?
2 What benefits are there in having so many countries involved with the ASKAP?
3 Other than astronomers, what other researchers work on the ASKAP program?
4 Why are super computers needed to interpret the data from the ASKAP?
5 What are the researchers using ASKAP hoping to find?

* REVIEW

6

Remember and understand

1 Match each word in the left column with its correct meaning in the right column.

Sun	groups of stars that are close together in the sky
galaxy	theory of the creation of the universe in a huge explosion-like event
star chart	everything that exists in space
constellation	huge collection of stars held together by gravity
universe	used to locate and identify objects in the night sky
Big Bang	our closest star

2 What is the main difference between astronomy and astrology?

3 What are scientists Penzias and Wilson famous for discovering?

4 Decide whether the following statements are true or false.

a All stars are yellow and very hot.

b All galaxies are the same shape and size.

c The brightness of a star when viewed from the Earth is its absolute magnitude.

d Bigger stars are usually hotter, brighter and burn for longer than smaller stars.

5 Why are light-years used instead of kilometres as a unit of distance?

6 Explain why it is difficult to judge the distance of a star by measuring only its brightness.

7 How does the night sky enable us to look back in time?

8 List the following in order of size from largest to smallest: neutron star, the Sun, white dwarf, red giant.

9 State two differences between a white dwarf and a red giant.

10 Explain why the ASKAP is an important tool for astronomers.

Apply and analyse

11 Briefly describe the Doppler effect.

12 What was the link between Hubble's observations and the Doppler effect?

13 Why can't you see stars (apart from the Sun) during the day?

14 Draw a diagram to show why different stars are visible from different places on the Earth's surface.

Evaluate and create

15 Many ancient cultures had legends about the origin of constellations. Investigate Koori, Polynesian or Ancient Greek legends about constellations. Do these legends still influence how we view and understand the constellations today?

16 a How does the pitch of an ambulance siren change as it races past you?

b Why does this change occur?

c Would the driver of the ambulance hear this change?

17 If the Sun is 149 600 000 km from the Earth and light travels at 300 000 km/s, calculate how long it takes for light to reach us from the Sun. Express your answer in minutes.

18 How many kilometres from the Earth is each of these celestial objects?

a Star Altair at 16.7 light-years

b Coalsack nebula at 600 light-years

c Jewelbox star cluster at 7600 light-years

19 If the speed of light is 300 000 km/s, what distance does light travel in:

a 1 second?

b 1 minute?

c 1 hour?

d 1 day?

20 Why don't we use light-years for measuring distances within our solar system?

Critical and creative thinking

21 Create a poster showing the fate of the Sun as it expands from its current size into a red giant and then as it contracts into a white dwarf. Label each stage and find photos from the Internet to illustrate the process.

22 View a space movie. What is its plot? Create a poster showing what things in the movie are scientifically correct and what things are not.

23 On 27 September 2007, the space probe Dawn was launched from Cape Canaveral at a cost of US$357 million, excluding the cost of the rocket (Figure 6.19). Dawn's journey includes exploration of the asteroid Vesta (in 2011) and the dwarf planet Ceres, between Mars and Jupiter, (in 2015). Humans hunger for knowledge but does this knowledge enhance our civilisation? Is space exploration vital to our survival?

24 Watch the movie 'Interstellar' and research how the discovery of gravitation waves would help us understand the nature of dark energy which is causing the Universe's expansion to accelerate. Have a class discussion about this.

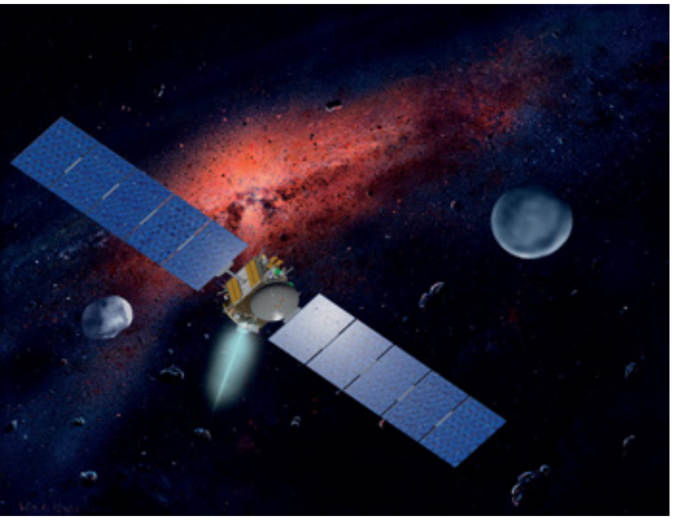

Figure 6.19 The Dawn space probe is on an interplanetary cruise.

Research

25 Choose one of the following topics for a research project. Some questions have been included to help you begin your research. Present your report in a format of your own choosing.

> **Dark matter**
>
> Scientists think that there is extra matter in the universe that is invisible. This is called dark matter. What is the difference between ordinary matter and dark matter? What evidence do scientists have for the existence of dark matter? What is the composition of dark matter? Scientists believe that the universe started from the Big Bang and that it will expand before gravitational forces pull it back in to start the entire process all over again. What effect does dark matter have on the future of our universe?

> **Ion propulsion**
>
> The engines on some spacecraft use a unique, hyper-efficient system called ion propulsion. What is an ion? Can such an engine lift a spaceship from the Earth's surface? Why? What is the fuel used? How does this fuel produce thrust? Why are large solar collectors necessary? What is the thrust produced by the engines?

> **Australian observatories**
>
> The Parkes Radio Telescope is a well-known Australian telescope. Find out a brief history of this telescope and what it is used for. The movie *The Dish* might be helpful in your research.

> **Exoplanets**
>
> Australian scientist Penny Sackett has led teams of scientists in searching for exoplanets similar to Earth. What is an exoplanet? How do astronomers search for them?

KEY WORDS

6

absolute magnitude scale
a scale for measuring the brightness of objects from the same distance

absorption spectrum
a spectrum with lines missing from the pattern; the opposite of an emission spectrum because the element has absorbed its characteristic light wavelengths and removed them from the spectrum

apparent magnitude scale
a scale for measuring the brightness of an object when viewed from Earth

Big Bang theory
the theory that the universe began from a hot, dense state at some time in the past, from when it has continued to expand and will continue to do so into the future

black dwarf
a remnant formed when a white dwarf star cools and gradually fades away

black hole
a region in space of infinite density where gravity is so large that nothing can escape from it, including light itself

cosmic microwave background radiation
a form of electromagnetic radiation in the microwave spectrum left over from the formation of the Universe; evidence of the Big Bang theory

Doppler effect
the apparent change in wavelength (or frequency) when the source of the waves or the observer is moving; responsible for the red shift of distant stars

emission spectrum
the pattern of wavelengths (or frequencies) that appear as coloured lines in a spectroscope; it is unique to each element

Hertzsprung-Russell diagram
graph displaying star data with spectral class or star temperature on the x-axis and absolute magnitude on the y-axis

hydrostatic equilibrium
this refers to a condition where the forces become balanced resulting in some form of stability

light-year
the distance that light travels in 1 year

luminosity
the actual brightness of a star. See *absolute magnitude scale*

nebula
a cloud of gas and dust in space

neutron star
a small, highly dense star, made mostly of neutrons

nova
this refers to a star showing a sudden large increase in brightness and then slowly fades away to its original state in a few months or years

nuclear fusion
this is a high energy reaction in which two lighter atomic nuclei fuse to form a heavier nucleus

planetary nebula
a glowing shell of gas formed when stars die

red giant
a large, bright star with a cool surface that forms when a star such as our Sun runs out of hydrogen fuel

red shift
the apparent decrease in frequency (towards the red end of the spectrum) of light from galaxies that are moving away from the Earth

singularity
this refers to a point at which a function takes an infinite value, for example, in space-time when matter is infinitely dense, such as at the centre of a black hole

stellar parallax
a change in the apparent position of a star against its background when viewed from two different positions

supernova
an explosive death of a star

white dwarf
a small, hot star that forms when a star such as our Sun runs completely out of fuel and slowly fades and cools

7.1 Displacement is change in position with direction

7.2 Velocity is speed with direction

7.3 Acceleration is change in velocity over time

7.4 An object in motion remains in motion until a force acts on it

7.5 Force equals mass × acceleration

7.6 Each action has an equal and opposite reaction

7.7 Momentum is conserved in a collision

MOTION 7

What if?

What you need:

stopwatches, trundle wheel

Do not distract drivers in any way during this activity because this could have serious consequences. Always remain on the footpath at a safe distance from the road.

What to do:

1. Working in a group of three or four, find a straight stretch of road near your school and set up a 'speed trap'. Measure a distance along the side of the road and, using a stopwatch, time the motion of vehicles over that distance.
2. You will need one person to stand at the start of the distance and wave to the others as each car passes them to indicate to the people in your group to start their stopwatches.
3. From your times and distance, work out the average speed of the vehicles in metres per second and then in kilometres per hour. Decide if any of the vehicles were speeding.

What if?

» What if you compared your results to a police speed gun? (Would they be the same?)

7.1 Displacement is change in position with direction

Distance describes how far an object travels in a set time. Displacement describes the final distance and direction of the object from its starting point. Displacement is a vector quantity because it has position and direction. The movement of an object can be shown on position–time graphs or distance and displacement diagrams.

Distance and displacement

During a normal day, you may cover a considerable distance – on the way to school, on the way home, around school from classroom to classroom. However, at the end of the day you will most likely end up in exactly the same place as where you started the day: your bed! So, you could say that you haven't really gone anywhere at all.

Distance is how far an object travels over a certain period of time. Displacement describes the change in position of an object and its direction over a certain period of time. Displacement only compares the end position with the starting position, not all the in-between movements. If you end up back in bed after a whole day of moving, then your displacement is zero. For both distance and displacement, we use the symbol *d*, and the standard unit (or SI unit) is the metre (m).

Distance is known as a scalar quantity because it only has size (or **magnitude**) and no direction. Displacement is known as a vector quantity because it has size and direction. The direction part can be a compass direction (north, south, east, west) or a bearing, or it may be as simple as left, right, up, down, forwards or backwards.

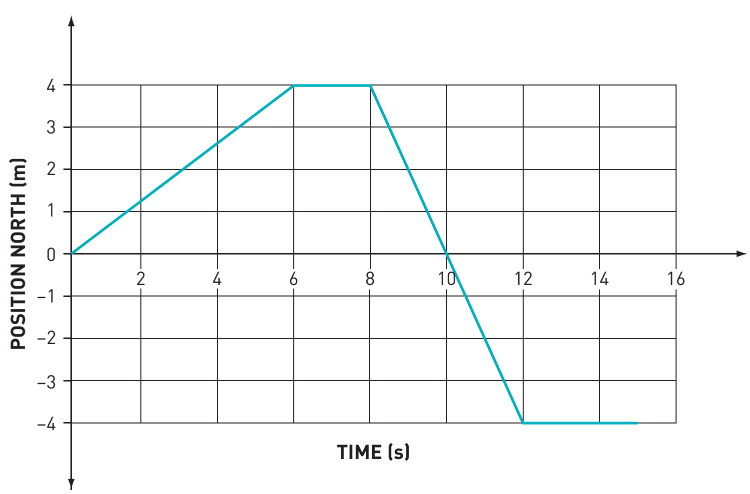

Figure 7.1 This position–time graph shows the position of a person walking north from the starting point for 6 seconds, stopping for 2 seconds and then walking south for 4 seconds. Their final position was 4 metres south of the starting point.

Position–time graphs

Have you ever seen a movie or read a book where a cryptic code is used to find the buried treasure or precious artefact? These codes often contain instructions such as 'walk 15 paces south and then 20 paces west', which could lead to a very different outcome depending on how big, or small, your steps are.

Motion graphs are a model or visual representation of a movement and can take many forms. The simplest is a position–time graph (also called a displacement–time graph). A position–time graph is a picture of the motion of an object. Position–time graphs are really only useful when the motion is linear; that is, in the same line, such as north–south or east–west or up–down. Time is always on the *x*-axis and position is always on the *y*-axis (Figure 7.1). Always remember to mark the units (e.g. seconds, metres) on the graph.

CHALLENGE 7.1: BRINGING GRAPHS TO LIFE
GO TO PAGE 235

Distance and displacement diagrams

The distance an object travels can also be represented by diagrams. Distance and displacement diagrams (as opposed to graphs) are most useful when the movement changes from linear to two dimensions. We can use arrows to show the directions and a scale to show the distances. North commonly points towards the top of the page. For example, Figure 7.2 shows a diagram of a person walking 5 metres north, then 4 metres west and then 2 metres south. This gives a total distance covered of 11 metres. However, this is not their displacement. Their displacement only compares where they finish to where they started.

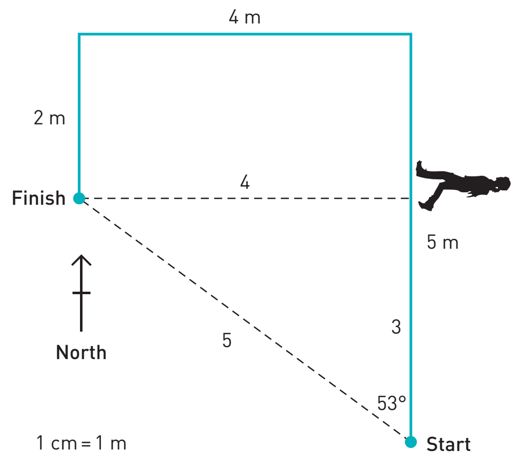

Figure 7.2 This person walks a total of 11 metres. The displacement can be calculated by drawing a right-angled triangle and using Pythagoras' theorem. The final position of the person is 5 m north 53° west or 5 m on a bearing of 307°.

Check your learning 7.1

Remember and understand

1 Describe a motion that has zero displacement.

2 What is the difference between displacement and distance?

Apply and analyse

3 An object moves 14 metres north and then 14 metres south. What distance has it covered? What is its displacement?

4 What is the difference between a vector quantity and a scalar quantity?

5 A person runs 50 metres north, then 20 metres south and then 30 metres west. What is the total distance covered? What is the person's displacement?

6 A car starts from rest (stationary) and moves north at a constant rate for 400 metres, then stops for 10 seconds before moving north another 150 metres. On a piece of paper, draw this movement as a position–time graph.

7 Consider the graph in Figure 7.3.
   a Describe the motion shown.
   b What is the distance covered in the graph?
   c What is the displacement shown?

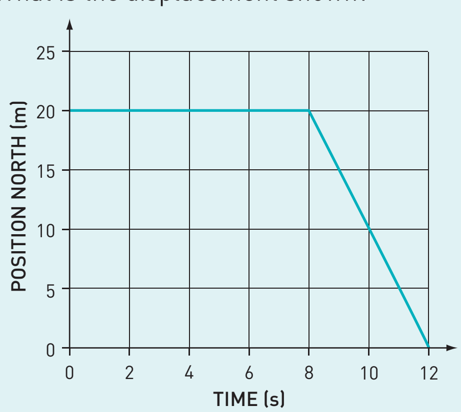

Figure 7.3

7.2 Velocity is speed with direction

Speed is a **scalar quantity** that measures the distance travelled in a set time. The average speed can be determined by dividing the distance travelled by the total time taken. A speedometer measures the instantaneous speed of an object. **Velocity** is a **vector quantity** and it measures the change in displacement over time.

Speed

Speed is a measure of how fast a car or a person or any moving object is travelling. It is measured in SI units of metres per second (m/s or m s^{-1}), although kilometres per hour (km/h or km h^{-1}) is often used instead, especially for cars and planes.

Speed is defined as the distance travelled per unit of time. Hence, a speed of 5 m/s means the object travels 5 metres in every second of its motion. Speed is a scalar quantity because it only has size and no direction.

Average speed

Often it is more convenient to work out (or calculate) an object's average speed. The symbol for average speed is s_{av}. To calculate average speed, divide the total distance travelled by the total time taken. The units for speed depend on the units of distance and time.

The formula for calculating the average speed is:

$$s_{av} = \frac{d}{t}$$

Figure 7.4 The cheetah is the fastest land animal. It can reach speeds of up to 112 km/h.

This rule, or formula, can also be expressed in a triangle as shown in Figure 7.5. The triangle is a good memory tool to help you work out three formulas from the one diagram.

Average speed can also be determined by the gradient (or slope) of a position–time graph (Figure 7.6).

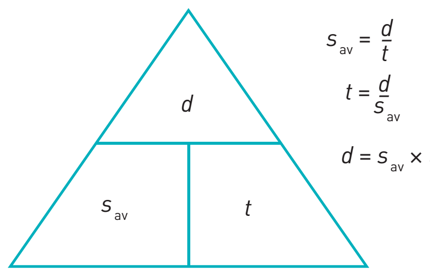

Figure 7.5 The average speed triangle is used to work out the formula for average speed. Cover the quantity you want to calculate with your finger and the other two quantities will form the formula.

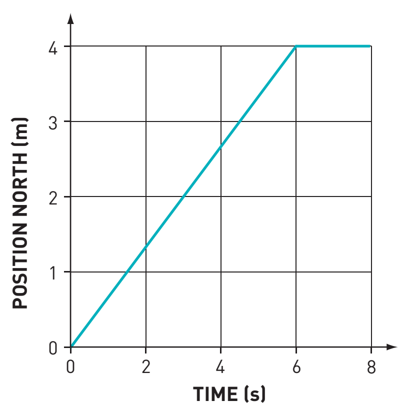

Figure 7.6 The speed of the object in this position–time graph can be calculated by determining the gradient of the graph. Gradient = change in position ÷ change in time = rise ÷ run = 4 m ÷ 6 s = 0.67 m/s.

EXPERIMENT 7.2A: THE TICKER TIMER
GO TO PAGE 236

EXPERIMENT 7.2B: USING A MOTION SENSOR
GO TO PAGE 237

Figure 7.7 A speedometer measures the instantaneous speed of a vehicle.

Instantaneous speed

Over the course of a bus or car trip, your speed changes. The speedometer in the vehicle gives the instantaneous speed in km/h (Figure 7.7). This is the speed at each moment of the trip.

Velocity

Pilots and sailors need to know both the speed of the wind and its direction. Velocity is speed in a particular direction and is therefore a vector quantity (a measurement of both size and direction). It has the same unit as speed (m/s). The average velocity of an object is calculated in a similar way to average speed, but displacement is used instead of distance (see Figure 7.8).

The direction of the average velocity is the same as the direction of the displacement. Like speed, average velocity can be determined from the gradient of a position–time graph, but the nature of the gradient indicates the direction. For example, if the gradient is positive (sloping upwards) in the north direction, then the velocity will be positive in the north direction. If the gradient is negative (sloping downwards), then the velocity will be negative in the south direction.

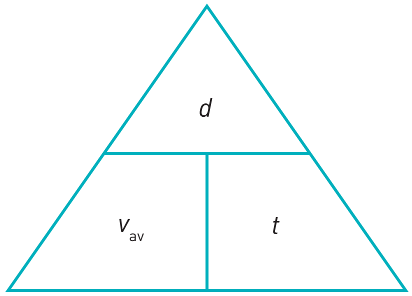

Figure 7.8 The average velocity triangle. Cover the quantity you want to calculate and the other two quantities will form the formula.

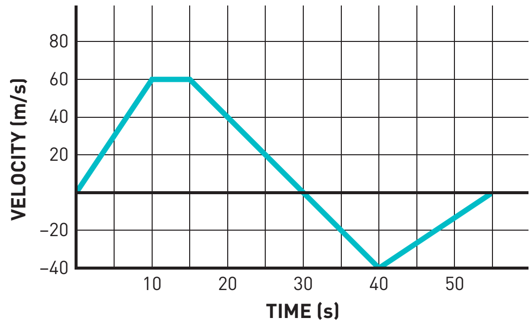

Figure 7.9 This velocity–time graph shows an object with changing velocity. The object increases its velocity from 0 m/s to 60 m/s in the first 10 seconds. It then travels at a constant 60 m/s for 5 seconds before slowing down. At 30 seconds, it has stopped and then starts travelling in the opposite (negative) direction before eventually slowing to a stop. The area under the graph describes the displacement as 1050 metres in the positive direction and 500 metres in the negative direction. The total displacement will be 250 metres in the positive direction.

Graphing speed

It is useful to represent an object's speed graphically. This is called a speed–time graph. In these graphs, speed is plotted on the *y*-axis and time on the *x*-axis. The area under the graph determines the distance travelled in that time.


Figure 7.10 The wind's speed and direction affect the speed of a yacht.

Check your learning 7.2

Remember and understand

1 Is 4 m/s a speed or a velocity? Explain your answer.
2 Use the average velocity triangle to write the three different formulas.
3 What does the gradient of a position–time graph indicate?
4 What does the area under a velocity–time graph indicate?

Apply and analyse

5 What other units do you know that are used to measure speed?
6 Convert 80 km/h to metres per second.
7 An object travels 40 km in 5 hours. What is its average speed?

Evaluate and create

8 Create a story that describes the motion of a person moving according to the graph in Figure 7.11. Describe their displacement from the point of origin.

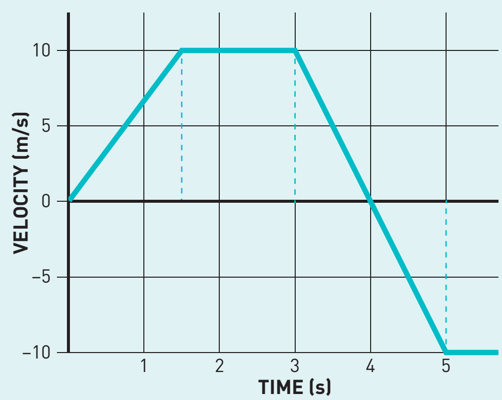

Figure 7.11

7.3 Acceleration is change in velocity over time

Acceleration is the rate at which the speed of an object changes. This is measured in m/s^2 or km/h^2. **Deceleration** is the rate at which the speed slows down. An object travelling at a constant, unchanging speed has an acceleration of zero. Gravity acceleration is the increase in speed of an object as it falls under the sole influence of gravity. This is calculated as 10 m/s^2 (9.8 m/s^2).

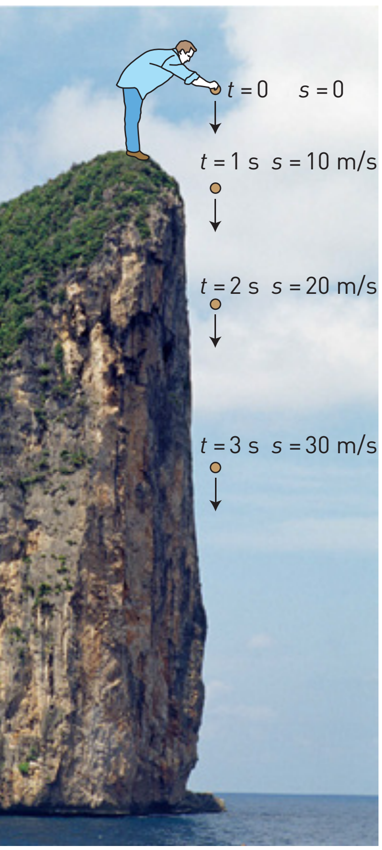

Figure 7.12 Each second, the speed of the falling rock increases by almost 10 m/s, ignoring air resistance. This means the acceleration is 10 m/s^2.

Acceleration

Pressing the accelerator pedal in a car makes the car move forwards and increase in speed. This is the same as saying the car accelerates. Acceleration is the rate of change of speed. The term 'rate' in this case refers to time, so acceleration is the change of speed over time.

Just as the accelerator pedal causes a car to speed up, the brake pedal causes a car to slow down. This is called deceleration (or negative acceleration).

Acceleration is measured in units of metres per second per second (m/s/s) or metres per second squared (m/s^2 or $m\ s^{-2}$) because speed is usually measured in metres per second and time is usually measured in seconds. However, other units for acceleration are possible depending on the units of speed and time.

To understand acceleration, we will only consider objects travelling in one direction in a straight line and under constant acceleration. Consider a falling object, such as the rock shown in Figure 7.12.

When held out to one side and dropped vertically (not thrown), the rock starts at rest and increases in speed as it falls. If it were dropped from high enough, the rock may accelerate to quite a high speed.

After 1 second, it should reach a speed of almost 10 m/s due to gravity (actually, it is 9.8 m/s, which is very close to 10). We say it has accelerated at a rate of 10 metres per second in 1 second or at 10 metres per second per second (written as 10 m/s/s or 10 m/s^2 or 10 $m\ s^{-2}$).

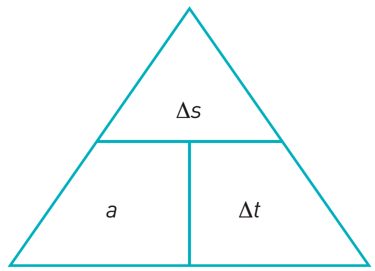

Figure 7.13 The acceleration triangle. Cover the quantity you want to calculate and the other two quantities will form the formula.

After another second at the same rate, the rock would reach a speed of almost 20 m/s.

After 3 seconds, it would reach a speed of almost 30 m/s. Of course, this analysis ignores the effects of air resistance, which would prevent the rock from reaching a speed of 30 m/s after 3 seconds.

The acceleration value of 10 m/s^2 is called **acceleration due to gravity** and is given the special symbol of g. When people skydive, their movement follows the pattern of the rock. They speed up as they fall until they open their parachute and slow down to land.

Calculating acceleration

The formula for calculating acceleration is:

$$a = \frac{\Delta s}{\Delta t}$$

where Δ is the Greek letter 'delta' and means 'change in'. This can also be seen in the acceleration triangle (Figure 7.13).

This can also be written as:

$$a = \frac{v - u}{\Delta t}$$

where v is the final speed and u is the initial, or starting, speed.

CHALLENGE 7.3: MEASURING ACCELERATION BY TIMING OR USING A MOTION SENSOR
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Acceleration is indicated by the gradient of a speed–time graph. The size of the gradient indicates the size of the acceleration. This is shown in Figures 7.14 and 7.15.

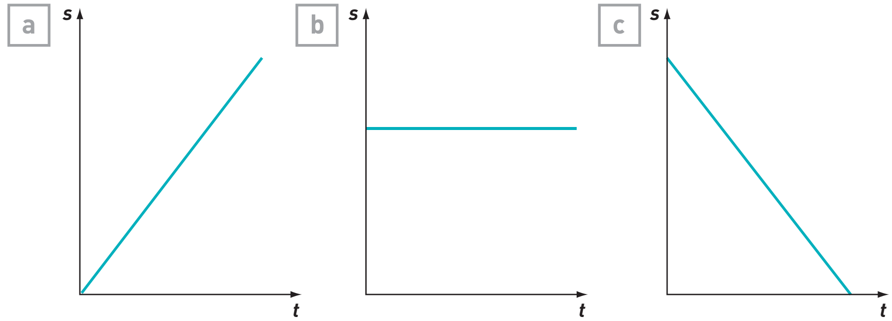

Figure 7.14 Speed–time graphs showing (a) constant positive acceleration (i.e. speeding up), (b) zero acceleration (i.e. constant speed) and (c) negative acceleration (i.e. slowing down or decelerating).

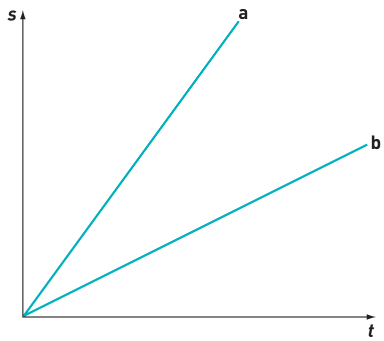

Figure 7.15 Speed–time graphs showing a (a) steep gradient, indicating high acceleration, and (b) gentle gradient, indicating lower acceleration.

Figure 7.16 Timing how long an object takes to fall also provides a practical way to measure distance. You can calculate the depth of a well by dropping a rock into the well and measuring the time required for it to reach the bottom. The depth can be calculated from the formula $d = \frac{1}{2}gt^2$.

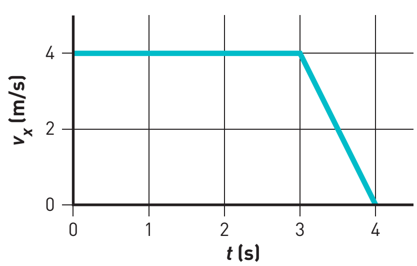

Figure 7.17 The object in this graph is travelling at a constant speed of 4 m/s for the first 3 seconds. Its gradient (and hence its acceleration) is zero. The object then slows down to 0 m/s in the last 1 second. Its acceleration according to the acceleration triangle is −2 m/s^2. The negative number indicates the object has decelerated.

Figure 7.18 Acceleration is the change in speed over time.

Check your learning 7.3

Remember and understand

1. Use the acceleration triangle to write the three different formulas.
2. What is meant by the term 'deceleration'?
3. What is the acceleration of an object if its velocity is constant?

Apply and analyse

4. Describe the motion of an object with the speed–time graph shown in Figure 7.19.

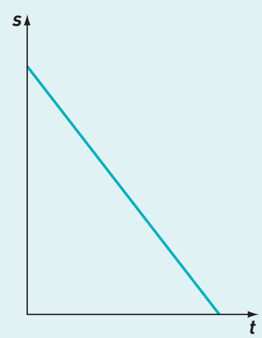

Figure 7.19

5. An object starts from rest and accelerates at a rate of 4 m/s^2. State its speed after each second for 5 seconds.
6. What do accelerating and decelerating objects have in common?

7.4 An object in motion remains in motion until a force acts on it

*

Newton's first law states: 'An object remains at rest or in constant motion in a straight line unless acted on by a net unbalanced force.' The greater the mass of an object, the larger the inertia. This means an object will remain at rest until an outside force acts on it. An object that is moving at a constant speed will not change its speed unless an outside force acts on it.

Sometimes high-speed movement, such as cruising in an aeroplane, is barely noticeable. You may not even feel that you are moving until you look out of the aeroplane's window and see the gradual movement of the land far below you. How can you be going so fast and hardly notice it? A force is a push or a pull acting upon an object as a result of its interaction with another object. Force has the symbol F and is measured in newtons (N). In relation to motion, a force is something that can change an object's motion. A force is not necessarily needed to keep an object moving, but most objects slow down because of the force of friction.

Newton's first law

English scientist Isaac Newton (1642–1727) formulated three laws of motion. In his book the *Philosophiae Naturalis Principia Mathematica*, Newton outlined his laws of motion and his law of universal gravitation. Newton's formulation of his second law of motion and his law of universal gravitation led to nearly all the important advances in physics in the areas of magnetic, electrical and atomic forces for the next 200 years.

The law of inertia

Newton's first law, also known as the law of inertia, has two applications. A stationary object, such as someone sitting on a chair (Figure 7.21), has the force of gravity (its weight force) acting on it to pull it down. It doesn't move because there is another force, equal in magnitude (strength) to the weight force but acting in the opposite direction, pushing up on the object from the surface. Because these two forces are equal in magnitude and opposite in direction, and because they both act on the same object, we say that the object has zero **net force** (or zero resultant force) acting on it. The two forces are balanced. The movement (or lack of movement) will only change if another force is added (such as someone pushing the object). This will cause the forces to become unbalanced.

Figure 7.20 Newton is famous for the story of the apple falling from a tree as he sat in his family orchard. Although the story is fictional, Newton himself is responsible for its creation.

CHALLENGE 7.4A: MAKE AN ACCELEROMETER
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CHALLENGE 7.4B: HOW DO YOU LIKE YOUR EGGS?
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Figure 7.21 Zero net force. This person will not move until a new force acts on them.

> Newton's first law states: 'An object remains at rest or in constant motion in a straight line unless acted on by a net unbalanced force.'

Figure 7.22 Inertia is responsible for vehicles tilting as they turn. Without friction from tyres gripping the road, turning would be nearly impossible.

How Newton's first law applies if the object is already moving

Think of any motion you have experienced today, maybe in a car, bus, train or tram, or even on a bike. In constant motion, you sometimes hardly notice you are moving, but if you stop or start suddenly or turn a sharp corner, your body may move unexpectedly.

If you are a passenger in a car and not wearing a seatbelt and the car comes to a very sudden stop, your body will continue moving forwards. This is due to **inertia**. Inertia is the property of matter that keeps it in its existing state of motion (Figure 7.23). The friction of the brakes stops the car; however, they do not stop you. Your seatbelt is the only thing stopping you moving at 60–100 km/h. If you are not wearing your seatbelt, Newton's first law says that you will keep moving at the same speed, through the windscreen and onto the road. The same thing also happens in a bus, train or tram, especially if you are standing up and not holding on to something. The larger the mass of the object, the more inertia it has and the harder it will be to change its motion.

Figure 7.23 Seatbelts are an inertia device. They are often called 'inertia reel seatbelts'. The aim of a seatbelt is to transfer the force on the car to the passenger wearing the seatbelt so that the person moves with the car. You start moving when the car starts moving and, when wearing your seatbelt, you stop moving when the car stops moving.

Check your learning 7.4

Remember and understand

1. What is meant by the term 'net force'?
2. What happens to a stationary object with zero net force acting on it?
3. What happens to a moving object with zero net force acting on it?
4. What is inertia?

Apply and analyse

5. Give an example of how inertia affects your motion inside a car, bus, tram or train.
6. Why do people lurch backwards in a tram when it starts moving suddenly?

7.5 Force equals mass × acceleration

Newton's second law states: 'The acceleration of an object is directly related to the magnitude and direction of the force acting on the object, and inversely related to the mass of the object: $F = ma$'. This means a heavy object (with a lot of mass) needs a greater force to start moving than a lighter object. **Weight** is a measure of the gravitational force acting on an object. It is measured in newtons (N).

Figure 7.24 Pedalling provides the thrust force when riding a bike.

Force affects acceleration

If an object experiences an unbalanced net force, the object will change its speed, direction or both. A moving object will speed up (accelerate) if the net force acts on it in the same direction as it is moving. A bike will speed up if you pedal harder to increase the driving force (known as thrust) (Figure 7.24).

When the net force acts in the opposite direction, the moving object will slow down (decelerate) and eventually stop. The brake adds a friction force to a moving bike. This means there is a net force in the opposite direction to bike's movement. This net force causes the bike to change its speed. It decelerates or slows down (Figure 7.25).

Force and mass

Would you need more push force to start moving a car or start moving a bike? A car has a greater mass than a bike; therefore, it needs a greater force to change its motion. A bike, with less mass, needs less force to changes its speed.

We can express this relationship in a simple equation:

net force = mass × acceleration

This relationship can also be expressed in a force triangle (Figure 7.26). You need a larger force to accelerate a heavy object from rest than to accelerate a lighter object from rest.

Mass or weight

Newton's second law also connects an object's mass to its weight. We often use the term 'weight' to indicate how much mass something has in kilograms but, strictly speaking, in physics weight is a force not a mass. Weight is the force of gravity acting on an object. Because it is a force, weight is measured in newtons. For example, gravity on the Moon is approximately 1.6 m/s^2 and on the Earth is 10 m/s^2. This means an object with a mass of 100 kg would have a weight of 160 N (100 kg × 1.6 m/s^2) on the Moon, and 1000 N (100 kg × 10 m/s^2) on the Earth.

An object on the Moon will have less weight (N) but the same mass (kg).

Figure 7.25 Braking provides a drag force.

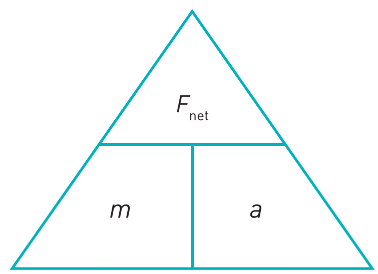

Figure 7.26 The net force equation can be written as a triangle. Cover the quantity you want to calculate and the other two quantities will form the formula.

EXPERIMENT 7.5A: RESULTANT FORCES
GO TO PAGE 239

EXPERIMENT 7.5B: ACCELERATING MASSES
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Figure 7.27 Cars can accelerate faster than trucks mainly because of their smaller mass. Cars will also decelerate faster. This means a truck will take longer to stop than a car.

Calculating acceleration

When mass is in kilograms (kg) and the acceleration is in metres per second squared (m/s^2), the net force will be in newtons (N). Acceleration and net force are both vectors and always act in the same direction:

$$\text{net force} = \text{mass} \times \text{acceleration}$$
$$F_{net} = m \times a$$

Often, you need to consider all the individual forces acting on an object in order to work out the net force.

Consider the cyclist and bike with a mass of 90 kg shown in Figure 7.29. The forwards-acting thrust force is 400 N and the total drag force from air resistance and friction is 300 N backwards. As a result, the net force is 100 N forwards. This would produce an acceleration of (100 N ÷ 90 kg) 1.11 m/s^2. The cyclist would increase his speed by 1 m/s every second.

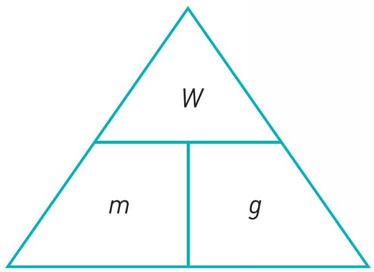

Figure 7.28 Weight is the force of gravity acting on an object's mass. Weight (force) = mass × acceleration due to gravity.

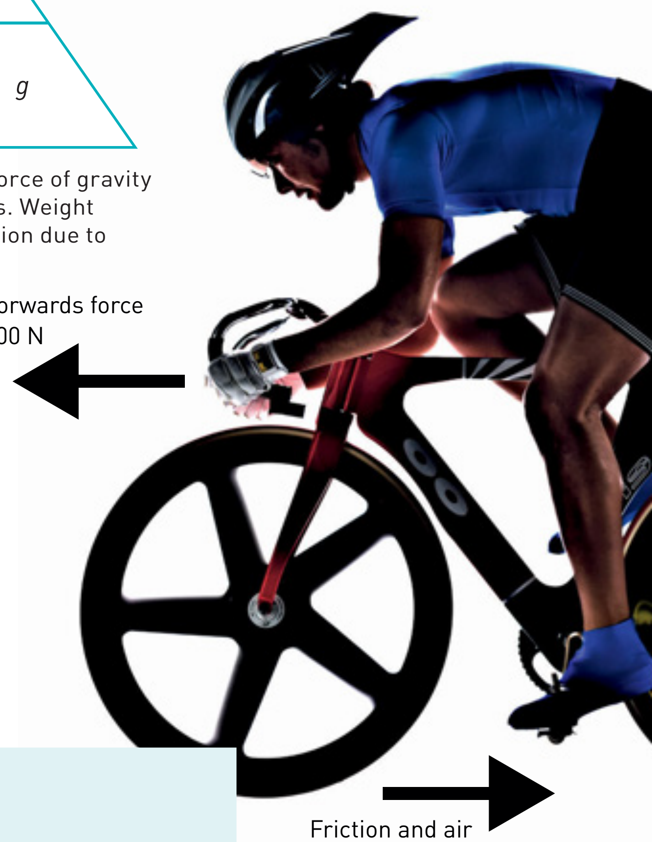

Figure 7.29 Various forces act on a cyclist.

Check your learning 7.5

Remember and understand

1 What is meant by the term 'weight force'?
2 What happens to a moving object if it is acted on by a net force in the same direction as its motion?
3 What happens to a moving object if it is acted on by a net force in the opposite direction to its motion?

Apply and analyse

4 How does the acceleration of a bus full of passengers compare with that of an empty bus for the same net force?
5 Why does a bike slow down on a level road when the rider stops pedalling?
6 A net force causes a mass of 10 kg to accelerate at 2 m/s^2. What is the magnitude of the net force?

7.6 Each action has an equal and opposite reaction

Newton's third law states: 'For every action, there is an equal and opposite reaction on the other object.' Action–reaction pairs always act on different objects and therefore cannot cancel each other out. This reaction is used to propel rockets through space, car wheels along roads and jet planes through the air.

Newton's third law

If you blow up a balloon and let it go, it flies around the room like a crazy rocket. As the air is forced backwards out of the opening, the balloon is propelled forwards by another force. These two forces are equal in magnitude and opposite in direction. They form an action–reaction pair and obey Newton's third law. The action force in this example is the rubber of the balloon contracting and pushing the air backwards. The **reaction force** is the force of the air rushing out, pushing forwards on the balloon.

Action and reaction pairs always act on different objects. When you lean against a wall, you exert a force on the wall. The wall exerts a force on you (you can feel it pushing against your hands). Because these two forces act on different objects (you and the wall), they cannot be described as being balanced or cancelling each other out. A net force is balanced or zero when all the forces acting on a single object are equal and opposite. Action–reaction pairs can never cancel under any circumstances because the two forces act on different objects.

When an insect hits a car windscreen, the action on the windscreen is equal and opposite to the reaction on the insect. The insect is much smaller, so its mass is less able to withstand the deceleration.

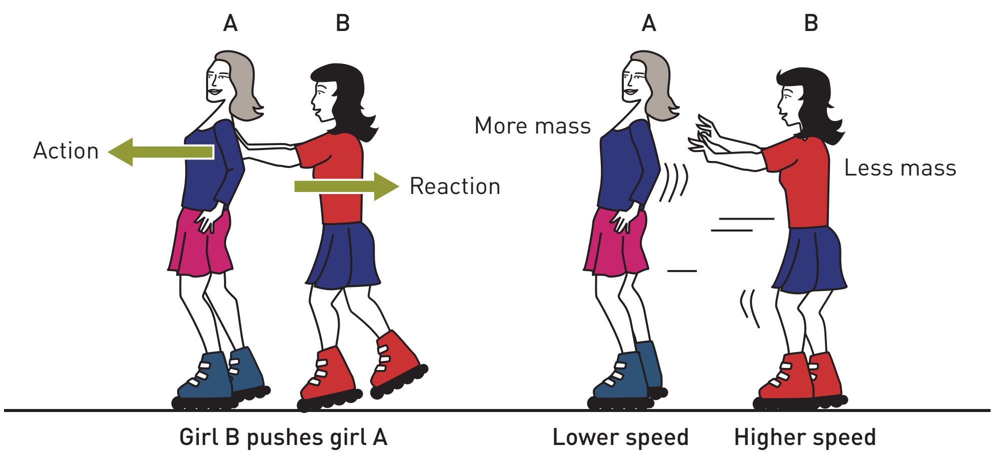

Figure 7.30 Different masses have different accelerations and reach different speeds even though the forces shown by the arrows are equal in size.

EXPERIMENT 7.6: WHAT IF FORCES WERE CHANGED ON NEWTON'S ROCKET?
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The motion of a girl on roller blades pushing off from another girl (Figure 7.30) works in a similar manner. The two girls experience an identical but opposite force. Newton's second law tells us that smaller masses have higher accelerations for the same force. So, if the two girls have different masses, the lighter girl will have a higher acceleration and will reach a higher speed while the force is acting.

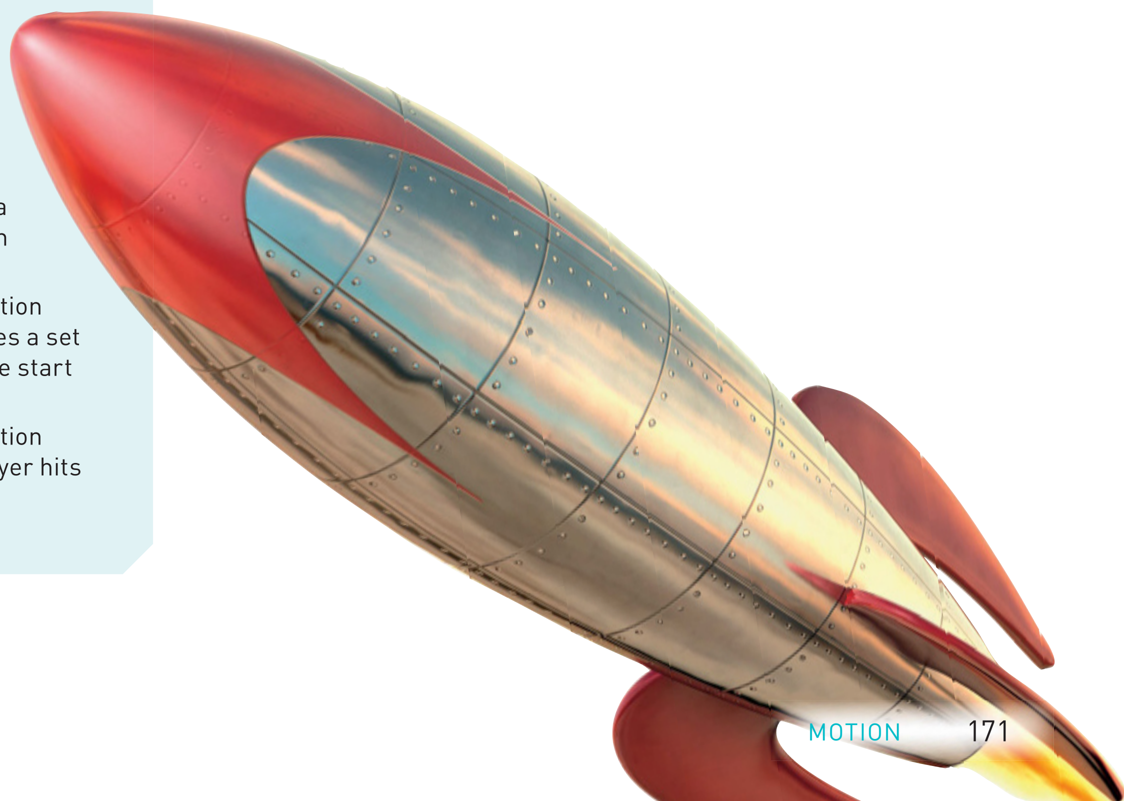
Rockets, missiles and jet engines work on the action–reaction principle. For many years, it was thought that rocket ships would not be able to accelerate in space as there was very little air for the rocket to push against. However, rocket fuel undergoes a combustion reaction, producing exhaust gases. These gases are forced out of the back of the rocket, producing an opposite and equal reaction on the rocket. This moves the rocket forwards (Figure 7.31).

Figure 7.31 The rocket pushes exhaust gases back. As a result the rocket is propelled forwards.

Check your learning 7.6

Apply and analyse

1. A person pushes forwards on an object with a force of 30 N. What reaction force acts on the person?
2. A boy of weight 500 N sits on a chair. What reaction force acts on the boy?
3. In space, an astronaut pushes on another astronaut with a force of 80 N. What is the reaction force in this case? Why might the second astronaut have a higher acceleration than the first astronaut?
4. Identify the action–reaction pair when a sprinter uses a set of starting blocks for the start of a sprint race.
5. Identify the action–reaction pair when a softball player hits a home run.



7.7 Momentum is conserved in a collision

Momentum is the product of the mass and velocity of an object.
The **law of conservation of momentum** states that in an isolated system, the total momentum does not change during a collision.

Modern cars are fitted with many safety devices, but arguably the most important are the airbags that deploy in the event of a crash. Sensors inside the car act like mini accelerometers and when they detect rapid deceleration, the airbag system is triggered. These innovations are the result of the scientific understanding of movement and, more importantly, collisions. All collisions involve force, mass and momentum, and these quantities link together to provide the laws of motion as we know them.

Momentum

All moving objects possess momentum. Momentum is not a form of energy, although the faster an object travels, the more momentum it has. A cricket ball is harder to stop than a tennis ball travelling at the same speed. This is because the cricket ball has more mass than the tennis ball. So, objects with more mass have more momentum. The formula for calculating momentum is:

$$\text{momentum} = \text{mass} \times \text{velocity}$$
$$p = m \times v$$

where mass is in kilograms (kg), velocity is in metres per second (m/s), and momentum is in kilogram metres per second (kg m/s).

This relationship can also be expressed in a momentum triangle (Figure 7.32).

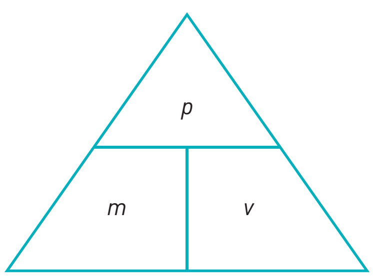


Figure 7.32 The momentum triangle. Cover the quantity you want to calculate and the other two quantities will form the formula.

In an isolated system, momentum is passed from one object to another in a collision but the total momentum of the system is conserved, or remains constant. This means the initial momentum before the crash is equal to the final momentum of all objects after the crash. This is known as the law of conservation of momentum and is similar to the law of conservation of energy.

The isolated system referred to in the law of conservation of momentum is the set of objects that interact in the collision. In the case of Newton's cradle (Figure 7.33), this would be the two spheres that collide. Because velocity is a vector, momentum is also a vector quantity. We can indicate opposite directions in a collision as positive and negative.

To stop a moving object, a force is used to reduce its momentum. In a car crash, a large force stops the car in a short time. If the brakes are applied slowly, a smaller force is used over a long time. In both examples, the force exerted on the car is related to the initial momentum of the car. The average force involved in a collision equals the change in momentum divided by the time it takes for the collision to occur.

Figure 7.33 Newton's cradle clearly demonstrates how momentum can be passed from one object to another.

EXPERIMENT 7.7: COLLIDING TROLLEYS
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Figure 7.35 represents a relatively safe head-on collision between two dodgem cars. If we take movement to the right as positive, the initial momentum (p) of the green car is given by mass (m) multiplied by initial velocity (u):

$$p = m \times u$$
$$= 701 \times 0.8$$
$$= 561 \text{ kg m/s}$$

The initial momentum of the blue car is:

$$p = m \times u$$
$$= 660 \times 0.7$$
$$= 462 \text{ kg m/s}$$

Because the cars are moving in opposite directions, the vector quantity of momentum must reflect this. Movement to the right becomes positive and movement to the left becomes negative. Therefore, the total initial momentum of the two cars is 561 – 462 = 99 kg m/s to the right.

The final momentum of the blue car is:

$$p = m \times v$$
$$= 660 \times 0.15$$
$$= 99 \text{ kg m/s to the right}$$

The final momentum of the green car is zero because it stops. Therefore, the total final momentum is 99 kg m/s to the right.

This shows that there is no change in the total momentum for the isolated system of the two dodgem cars and their drivers during the collision.

Figure 7.34 The rapid change in momentum as a result of a car crash can be seen in the crushed panels of this car.

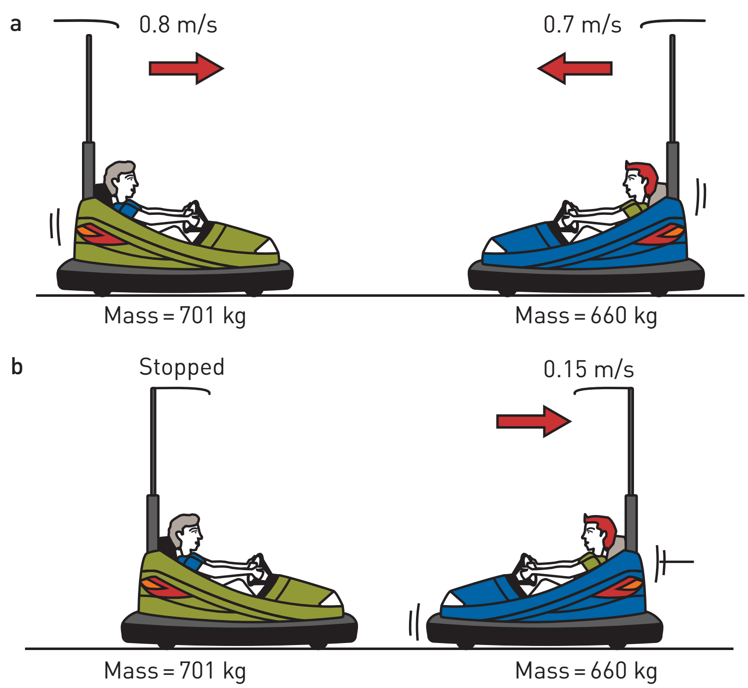


Figure 7.35 (a) Before the collision. (b) After the collision.

Check your learning 7.7

Remember and understand

1 What are the units of momentum?
2 What is the law of conservation of momentum?

Apply and analyse

3 Use the momentum triangle to write the three different formulas.
4 Is it harder to stop a cricket ball or a tennis ball travelling at the same velocity? Why?
5 Is it harder to stop a fast-moving tennis ball or a slow-moving tennis ball? Why?
6 If a 600 kg golf cart is travelling at 0.8 m/s, what is its momentum?

Remember and understand

1 Match each word in the left column with its correct meaning in the right column.

vector	speed of an object at a moment in time
average velocity	rate at which an object's speed changes
average speed	slope of a graph
acceleration	graph where speed is plotted against time
distance	quantity that has magnitude and direction
instantaneous speed	calculated by dividing distance by time
gradient	how far an object has travelled
speed–time graph	calculated by dividing displacement by time

2 What happens to an object's speed if it travels with zero acceleration?

3 What happens to an object's speed if it travels with constant deceleration?

4 Which of the following are true and which are false?

- A A force will only change an object's speed.
- B A force is always needed to keep an object in motion.
- C The quantity of weight is measured in kilograms.
- D A force has magnitude and direction, making it a vector.
- E Acceleration increases if the net force increases and the mass is kept constant.
- F A stationary object can have several forces acting on it.
- G Mass is a measure of how much space an object occupies.

Apply and analyse

6 A car is driven along a straight road. Starting from rest, it takes 10 seconds of steady acceleration for the car to reach a speed of 20 m/s. The car then cruises for 60 seconds at 20 m/s, before slowing down to a halt over a period of 30 seconds.

- a What is the maximum speed of the car in km/h?
- b Plot a speed–time graph for the car using SI units.
- c Use the graph to calculate the distance moved in metres and then in kilometres.

7 Figure 7.36 shows a rear-end car crash between two dodgem cars. Before the collision, the green car had a velocity of 2.2 m/s and a mass of 140 kg. The blue car had a velocity of 1.7 m/s and a mass of 160 kg.

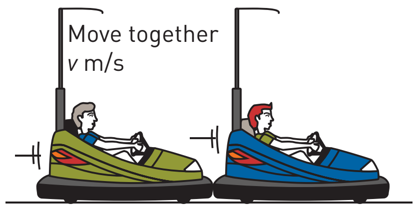


Figure 7.36

- a Calculate the momentum of each of the two dodgem cars before the collision.
- b Calculate the total momentum of the two dodgem cars before the collision.
- c Calculate the velocity of the two dodgem cars after the collision.

Evaluate and create

8 On a wet Monday morning, a school bus that has to travel 24 km leaves its starting place at 7.35 am and only manages an average speed of 36 km/h on its trip to school. There is a clear section on the highway when the bus has a speed of 74 km/h. The bus then does various runs during the day and arrives back at the school in time to depart at 3.45 pm. It arrived back exactly at its starting place at 4.25 pm.

- a What is the displacement of the bus between 7.35 am and 4.25 pm?
- b At what time will the bus arrive at school?
- c What is the average speed of the bus?
- d The bus's average speed on the way to school is 36 km/h, but on one stretch the bus moves at 74 km/h. Use this data to explain the difference between 'average speed' and 'instantaneous speed'.

9 Renee catches a softball.

   a What is the action?
   b What does the action do?
   c What is the reaction?
   d What does the reaction do?

10 What mass object would accelerate at 3.5 m/s^2 under the influence of a net force of 70 N?

11 Calculate the acceleration of a 500 g object under the influence of a net force of 500 N.

Critical and creative thinking

12 Some objects or devices require high accelerations that are many times greater than 9.8 m/s^2, the acceleration due to gravity. Think of an object or device in this category. Does it have an engine or some other propulsion mechanism? What fuel does it use? How does this enable it to achieve such a high acceleration?

13 Design a poster on motion that explains each of Newton's three laws. Give a detailed example that illustrates each law and is not already mentioned in the text.

14 Motion is the result of forces acting in different directions. Describe the forces you believe to be acting when an object is stationary, moving, accelerating and changing direction. Which forces are always acting?

15 Identify the safety features of the car shown in Figure 7.37. Which safety features are missing?

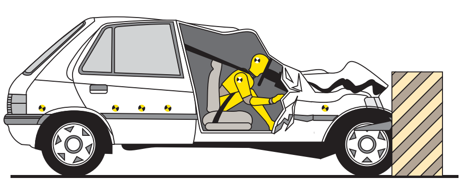


Figure 7.37

Research

16 Choose one of the following topics for a research project. Some questions have been included to help you begin your research. Present your report in a format of your own choosing.

> **Car safety features**
>
> Modern cars may be equipped with electronic stability control (ESC), anti-lock braking systems (ABS), electronic brake distribution (EBD), RVC tachometers, traction control systems (TCS) and park assist. Find out about each of these and other car safety features under development. How do they contribute to the safety of passengers?

> ***g*-forces**
>
> Aircraft pilots flying military jets and those in the Red Bull Air Race commonly experience *g*-forces. A ride at Luna Park is called '*g*-force'. When do pilots experience *g*-forces? What is the human tolerance of *g*-forces and what effect do they have on the body? What other examples are there of theme park rides or situations where people experience *g*-forces?

> **Movement of aircraft**
>
> Aircraft are the second fastest mode of transport, after rockets. Find out about the different types of aircraft and how they move. Explain the interactions between lift, weight, thrust and drag in aircraft movement. What speeds can aircraft attain?

KEY WORDS

7

acceleration
rate of change of velocity; rate of change of speed if the motion is in a constant direction

acceleration due to gravity
the acceleration of an object due to a planet's gravitational field; on Earth, $g = 9.8$ or 10 m/s^2

deceleration
slowing down; also known as negative acceleration

inertia
the tendency of an object to resist changes in its motion while either at rest or in constant motion

law of conservation of momentum
a scientific law that states the total momentum in an isolated system does not change during a collision

magnitude
the size or extent of something

momentum
the product of an object's mass and its velocity

net force
the vector sum of all the forces acting on an object; also known as resultant force

Newton's first law
Newton's first law of motion states that an object will remain at rest and will not change its speed or direction, unless it is acted upon by an outside, unbalanced force

Newton's second law
Newton's second law of motion describes how the mass of an object affects the way it moves when acted upon by one or more forces; It is often expressed as $F = ma$

Newton's third law
Newton's third law of motion states that for every action, there is an equal and opposite reaction

reaction force
the force acting in the opposite direction

scalar quantity
a quantity that only has size, for example, speed and distance

speed
the distance travelled per unit of time

vector quantity
a quantity that has size and direction (e.g. velocity, displacement)

velocity
the vector quantity that measures speed in a particular direction

ENERGY 8

8.1 Work occurs when an object is moved or rearranged. Energy can be calculated

8.2 Energy is always conserved

8.3 Thermodynamic systems that are connected reach thermal equilibrium

8.4 Conduction transfers kinetic energy between particles. Convection causes the particles to move

8.5 Thermodynamics can be described by laws

What if?

What you need:

ramp, toy car, small weights

What to do:

1. Set up the ramp so that one end is 20 cm above the ground.
2. Place the toy car at the top of the ramp and release it without pushing.
3. Measure how far the car rolls beyond the bottom of the ramp.

What if?

» What if the ramp was lifted higher? What if weight was added to the toy car?

8.1 Work occurs when an object is moved or rearranged. Energy can be calculated

*

Work is a measure of how much energy has been transferred into moving or rearranging an object. If an object is not moved by a force, then no work has been done. **Kinetic energy** is a measure of how much movement energy an object has. This is affected by the object's speed and mass. **Gravitational potential energy** is a measure of how much energy is stored in an object because of its height above the ground. This is also affected by the mass of the object. **Elastic potential energy** is the energy stored in an object because of its deformation.

Work

In a car crash, the crumple zones of a car are designed to absorb energy by crumpling. In scientific terms, we say that work is done. Work happens whenever things are moved or rearranged by a force. The larger the force acting, the greater the work done. The longer the distance over which the force acts, the greater the work done. Hence, the amount of work done depends on the size of the force and the distance (see Figure 8.1):

$$\text{work} = \text{force applied} \times \text{distance moved}$$
$$W = F \times d$$

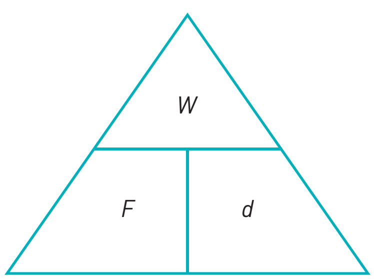


Figure 8.1 The work triangle. Cover the quantity you want to calculate and the other two quantities will form the formula.

Work and energy are scalar quantities, so no direction is needed. If you apply a force to an object and it doesn't move, no work is done.

When a force is applied to an object and it moves, the object will gain (kinetic) energy. Therefore, work is a measure of how much energy has been transferred from one object to another.

If the force is measured in newtons (N) and the distance is measured in metres (m), the work done will be in units called joules (J). For example, when 1 N of force is used to move an object 1 m, the amount of work done is 1 J.

Kinetic energy

Motion is needed for cars to crash. The energy of motion is called kinetic energy (KE). The larger the mass of an object, the greater its kinetic energy. Also the faster an object is travelling, the greater its kinetic energy. Kinetic energy depends on the speed of the object, squared:

$$\text{kinetic energy} = \frac{1}{2} \times \text{mass} \times \text{speed squared}$$
$$\text{KE} = \frac{1}{2} \times m \times v^2$$

EXPERIMENT 8.1: WHAT IF AN ELASTIC BAND WAS STRETCHED FURTHER?
GO TO PAGE 243

Figure 8.2 The gravitational potential energy of a roller coaster is transformed into kinetic energy.

Figure 8.3 When the ball hits the ground, the ball becomes deformed transforming the kinetic energy into elastic potential energy.

where mass is in kilograms (kg), speed is in metres per second (m/s), and KE is in joules (J).

When a car driver presses on the brake pedal, all the kinetic energy of the car is dissipated (released) by the brakes as heat. In a car crash, the kinetic energy is dissipated much quicker, mainly as work as the car crumples and deforms.

Gravitational potential energy

If we lift an object to a height, we use energy and the object gains gravitational potential energy (GPE). The larger the mass and the height, the more energy we use and the more gravitational potential energy the object gains:

gravitational potential energy = mass × gravity × height

$$GPE = m \times g \times h$$

where mass is in kilograms (kg), height is in metres (m) and GPE is in joules (J). Gravity has its normal value of 9.8 or 10 m/s^2.

Elastic potential energy

Bouncing a ball is a collision with the ground (Figure 8.3). It involves gravitational potential energy, kinetic energy and elastic potential energy (EPE), plus usually a small amount of sound and heat energy. As the ball hits the ground, it compresses and stores elastic energy. This energy transforms to kinetic energy when the ball expands again and is propelled upwards into the air. A 'flat' ball cannot transform this energy, so it doesn't bounce.

elastic potential energy = $\frac{1}{2}$ × spring constant × extension (or compression) squared

$$EPE = \frac{1}{2} \times k \times x^2$$

where k is the spring constant (a measure of how 'stiff' the object is) in newtons per metre (N/m), x is the extension (or compression) in metres (m) and EPE is in joules (J).

Check your learning 8.1

Remember and understand

1 When is the scientific term 'work' done?

2 Use the work triangle to write the three different formulas.

Apply and analyse

3 How much work is done if a force of 200 N moves an object 6 m?

4 How much work is done if a force of 400 N is applied to a heavy object and it doesn't move?

5 How is the kinetic energy of an object affected if its mass decreases and the other variables remain constant?

6 How is the gravitational potential energy of an object affected if its height increases and the other variables remain constant?

7 How is the elastic potential energy of an object affected if its stiffness increases and the other variables remain constant?

8.2 Energy is always conserved

The **law of conservation of energy** states that energy cannot be created or destroyed. This means that any energy that is transferred into an object can be released. Waste energy in the form of heat and sound energy can be formed in the transfer. The efficiency of the energy transformation can be calculated.

Whenever energy is converted from one form into other forms, the total energy of the system remains constant because extra energy cannot be created, nor can energy be destroyed. This is called the law of conservation of energy.

This is most obvious when you jump on a trampoline (Figure 8.4). When you are high above the trampoline, you have gravitational potential energy. As you start to move down, you gain velocity and therefore kinetic energy. The closer to the ground you get, the less gravitational potential energy and the more kinetic energy you have. Just before you touch the trampoline, you are travelling at your fastest velocity. As soon as you start stretching the trampoline, you start slowing down. Your kinetic energy is being transformed into elastic potential energy in the trampoline. Eventually you will stop moving and the trampoline will be completely stretched. All the kinetic energy has been transformed into elastic potential energy. Eventually the elastic potential energy is transformed back into kinetic energy and gravitational potential energy, and you will start moving up into the air again.

Figure 8.4 Although the individual energy quantities vary between the highest point (a), through position (b) to the lowest position (c), the total energy of the 'system' remains constant.

CHALLENGE 8.2: CONSERVATION IN ACTION
GO TO PAGE 244

Theoretically, the total amount of energy is constant when you jump on a trampoline. In reality, there may be a small amount of heat energy produced as you fall due to air resistance. This 'loss' of energy is not really a loss, just a transfer of energy to a non-usable form. The efficiency can be calculated by comparing how high above the trampoline you started, and the height you reached on the rebound (usable final energy):

energy efficiency = amount of usable final energy ÷ amount of initial energy × 100

Any difference in height is a result of heat or sound energy.

Pendulums

A pendulum is a mass that is attached by a string to a pivot point. When the mass is drawn upwards, it gains gravitational potential energy. When the mass is let go, the force of gravity pulls it down to its original position, converting the gravitational potential energy to kinetic energy. The momentum built up by the moving mass causes the mass to then swing in the opposite direction. This means all the kinetic energy is converted back into gravitational potential energy. However, pendulums (such as a swing in a playground (Figure 8.5)) are a good example of how energy efficiency can be measured. Some kinetic energy is always lost as waste energy when it is transformed to heat (and sometimes sound). This is evident when the pendulum does not quite reach the height at which it started.

Figure 8.5 A swing will not reach its original height because it 'loses' energy as heat and sound energy.

Check your learning 8.2

Remember and understand

1 Explain the law of conservation of energy using an example of your own.
2 What is waste energy?

Apply and analyse

3 Some people claim energy is lost. Do you agree? Justify your answer using the law of conservation of energy.
4 Describe the conservation of energy that occurs when you use a slinky.
5 The following statements are incorrect. Rewrite them to make them correct.
   a The energy efficiency of all systems is always 100%.
   b The law of conservation of energy doesn't always apply.
   c Pendulums always return to their original height.
   d A roller coaster rolling down a ramp will stop at the bottom of the ramp.

8.3 Thermodynamic systems that are connected reach thermal equilibrium

*

A **thermodynamic system** is a quantity of matter that has a boundary around it. This system can exchange energy with its surroundings. Energy is transferred from a hot system to a cold system by the particles. This process of energy transfer is called heat; heat is energy in transit. The energy generated by the motion of particles is called thermal energy. Temperature is a measure of the average thermal energy of all the particles in a thermodynamic system. Thermal energy can be transferred from hotter thermodynamic systems to cooler thermodynamic systems. This will continue to happen until both objects are the same temperature and thermal equilibrium is reached.

Thermodynamics

Thermodynamics is the study of how heat, or thermal energy, can be transferred between objects, or transformed into other forms of energy. Because energy cannot be created or destroyed, when a hot object cools down, the thermal energy is transferred from the molecules in the hot object to the surrounding air particles. Alternatively, the energy can be transformed into another form of energy.

Thermodynamic systems

If you put a hot brick into a bucket of cold water, the water will gradually heat up, and the brick will gradually cool down. This is because the thermal energy is transferred from the brick to the water. The brick and the bucket of water can each be described as a thermodynamic system.

A thermodynamic system is a system that connects or interacts with other systems. It is defined as a quantity of matter that has a boundary around it. When two thermodynamic systems are connected, an exchange of thermal energy may occur.

Thermal energy is the total energy of all the moving or vibrating particles in an object. Substances such as bricks, water and air are made of particles. The particles in solid objects such as the brick cannot move around very much. Instead, they vibrate against and transfer thermal energy to each other. The particles in solids have very little kinetic energy owing to their lack of freedom of movement. The particles in water have more kinetic energy than the brick. These molecules can move more freely around each other, while remaining in contact. The molecules in air have the most kinetic energy. They are free to move in any direction, resulting in many collisions (Figure 8.6).

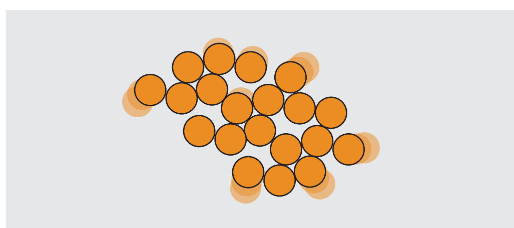


Figure 8.6 Particles move further apart and faster when they are heated.

The particles in a thermodynamic system move around at different speeds, depending on their temperature. When a system is hot, its molecules move faster than when it is cold (Figure 8.7). Because the molecules are moving

EXPERIMENT 8.3: THERMAL ENERGY VERSUS TEMPERATURE
GO TO PAGE 245

faster, they collide with more energy and push each other further apart to occupy more space, or increase the pressure if the gas is contained in a fixed volume. We say the gas expands – the particles don't get bigger, but the space between the particles does increase.

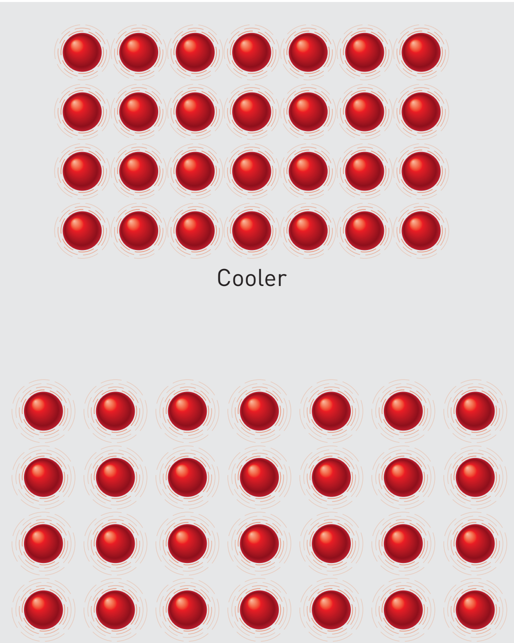


Figure 8.7 Particles in a thermodynamic system vibrate faster when they are heated.

Insulation

If a thermodynamic system is perfectly insulated from its surroundings, it is described as a **closed system**. Because energy cannot be created or destroyed, the thermal energy, and therefore temperature, of the system will not change: the vibration of the atoms or the movement of the molecules would never stop. However, every hot object eventually transfers some of its thermal energy to its surroundings and cools until both systems reach the same temperature. The only way to avoid this is to constantly transfer more thermal energy from somewhere else to replace the 'lost' thermal energy.

Thermal equilibrium

Thermal energy is different from the temperature of an object. Temperature is the average kinetic energy of the particles moving in the system, while thermal energy is the total energy of all the moving particles.

When two objects or systems are at different temperatures, there is a temperature gradient. The thermal energy of the hot object will be transferred down the temperature gradient to the cooler object. Examples include a hot brick in a bucket of cold water (Figure 8.8) or you sitting in a warm bath. The thermal energy of the bath water will be transferred to you. You become warmer, and the bath water becomes cooler. Eventually, you and the bath water will reach the same temperature, and the transfer of energy will stop.

When the thermal energy of an object is the same as that of its surroundings, thermal equilibrium has been achieved.

When you use a thermometer to measure temperature, such as that of the air in the room, the thermometer is actually measuring its own temperature. When the thermometer is in thermal equilibrium with the air around it, the temperature that it measures will be the temperature of the surrounding air. To get an accurate measurement, you have to allow time for the thermometer to reach thermal equilibrium with the object being measured. You are waiting for the transfer of thermal energy from the hotter object: either the thermometer or the object it is measuring.

Figure 8.8 A hot brick will pass on thermal energy to the water until they reach thermal equilibrium.

Check your learning 8.3

Remember and understand

1. What happens to molecules when they are heated?
2. Which has the higher temperature: a cup of water at 70°C or a bucket of water at 70°C? Which has more thermal energy?
3. Describe what happens to a hot cup of tea as it reaches thermal equilibrium.

Apply and analyse

4. Describe something you can do at home that uses objects at different temperatures and creates thermal equilibrium.
5. Some ice at 0°C is added to a bucket of water at 20°C. The resulting combination reaches an equilibrium temperature of 19°C. Why didn't it reach 10°C?

8.4 Conduction transfers kinetic energy between particles. Convection causes the particles to move

Thermal energy moves spontaneously from a hotter thermodynamic system to a cooler thermodynamic system. This energy transfer is called heating, even though one substance is being cooled. Heat transfer can occur when one system passes its kinetic energy on to another (**conduction**) or when the hot, highly kinetic particles themselves move (**convection**).

Heating by conduction

Heat transfer by conduction is the transfer of thermal energy from matter that is warmer to matter that is cooler. This happens spontaneously when two thermodynamic systems make direct contact with each other and reach thermal equilibrium.

Consider what happens when we heat a saucepan of water on a gas burner.

1. When the gas burns, thermal energy is released.
2. The hot molecules in the gas flame move quickly and occasionally bump into atoms of the relatively cold metal of the saucepan.
3. Kinetic energy passes to the slowly vibrating atoms in the saucepan so that they vibrate faster.
4. The quickly vibrating atoms in the saucepan bump into other nearby metal atoms, transferring thermal energy to them. This heats the saucepan.
5. When the saucepan heats up, energy is transferred to the water inside it.

Although the thermal energy moves through the metal of the saucepan and into the water, the atoms in the metal do not change their positions – metal atoms do not move into the water.

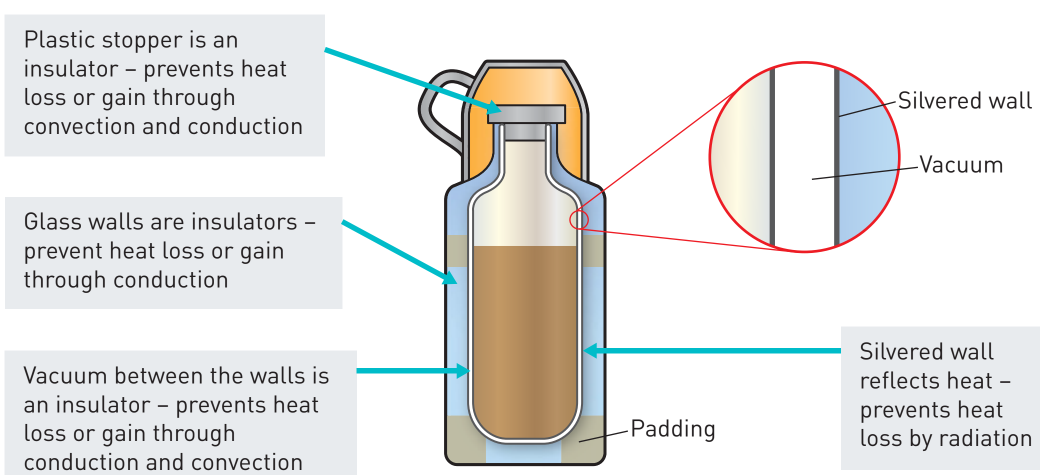


Figure 8.9 Vacuum flasks are designed to keep hot substances hot and cold substances cold. To do this they must prevent the contents from losing or gaining heat – conduction, and convection must be minimised. Careful choice of materials and clever design make this possible.

EXPERIMENT 8.4: INVESTIGATING HEATING BY CONVECTION
GO TO PAGE 245.

Conductors and insulators

A thermal conductor is any material that allows thermal energy to flow easily through it. All metals are conductors, although some are better conductors than others. Thermal insulators are materials that slow down the transfer of thermal energy because the molecules don't allow the energy to flow very easily. Insulators such as socks, jumpers and blankets keep us warm in cold weather. They make it difficult for our 'body heat' to escape, insulating us against the cold. Insulation in the roof and walls of a house prevents heat gain and loss during summer and winter. So insulation can hold thermal energy in or keep it out.

Heating by convection

In liquid and gas thermodynamic systems, thermal energy moves by convection. Tiny currents, called **convection currents**, carry the thermal energy. A convection current is a movement within a liquid or gas.

When we heat a saucepan of water on a gas flame, the following occur.

1 Thermal energy transfers by conduction from the hot saucepan to the water molecules that are touching the metal.
2 The water molecules in contact with the metal gain kinetic energy and move faster than the molecules in the water above. Because they are moving faster, they take up more space. They are less dense.
3 As a result, the heated water molecules near the bottom of the saucepan begin to rise, leaving room for the cooler water molecules to take their place.
4 The heated water molecules take thermal energy with them as they move.

We heat liquids from below because most of the energy transfer in liquids (and gases) takes place by convection. This process happens in the air. The Sun heats the ground and the warmed ground then heats the air next to it by conduction. The warmed air, being less dense than the cooler air above, rises, taking the thermal energy with it. This distributes the energy through a much deeper layer of air than could occur just by conduction from the ground. This process of convection in the air is what drives the weather on Earth.

Figure 8.10 Convection currents are created in a saucepan of water when it is heated. The heated water molecules (shown in red) rise while the cooler ones (shown in blue) sink.

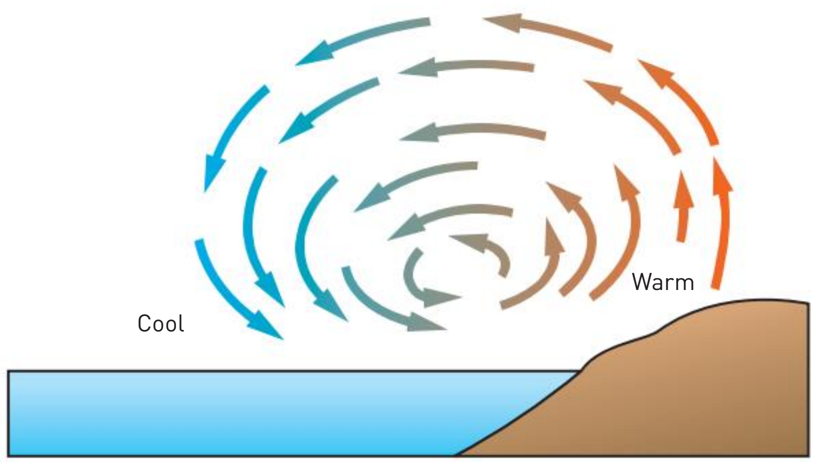


Figure 8.11 The circulation of air in a sea breeze.

Check your learning 8.4

Remember and understand

1 Think of a situation where you can see expansion due to heating of a solid, liquid or gas. Explain what the molecules or atoms are doing to cause the expansion.
2 Give two examples of situations where thermal energy is transferred by:
   a conduction
   b convection.
3 Give some examples of where good thermal insulators and conductors are needed in everyday life. Which materials are used in each situation?
4 Explain why scientists are happy to refer to thermal energy transfer as heating, even though in every case something is being cooled.

Apply and analyse

5 Modern saucepans have a copper bottom, steel sides, a plastic handle and a glass lid. Why is each of these materials used for a particular part of each saucepan?

8.5 Thermodynamics can be described by laws

The total amount of energy in a system is the sum of its kinetic energy, gravitational potential energy and internal energy. Internal energy is the energy of, and between the particles in the thermodynamic system. The **first law of thermodynamics** describes how the internal energy of a system can increase if heat is added and decrease if work is done by the system. As energy is transformed from one form to another, thermal energy is formed. This thermal energy increases the amount of **entropy** in a system. This is the **second law of thermodynamics**.

Total energy of a system

The total energy of an object, or thermodynamic system, can be calculated by adding the kinetic energy of the system, the gravitational potential energy of the system and the internal energy of the system. Consider the energy of a light bulb (Figure 8.12). A light bulb hanging from the ceiling has gravitational potential energy. If a breeze is blowing in the room, the light bulb may swing slightly. This adds kinetic energy to the light bulb. There is also the energy inside the light bulb – the light bulb's internal energy.

Figure 8.12 The total amount of energy in a light bulb is the sum of its kinetic energy, gravitational potential energy and internal energy.

Internal energy

The internal energy of a system can be calculated by adding the kinetic energy of the molecules (their thermal energy) and the energy that attracts the atoms to each other in the molecule (their bonds). Because energy cannot be created or destroyed, the internal energy of any system will remain the same until energy is transferred in or out. An example of this is sealed thermos flask that contains hot water. Because heat cannot be transferred in or out of the system, the internal energy will be conserved. This is known as a closed system, from which no energy is being transferred in or out.

Closed (or isolated) systems do not usually exist in the real world. Because thermal energy is always transferred

Figure 8.13 In an open thermodynamic system, energy can be transferred to the surroundings. The internal energy of this saucepan of boiling water needs to be replaced because energy is lost with the escaping steam.

Figure 8.14 This sealed thermos acts like a closed thermodynamic system where the internal energy is conserved.

from a hot object to a cold object, most thermodynamic systems transfer some heat to their surroundings. You would see this if you left the thermos sitting on a table for 24 hours. Eventually, thermal energy will be transferred from the hot water to the thermos, and from the thermos to the atmosphere. As a result, the hot water will lose internal energy and cool down.

Heat engines

Another example of how internal energy can change is found in the operation of heat engines. Heat engines convert thermal energy into mechanical movement.

A steam engine is an example of a heat engine. A steam engine heats water to produce steam. The steam exerts a force on a piston, causing it to move. The piston is used to move the wheels on a steam train (Figure 8.15). The internal energy of the water remains constant until thermal energy is added. This increases the kinetic energy of the water molecules so that they can leave the liquid state and move as a gas. The internal energy of a gas is higher than that of a liquid. This higher internal energy results in the steam pushing against the piston, transferring some of the energy into movement (kinetic energy). As the piston pushes, the crank and connecting rod turn the locomotive's wheels and the train moves.

You will remember that work is a measure of how much energy has been transferred into moving or rearranging an object. As energy cannot be created or destroyed, the internal energy of the steam will decrease as a result of the piston's movement.

First law of thermodynamics

You have just seen two ways in which the amount of internal energy of a thermodynamic system can change. Internal energy can be increased by the addition of heat, and decreased by doing work. This is the first law of thermodynamics.

Second law of thermodynamics

Every time energy is transformed, thermal energy is generated. In most cases, the thermal energy is transferred to the surrounding air molecules, increasing their random movement. The energy in the randomly moving air particles cannot be transferred, transformed or reused in any way. This means the amount of useful energy decreases and the amount of disorganised random movement (entropy) increases. The second law of thermodynamics describes this relationship. Over time, energy is transformed from one form to another, causing thermal energy to be produced and increasing the amount of entropy.

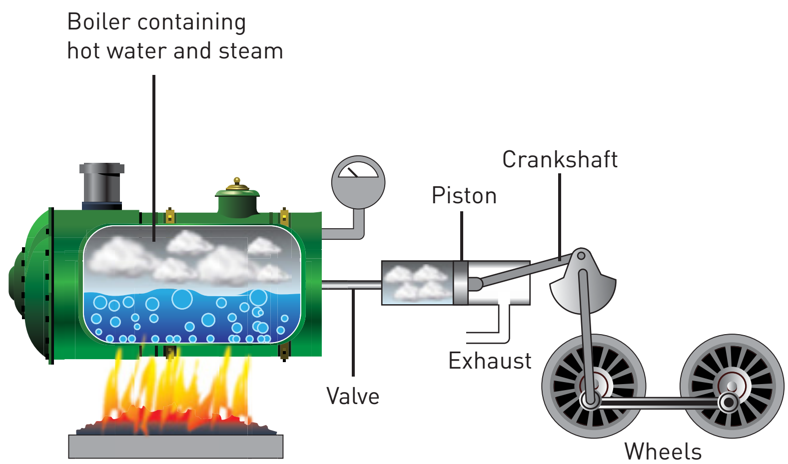


Figure 8.15 The internal energy of a steam engine decreases as the work of steam pushing the pistons is done. This energy is replaced by burning fuel.

Check your understanding 8.5

Remember and understand

1. What is thermodynamics?
2. Describe the first law of thermodynamics. Provide an example to support your description.
3. Describe the second law of thermodynamics. Provide an example to support your description.
4. What is entropy?

Apply and analyse

5. If the total energy of a thermodynamic system is 45 joules, and 6 joules of work was done by the system, what is the final total energy of the system?
6. For many centuries, scientists and inventors worked to design a perpetual motion machine that would keep moving forever without any additional energy. Use the laws of thermodynamics to suggest why this is not possible.

Remember and understand

1 Write the general equations used to determine:
  a Work done on an object
  b Kinetic energy of an object
  c Gravitational potential energy of an object
  d Elastic potential energy

2 What is the difference between thermal energy and temperature?

3 Define the following terms:
  > Thermodynamic system
  > Thermal insulator
  > Thermal equilibrium
  > Temperature gradient

4 What are the differences and similarities between conduction and convection?

5 Figure 8.16 shows a block of ice melting.
  a What is happening to the molecules as the ice melts? Draw a diagram to illustrate your answer.
  b Where does the energy to melt the ice come from? Explain how the energy is transferred to the molecules of ice.

Figure 8.16

6 Some thermodynamic systems are described as closed systems. What is a closed thermodynamic system?

7 Show, using the formula for kinetic energy, that if speed is doubled, the energy of a car crash would be four times as high.

8 True or false? If two thermodynamic systems are in equilibrium with a third system, then they are in thermal equilibrium with each other.

9 What is entropy?

Apply and analyse

10 If a force of 30 N is used to move an object 0.2 m, how much work was done?

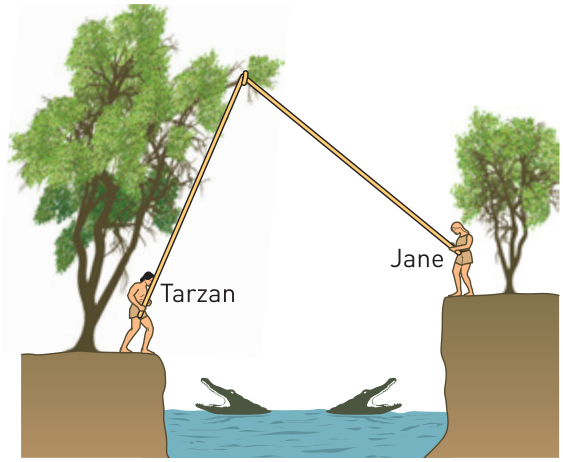


Figure 8.17

11 Use the Figure 8.17 to answer the following questions.
  a Would Tarzan be able to use a vine to swing to Jane? Why or why not?
  b Would Jane be able to use a vine to swing to Tarzan? Why or why not?
  c Who (Tarzan or Jane) has the greatest gravitational potential energy?
  d If Jane has a mass of 60 kg and her height above the ground is 3 m, determine her gravitational potential energy.
  e If Jane uses the vine to swing down to Tarzan, use the law of conservation of energy to determine her kinetic energy when the vine is vertical.
  f What is Jane's velocity at this point?

12 Zelda wanted to bungy jump off a 50 m high bridge.

Figure 8.18

a. If Zelda has a mass of 75 kg, what is her gravitation potential energy?
b. As she jumps, the elastic bungy cord stretches. Use the conservation of energy law to determine the elastic potential energy of the bungy cord when Zelda is at the lowest point of her jump.
c. If the spring constant of the bungy cord is 15 N/m, what distance did the bungy cord stretch?
d. What assumption is made regarding air resistance in this question?

13 A student claimed that their vacuum flask containing hot coffee was a closed thermodynamic system and therefore the coffee would never cool down. Do you agree with them? Explain your answer.

14 A silver teaspoon is placed in a cup filled with hot tea. After some time, the exposed end of the spoon becomes hot, even without a direct contact with the liquid. Explain, using the correct terminology, how this occurred.

Evaluate and create

15 Describe, in terms of kinetic energy of particles, why:
a. convection can only occur in liquids and gases and not solids.
b. when energy transfers by convection or conduction, the substance through which the energy transfers also gets heated.
c. good thermodynamic insulators are usually solids.
d. energy can transfer between objects only from the warmer thermodynamic system to the cooler thermodynamic system.
e. neither convection nor conduction is a way of transferring energy through a vacuum.

16 In some countries, double-glazed windows are used for heat insulation. They consist of two sheets of glass with a thin gap between them. How does this make them better insulators than other glass windows?

Critical and creative thinking

17 Design a poster with a picture that describes the first or second law of thermodynamics.

18 Design a poster that shows the physics of bungy jumping.

Research

Choose one of the following topics for a research project. A few guiding questions have been provided, but you should add more questions that you wish to investigate. Present your report in a format of your own choosing.

> **Perpetual motion machine**
> Research attempts by scientists to design a perpetual motion machine. Describe three machines that were claimed by the inventor to be perpetual motion machines. Use the laws of thermodynamics to explain why one of these machines could not possible remain in motion indefinitely.

> **Newton's cradle**
> What is Newton's cradle? Use the law of conservation of energy to describe its motion. Why does the movement eventually slow?

> **Bungy jumping**
> Research the sport of bungy jumping. Who originally developed the sport? Where did they jump to provide evidence that it was safe? What factors need to be taken into account before a person is allowed to jump?

KEY WORDS

8

closed system
a system with a boundary that does not exchange any energy with its surroundings

conduction
a transfer of thermal energy involving direct contact with no movement of material

convection
a transfer of thermal energy in a liquid or gas involving the movement of the material

convection currents
the circular movement in liquids and gases caused by the rising of hot material

elastic potential energy
the energy possessed by stretched or compressed objects

entropy
the amount of energy in a closed system that is no longer available to be transformed

first law of thermodynamics
the amount of internal energy of a thermodynamic system can change; increasing by the addition of heat, and decreasing through work being done

gravitational potential energy
the energy possessed by objects raised to a height in a gravitational field

kinetic energy
the energy possessed by moving objects

law of conservation of energy
a scientific law stating that the total energy in a system is always constant and cannot be created or destroyed

second law of thermodynamics
over time, energy is transformed from one form to another causing thermal energy to be produced and increasing the amount of entropy

thermodynamic system
a quantity of matter than has a boundary around it

work
occurs whenever an object is moved by a force

EXPERIMENTS 9

1.1 EXPERIMENT

Extracting DNA

Aim

To extract a sample of DNA from peas.

Materials

PART A

- 100 g (½ cup) dried peas soaked overnight in 2 cups of water, or frozen peas (thaw first)
- 200 mL (1 cup) water
- 6 g (1 tsp) table salt
- 20 mL dishwashing liquid
- 1 g (¼ tsp) meat tenderiser
- Blender
- 1 L beaker
- Sieve
- Stirring rod or spoon
- Timer

PART B

- Ice-cold ethanol (stand a sealed bottle containing 200 mL ethanol in a metal bowl of ice water for an hour prior to using)
- Methylene blue stain
- Test tubes and test-tube rack or 50 mL glass vials
- Skewer or, glass stirring rod (toothpick for vials)
- Microscope
- Clean microscope slides and cover slips

Method

PART A

1. Dissolve the salt in the water.
2. Combine the peas and salty water in a blender. Mix for 15 seconds to form a lumpy liquid in which the peas are only just broken up. Do not overblend the mixture.
3. Pour the contents through a sieve into the 1 L beaker. Discard the pulp in the sieve.
4. Add the dishwashing liquid and stir the mixture gently to avoid making bubbles. Stir for 8 minutes.
5. Add the meat tenderiser and continue to stir gently for another 2 minutes.
6. This is your prepared DNA source.

PART B

1. Pour 15 mL of the DNA source into a test tube or a 50 mL glass vial. There should be enough of this mix for eight test tubes or vials, which can be shared in the class.
2. Dribble 15 mL of ice-cold ethanol down the side of the test tube or vial – there should be equal amounts of filtrate and ethanol in the test tube or vial.
3. Leave the test tube or vial to separate into layers. This will take at least 10 minutes. The alcohol will eventually settle on top of the watery pea mixture. DNA is less dense than water and should float up into the alcohol layer, leaving the other cellular components behind.

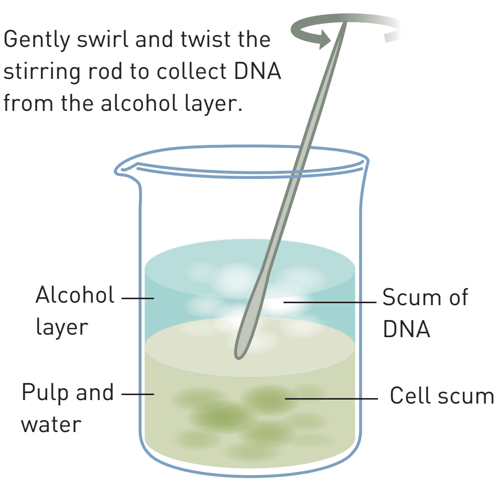


Figure 9.1 Procedure for collecting DNA from the alcohol layer.

4. When the mixture has separated completely, use a stirring rod to gently twirl and twist the DNA to collect it from the alcohol layer (Figure 9.1). DNA is white in colour.
5. Put a small amount of the DNA sample onto a glass slide. Gently spread the DNA mixture. Add 1 drop of methylene blue stain to the DNA mixture. Place the cover slip on the edge of the methylene blue and allow it to fall into place. This should eliminate any air bubbles.
6. Look at your sample under ×10 magnification. Once you have focused the microscope, you can then try the higher magnifications using the fine focus knob to focus. You will not see the double helix strands, but you should see clumps of DNA material that may look like a tangled mass of strands.

Results

Present your results as a labelled diagram, with several short statements or labels explaining your observations.

Discussion

1. Briefly describe the appearance of the DNA under the microscope. Why can you not see the double helix?
2. Do you think human DNA will look the same as the DNA from dried peas?
3. What role does each of the additives (dishwashing detergent, meat tenderiser and alcohol) play?
4. What materials remain in the watery layer?

Conclusion

Summarise the outcomes of this experiment.

CAUTION: Ethanol is flammable.

Modelling the structure of DNA

Aim

To construct a model of DNA that shows the complementary bases arranged in a double helix.

What you need

> 4 long pipe cleaners (2 different colours)
> 24 beads (6 different colours)

What to do

1 Choose two pipe cleaners of the same colour.

2 On each pipe cleaner, thread beads of two alternating colours. Leave about 2 cm of space between each bead. This represents the sugar–phosphate backbone of DNA molecules (Figure 9.2).

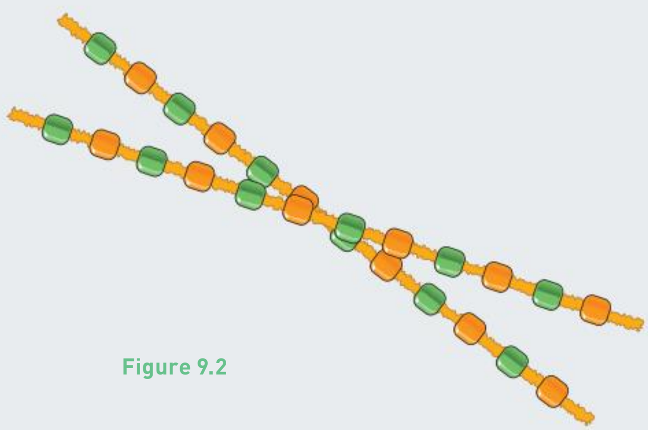


Figure 9.2

3 Cut the remaining two pipe cleaners into 5 cm segments. These will be used to create the paired nitrogen bases A-T and G-C.

4 Choose two colours to represent adenine and thymine. Thread these two beads on six of the cut pipe cleaner strands.

5 The remaining colours represent guanine and cytosine. Thread these two beads on the remaining cut pipe-cleaner strands (Figure 9.3).

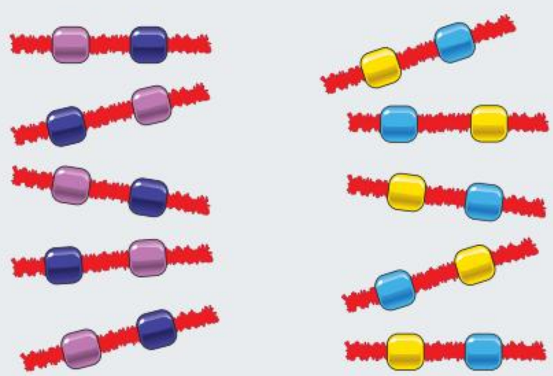


Figure 9.3

6 Attach the short segments of nitrogen bases onto the backbone of the DNA molecule. Make sure each nitrogen base strand is attached next to the same coloured bead (that represents the sugar in the sugar–phosphate backbone). You should have formed a ladder-like structure with the A-T and G-C nitrogen bases as the rungs of the ladder.

7 Twist your ladder so that it forms a double helix structure (Figure 9.4).

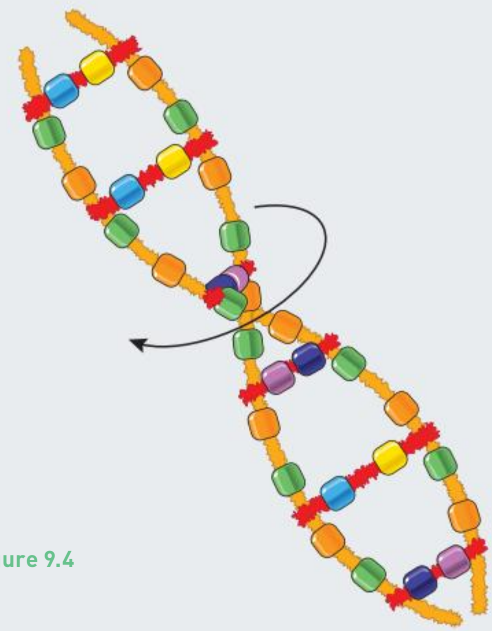


Figure 9.4

Discussion

1 What colour beads represented:
   a adenine?
   b thymine?
   c guanine?
   d cytosine?

2 What do the letters DNA stand for?

3 Describe a 'double helix'.

4 Draw a single nucleotide from your model.

Making protein

A section of a DNA sequence made from a particular gene is shown below:
T A C T T A G A G A T G C T G A C T

1 Write down the complementary sequence of DNA for this part of the gene.

2 If the strand shown is the template strand of the gene, write the RNA sequence that would be made. (Remember to use uracil instead of thymine.)

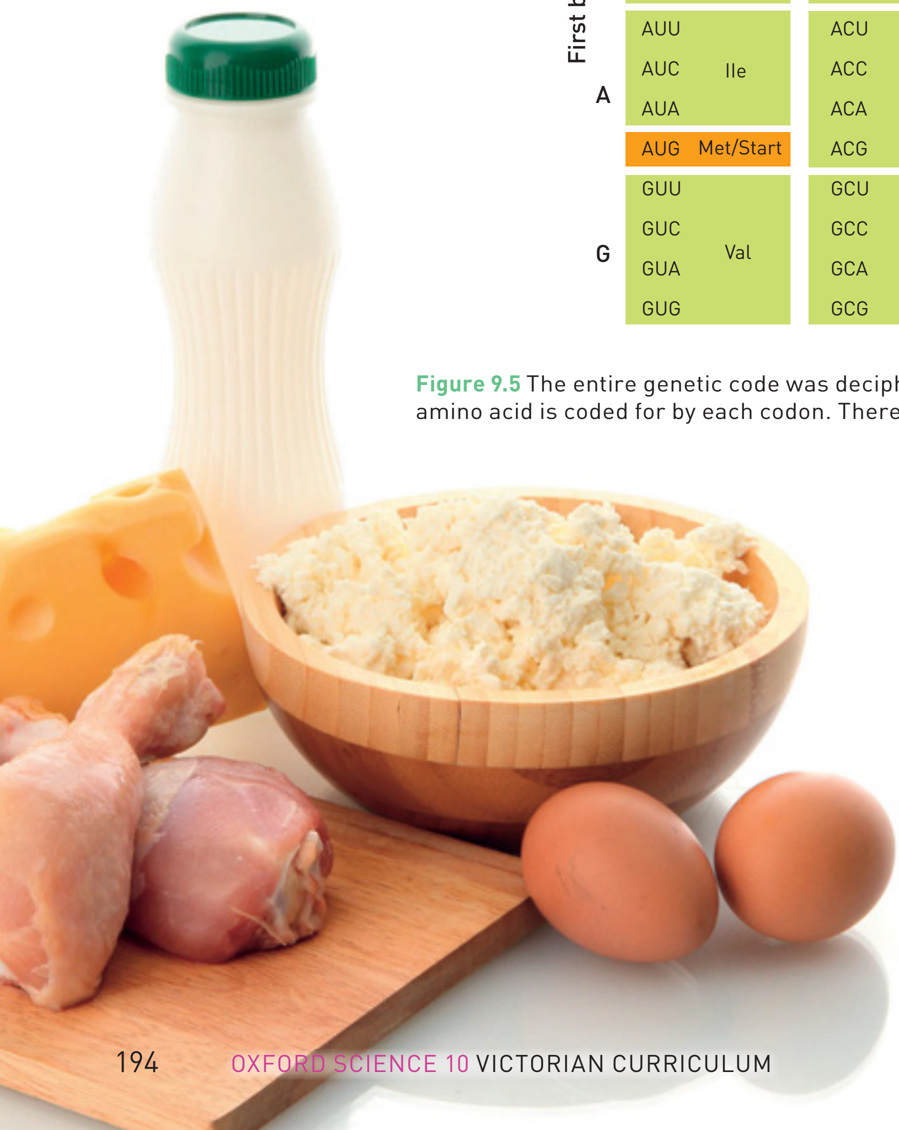
3 Break the strand into groups of three. Each group is called a codon. Using the genetic code in Figure 9.5, write down the amino acids that the sequence codes.

4 How would the protein strand change if the 12th nucleotide in the DNA template strand (guanine) was changed to a thymine?

(base triplet) acid

First base	Second base: U		C		A		G		Third base
U	UUU	Phe	UCU	Ser	UAU	Tyr	UGU	Cys	U
	UUC	Phe	UCC	Ser	UAC	Tyr	UGC	Cys	C
	UUA	Leu	UCA	Ser	UAA	Stop	UGA	Stop	A
	UUG	Leu	UCG	Ser	UAG	Stop	UGG	Trp	G
C	CUU	Leu	CCU	Pro	CAU	His	CGU	Arg	U
	CUC	Leu	CCC	Pro	CAC	His	CGC	Arg	C
	CUA	Leu	CCA	Pro	CAA	Gln	CGA	Arg	A
	CUG	Leu	CCG	Pro	CAG	Gln	CGG	Arg	G
A	AUU	Ile	ACU	Thr	AAU	Asn	AGU	Ser	U
	AUC	Ile	ACC	Thr	AAC	Asn	AGC	Ser	C
	AUA	Ile	ACA	Thr	AAA	Lys	AGA	Arg	A
	AUG	Met/Start	ACG	Thr	AAG	Lys	AGG	Arg	G
G	GUU	Val	GCU	Ala	GAU	Asp	GGU	Gly	U
	GUC	Val	GCC	Ala	GAC	Asp	GGC	Gly	C
	GUA	Val	GCA	Ala	GAA	Glu	GGA	Gly	A
	GUG	Val	GCG	Ala	GAG	Glu	GGG	Gly	G

Figure 9.5 The entire genetic code was deciphered by 1966 and scientists now understand which amino acid is coded for by each codon. There are three stop codons and one start codon.



1.4

SKILLS LAB

Cell division in action

Aim

To identify cells undergoing different stages of mitosis.

What you need

- Prepared microscope slide/s showing a tissue that is in the process of growth and development
- Light microscope

Alternatively, you could prepare your own slides from the growing root tips of a plant, such as garlic or spring onion.

What to do

1. View a slide under the microscope at the greatest magnification possible.
2. In your field of view, identify the cells that are in interphase and those that are undergoing the other phases of mitosis.
3. Sketch at least four cells undergoing different stages of cell division. Remember the conventions for drawing biological images under the microscope. Clearly label all the components within the cell that you can identify correctly.

- DNA is visible under the microscope during interphase but not as individual chromosomes.
- What might be an advantage for DNA being tightly wound during mitosis?
- Describe the possible consequences for a cell if errors occur during the process of DNA replication that occurs during interphase.
- Explain the significance of mitosis for an organism.

1.5

CHALLENGE

Modelling meiosis

Aim

To model the stages of meiosis.

What you need

- Pipe cleaners
- Sticky tape
- Felt-tipped pens
- A4 sheet of paper

What to do

1. Draw the outer membrane of a cell on the sheet of paper.
2. Cut a pipe cleaner in half and place both halves in the centre of the cell. These represent two chromosomes in a cell starting meiosis.
3. Cut a second pipe cleaner in half and twist each half around the centre (centromere) of the first chromosomes.
4. Place the two chromosomes in the centre of your cell.
   - What phase does your cell represent?
5. Move each chromosome to opposite ends of your cell, keeping the twisted centromeres intact.
   - What phase does your cell represent?
6. Turn the paper over and draw two cells half the size of the original cell.
7. Place one chromosome in the centre of each cell.
   - What phase do your cells represent?
8. Untwist the two pipe cleaners and move them to the opposite ends of each cell.
   - What phase do your cells represent?
9. Draw a line down the centre of each cell.
   - What phase do your cells represent?
10. Draw a picture of each stage that you demonstrated with the pipe cleaners.

Discussion

1. How many sets of chromosomes does a cell have before it undergoes meiosis?
2. How many sets of chromosomes does a cell have after it undergoes meiosis?
3. Why do gametes need to be haploid?

1.6
EXPERIMENT

Zazzle genetics

Aim

To demonstrate the role of alleles in determining the phenotype of an individual.

Materials

- A bag containing 6 different coloured counters
- Permanent marker
- Toothpicks
- Pipe cleaners
- Pink and white large marshmallows
- Small marshmallows
- Blue and black felt-tipped pens

Method

1 Choose a counter from the bag. Use the permanent marker to draw an 'A' on one side and an 'a' on the other side. This represents the inheritance of a long antenna (A) or a short antenna (a) from the parent.

2 Flip the counter to determine which allele is passed on to your Zazzle from the father. Write your results in the table in the results section.

3 Use a second counter to represent two body segments (L) or one body segment (l). Flip the counter to determine which allele is passed on from the father. Write your result in the table.

4 Use three of the remaining counters to represent the following characteristics of the father and write your results in the table.
   - Four eyes (E) or two eyes (e)
   - Straight tail (T) or curly tail (t)
   - One hump (H) or two humps (h)

5 Repeat steps 1–4 for the alleles passed from the mother to your Zazzle.

6 The final counter is used to determine the sex of your Zazzle. The mother has two X chromosomes. This means she can only pass on an X chromosome to your Zazzle baby. Draw an 'X' on one side of the counter and a 'Y' on the other. Flip the counter to determine which chromosome is passed from the father to the child. You have now determined the sex of your Zazzle. A girl will have a pink marshmallow body. A boy will have a white marshmallow body.

7 Determine the phenotype of your Zazzle.

8 Use the materials to construct your Zazzle.

Results

Alleles inherited from the parent

CHROMOSOME	TRAIT AND LETTER REPRESENTING IT	ALLELE DONATED BY FATHER	ALLELE DONATED BY THE MOTHER	PHENOTYPE OF BABY ZAZZLE
1	Antenna (A or a)			
2	Body length (L or l)			
3	Eyes (E or e)			
4	Tail (T or t)			
5	Hump (H or h)			
6	Sex (X or Y)		X	

Discussion

1 How many chromosomes were present in each of the:
   a mother's somatic cells?
   b father's gametes?
   c baby Zazzle cells?

2 Write down your baby Zazzle's genotype for each trait.

3 Why does the baby Zazzle have two alleles for each trait?

4 Draw a diagram of your baby Zazzle.

Conclusion

Describe how dominant and recessive traits are inherited.

SAFETY: Do not eat or drink in the laboratory

1.7 EXPERIMENT

Aim

To determine the inheritance of blood groups.

Materials

- Anti-A solution (2 M hydrochloric acid solution)
- Anti-B solution (2 M sulfuric acid solution)
- Sample blood O (distilled water)
- Sample blood A (0.1 M silver nitrate solution)
- Sample blood B (0.1 M barium nitrate solution)
- Sample blood AB (a 50:50 mix of 0.1 M silver nitrate and 0.1 M barium nitrate solution)
- Spotting tiles
- 6 pipettes, one for each solution

Blood typing experiment

Method

1. Place two drops of sample blood O in the first wells of the first two rows of your spotting tile (Figure 9.6).
2. Using a fresh pipette, place two drops of sample blood A in the second wells of your spotting tile.
3. Repeat for the remaining blood samples.
4. Add a drop of anti-A solution to each of the wells in the first row of your tile.
5. Add a drop of anti-B solution to each of the wells in the second row of your tile.
6. Record your observations in the table in the results section.

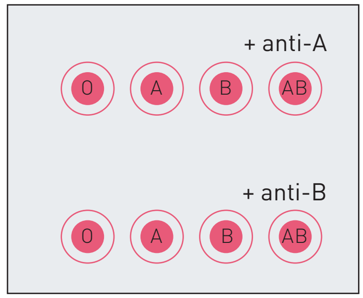


Figure 9.6 Spotting tile.

Results

	SAMPLE BLOOD O	SAMPLE BLOOD A	SAMPLE BLOOD B	SAMPLE BLOOD AB
Anti-A				
Anti-B				

Discussion

1. What possible genotype/s could the following people have?
   a. Person with blood group A
   b. Person with blood group B
   c. Person with blood group AB
   d. Person with blood group O
2. Could a person with blood group AB have a child with blood type O? Explain your answer.
3. A child with blood group O claimed that she was adopted because her mother had blood group A and father had blood group B. How would you explain that this is still possible?

Conclusion

How is blood grouping inherited?

1.8
EXPERIMENT

Aim

To examine the inheritance of X-linked traits.

Materials

- 2 counters
- Permanent marker

Colour-blindness inheritance

Li is colour blind (X^bY) and would like to start a family with Maria. Maria is not colour blind but knows that she is heterozygous (X^BX^b) for the trait as her father is colour blind.

Method

1. On one counter, write X^b on one side and Y on the other.
2. On the second counter, write X^b on one side and X^B on the other.
3. Toss the counters eight times and record the possible genotypes of Li's and Maria's children.

Results

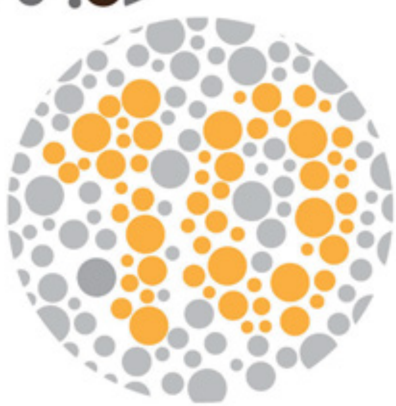
COIN TOSS	GENOTYPE OF CHILD
1	
2	
3	
4	
5	
6	
7	
8	

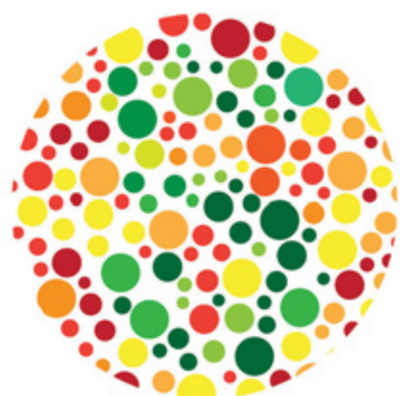
Discussion

1. How many girls and boys did Li and Maria have in your experiment?
2. How many children were colour blind? How many had normal vision?
3. Was colour blindness more common in boys or girls?
4. Can non-colour-blind parents have a colour-blind son? Use a Punnett square to support your answer.
5. Can a non-colour-blind daughter have a colour-blind father? Use a Punnett square to support your answer.
6. Can two colour-blind parents have a non-colour-blind son? Use a Punnett square to support your answer.

Conclusion

How is colour blindness inherited?





1.10
SKILLS LAB

Identifying mutations

First base	Second base: U	Second base: C	Second base: A	Second base: G	Third base
U	UUU Phe	UCU Ser	UAU Tyr	UGU Cys	U
U	UUC Phe	UCC Ser	UAC Tyr	UGC Cys	C
U	UUA Leu	UCA Ser	UAA Stop	UGA Stop	A
U	UUG Leu	UCG Ser	UAG Stop	UGG Trp	G
C	CUU Leu	CCU Pro	CAU His	CGU Arg	U
C	CUC Leu	CCC Pro	CAC His	CGC Arg	C
C	CUA Leu	CCA Pro	CAA Gln	CGA Arg	A
C	CUG Leu	CCG Pro	CAG Gln	CGG Arg	G
A	AUU Ile	ACU Thr	AAU Asn	AGU Ser	U
A	AUC Ile	ACC Thr	AAC Asn	AGC Ser	C
A	AUA Ile	ACA Thr	AAA Lys	AGA Arg	A
A	AUG Met/Start	ACG Thr	AAG Lys	AGG Arg	G
G	GUU Val	GCU Ala	GAU Asp	GGU Gly	U
G	GUC Val	GCC Ala	GAC Asp	GGC Gly	C
G	GUA Val	GCA Ala	GAA Glu	GGA Gly	A
G	GUG Val	GCG Ala	GAG Glu	GGG Gly	G

Figure 9.7 The codon table.

1 A normal RNA sequence is shown below, together with two different genetic mutations.

> Normal
AUG ACG CAG AAU UGG GAU CCU ACG

> Mutation 1
AUG ACA CAG AAU UGG GAU CCU ACG

> Mutation 2
AUG AGC AGA AUU GGG AUC CUA CG

a Name the type of mutation represented in each case. Explain your answer.

b Describe the outcome of mutation 1 on protein synthesis. You may wish to consult the codon table in Figure 9.7.

c Describe the outcome of mutation 2 on protein synthesis.

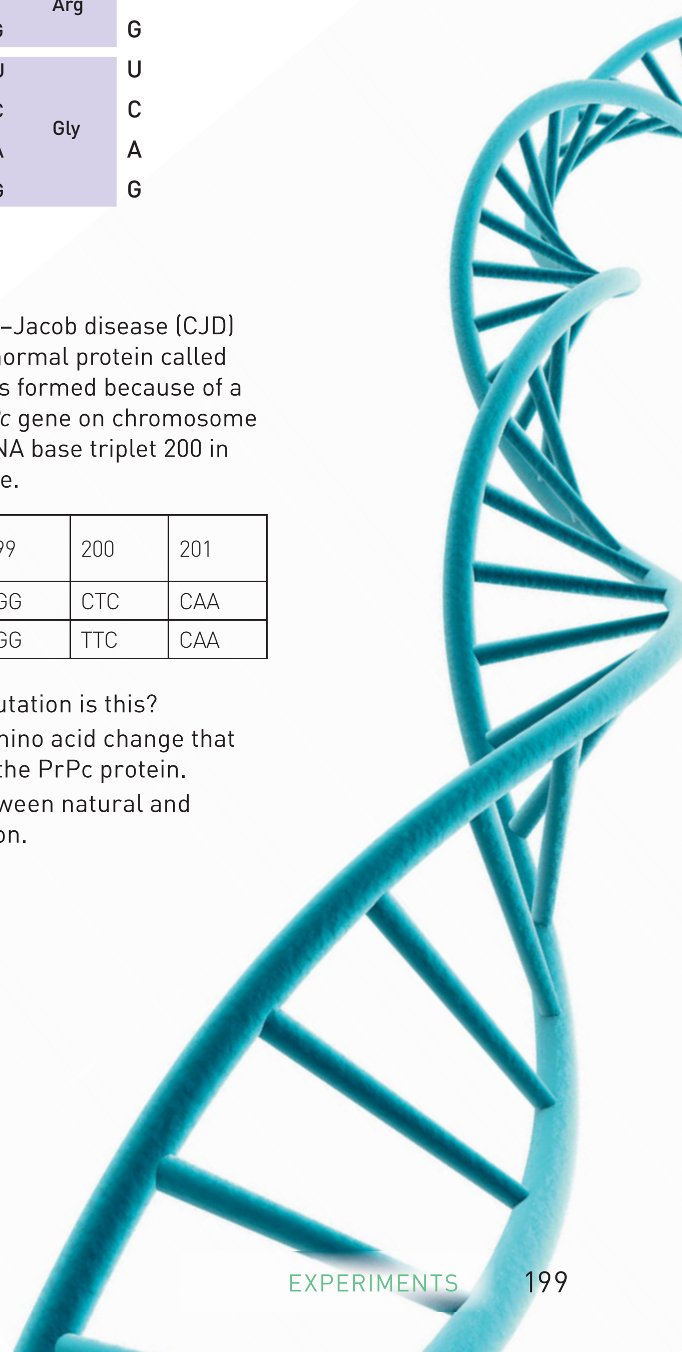
2 Genetic Creutzfeldt–Jacob disease (CJD) is caused by an abnormal protein called PrPc. This protein is formed because of a mutation in the *PrPc* gene on chromosome 20 and occurs in DNA base triplet 200 in the gene's sequence.

DNA base triplet number	199	200	201
Normal gene	TGG	CTC	CAA
Mutated gene	TGG	TTC	CAA

a What type of mutation is this?

b Describe the amino acid change that would occur in the PrPc protein.

c Distinguish between natural and induced mutation.



Edible genetic engineering

Aim

To model how insulin is genetically engineered.

What you need

- 1 packet of lolly snakes
- 1 packet of sour worm lollies

What to do

1 Carefully remove a small amount from the end of one lolly snake and stick the ends together so they form a loop. You have formed a plasmid of DNA.

2 Obtain one sour worm. This is your insulin gene. Carefully remove a small amount of the ends of your insulin gene and insert it into your plasmid to form a larger circle. You have created a recombinant plasmid with DNA from a different organism.

3 Draw a picture of your plasmid. Label the plasmid and the introduced gene.

4 Describe how you could clone your insulin plasmid in a bacterial cell.

Discussion

1 What is a plasmid?

2 Why is insulin needed by some members of the community?

3 Before genetic engineering was possible, pig insulin was often used. Why would genetically engineered human insulin be preferable? (Consider the way the immune system would respond to pig insulin.)

2.2
EXPERIMENT

Aim

To examine the selection pressures involved in hunting prey.

Materials

- Paper cups
- Tools: knives, forks, spoons, sticky tape, plastic gloves
- Bean prey: red butted beans (kidney beans), long-toothed yellow beans, panther-toothed black beans, wicked white beans
- Timer

What if the habitat of bean prey was changed?

Method

1. Divide the class into five groups. Each group represents a separate tribe.
   - The Knife tribe can only use knives to hunt beans.
   - The Spoon tribe can only use spoons to hunt beans.
   - The Hand tribe are allowed to use their hands to hunt beans.
   - The Sticky-tape tribe can only use sticky tape to hunt beans.
   - The Glove tribe must wear plastic gloves to hunt beans but turn the thumb of their glove inside out so they cannot use their opposable thumb.
2. On a section of grass, spread 20 of each bean type onto the grass.
3. Each tribe has 10 seconds to collect as many beans as they can. Record the data in an appropriate table as shown in the Results section.
4. The two tribes with the least beans become extinct and must sit down.
5. Each bean left on the grass will breed. This means the amount of beans remaining on the grass will double. For example, if 6 white beans were collected, then 14 remain, and you need to add another 14 white beans to the area. Repeat with the other three colours.
6. Repeat for two further generations so that only one tribe is left.

Inquiry

What if the habitat of bean prey was changed?

1. Write a hypothesis for your inquiry.
2. What is the independent variable?
3. What is the dependent variable?
4. List at least three variables that will need to be controlled. How will you control them?

Results

Copy and complete the following table to record your results for generation 1.

	KNIFE TRIBE	SPOON TRIBE	HAND TRIBE	STICKY-TAPE TRIBE	GLOVE TRIBE	TOTALS
Red-butted beans						
Long-toothed yellow beans						
Panther-toothed black beans						
Wicked white beans						
TOTALS						

Create two more tables for the other two generations.

Discussion

1. Which tribes became extinct first? What was the selection pressure that contributed to their extinction?
2. Why were the bean prey numbers doubled after each generation?
3. Which beans were selected against?
4. Use the mechanism of natural selection to explain the change in bean prey numbers.
5. Suggest a similar example to this experiment that might occur in nature.

Conclusion

Describe how the mechanism of natural selection changes the frequency of alleles in a population.

2.3 EXPERIMENT

Aim

To model divergent and convergent evolution in beak size.

Materials

- 6 previously prepared bags of food:
  - North Trayland/ Season 1 = 4 handfuls popcorn + 20 kidney beans + 50 marbles
  - North Trayland/ Season 2 = 1 handful popcorn + 10 kidney beans + 50 marbles
  - North Trayland/ Season 3 = 100 marbles
  - South Trayland/ Season 1 = 4 handfuls popcorn + 20 kidney beans + 50 marbles
  - South Trayland/ Season 2 = 6 handfuls popcorn + 10 kidney beans + 5 marbles
  - South Trayland/ Season 3 = 8 handfuls popcorn
- 20 large bulldog clips
- 20 medium-sized bulldog clips
- 20 small bulldog clips
- 30 plastic cups
- 2 large trays
- 6 plastic bags
- Timer

Divergent and convergent evolution of big beaks and small beaks

Method

1. Twelve students will represent a population of birds living on an island. Four students should be Giant birds (with a large bulldog clip each). Four students are Midbill birds with the medium-sized bulldog clips. The remaining four students are Babybill birds with the small bulldog clips.
2. A permanent barrier separates the bird population into two groups (North Trayland and South Trayland) with two birds of each type (2 large, 2 medium and 2 small) in each. Place the trays at opposite ends of the classroom.
3. Place the first season's food for each population in the tray. The 12 birds have 25 seconds to collect as much food as possible with their bulldog-clip 'beaks' and place it in their cup 'stomachs'.
4. At the end of the time, calculate how many kilojoules each bird has consumed if popcorn = 2 kilojoules, beans = 5 kilojoules, marbles = 10 kilojoule. The following tables shows you how many kilojoules each type of bird needs to survive. Record the number of surviving birds in the results table.

BIRD	KILOJOULES NEEDED TO SURVIVE	KILOJOULES NEEDED TO REPRODUCE
Giant	80	160
Midbill	50	100
Babybill	25	50

5. Reproducing birds should choose another student (who is not already a bird) to be their baby (with the same-sized beak).
6. Remove any remaining food from the trays and place back into the plastic bags. Place the food for season 2 in each tray. Repeat steps 3–5.
7. Remove any remaining food from the trays and place the food for season 3 in each tray. Repeat steps 3–5.
8. Clean up any remaining food.

Results

Copy and complete the following tables.

North Trayland

BIRD	BEFORE ISOLATION	SEASON 1	SEASON 2	SEASON 3
Giant	2			
Midbill	2			
Babybill	2			

South Trayland

BIRD	BEFORE ISOLATION	SEASON 1	SEASON 2	SEASON 3
Giant	2			
Midbill	2			
Babybill	2			

Discussion

1. Describe what happened to the North Trayland population of birds after they were isolated from South Trayland.
2. Describe what happened to the South Trayland population of birds after they were isolated from North Trayland.

Conclusion

Use the terms 'natural selection' and 'selection pressures' to explain the type of evolution that occurred between the two species.

2.4 EXPERIMENT

Aim

To determine the absolute date of an unknown sample of popped popcorn.

Materials

- Previously prepared bags of microwave popcorn (unbuttered):
  - Bag A: stop microwave 10 seconds after first pop (record the actual time)
  - Bag B: stop microwave 30 seconds after first pop (record the actual time)
  - Bag C: stop microwave 10 seconds after last pop (record the actual time)
  - Bag D: mystery fossil bag (your teacher will have microwaved this bag for a time between bag A and C)
- Microwave oven
- 4 large trays

SAFETY: Do not eat or drink in the laboratory

Popcorn dating

Method

1 Open bag A and count how many corn kernels have popped and how many have not popped.

2 Determine the percentage of popped kernels using the following equation.

Percentage of popped kernels

$$= \frac{\text{Number of popped kernels}}{\text{Total number of kernels}} \times 100$$

3 Repeat steps 1 and 2 with bags B and C.

4 Graph the percentage of popped kernels against the time spent in the microwave oven.

5 Repeat steps 1 and 2 with bag D. Use your graph to determine how long bag D was in the microwave oven.

Results

Copy and complete the following table and draw a graph of your results.

BAG	TIME IN THE MICROWAVE	NUMBER OF POPPED KERNELS	NUMBER OF UN-POPPED KERNELS	PERCENTAGE OF POPPED KERNELS
A				
B				
C				
D				

Discussion

1 What is a half-life?

2 How long was the half-life of your popcorn kernels?

3 For how long was bag D heated? (Confirm your answer with your teacher.)

4 How accurate was your estimate? Provide evidence to support your answer.

Conclusion

How does this experiment provide an example of absolute dating methods?

2.6 EXPERIMENT

Aim

To determine the evolutionary relationship between different species.

Who is my cousin?

Materials

> DNA sequences
  – Hippo AGTCCCCAAAGCAAAGGAGACTATCCTTCCTAAGCATAAAGAAATGCCCTTCTCTAAATC
  – Giraffe AGTCTCCAAATGAAAGGAGACTATGGCTCCTAAGCACAAAGAAATGCCCTTCCCTAAATA
  – Rhino AGTCCTCCAAACTAAGGAGACCATCTTTCCTAAGCTCAAAGTTATGCCCTCCCTTAAATC
  – Pig AGATTCCAAAGCTAAGGAGACCATTGTTCCCAAGCGTAAAGGAATGCCCTTCCCTAAATC
  – Cow AGTCCCCAAATGAAAGGAGACTATGGTTCCTAAGCACAAGGAAATGCCCTTCCCTAAATA

Method

1 Compare the DNA sequences with each other and determine the number of differences between each pair.

2 Write your results in a results table as shown below.

Results

Copy and complete the following table to show the number of differences in DNA sequence between each animal.

Hippo					
Cow					
Giraffe					
Rhino					
	Pig	Hippo	Cow	Giraffe	

Discussion

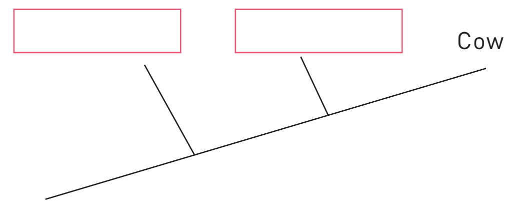
1 a Which animal has the least number of differences in DNA sequence when compared to a cow?

b What does this suggest about the evolutionary relationship between these two animals?

2 a Which animal has the most number of differences in their DNA sequence when compared to a cow?

b What does this suggest about the evolutionary relationship between these two animals?

3 Use your answers to questions 1 and 2 to complete the following phylogenetic tree.



Conclusion

How do DNA sequences determine the evolutionary relationships between different organisms?

Selective breeding of dogs

Aim

To examine how selective breeding for chosen characteristics can develop a new breed of dog.

What you need

- Counter
- Permanent marker

What to do

1. You are a scientist who studies small mammals in the bush. You need a dog to find and retrieve the mammals without causing them unnecessary stress. This will allow you to tag and release the mammals. Below is a list of possible traits of dogs.

Possible traits of dogs

TRAIT	DESIRED FORM			
Trainability	High	Moderate	Low	Any
Temperament	Vicious	Friendly	Timid	Any
Bark	Very loud	Moderate	Quiet	Any
Coat colour	Black	Brown	Caramel	Any
Hair length	Long	Moderate	Short	Any
Smell	High ability	Moderate	Low ability	Any
Sight	High ability	Moderate	Low ability	Any
Hearing	High ability	Moderate	Low ability	Any
Speed	Fast	Moderate	Low	Any
Endurance	High	Moderate	Low	Any

2. Identify which two traits are most important for your new breed to inherit.
3. Choose which dogs you need to breed to achieve your desired traits from the following table.
4. Choose dogs to be the mother and the father. Write an 'M' for mother on one side of the counter and an 'F' for father on the other side of the counter.
5. Flip the counter for each trait. If it lands with the 'M' side up, then the puppy will inherit the mother's trait. An 'F' indicates that puppy inherits the father's trait. Write your results in the table.
6. Flip the counter three times for each trait because each pair will have three puppies.

Traits of different dog breeds

BREED	Animo	Bax	Coota	Dallie	Enos	Favious
TRAINABILITY	Moderate	Moderate	High	Low	Moderate	High
TEMPERAMENT	Timid	Timid	Vicious	Timid	Friendly	Vicious
BARK	Moderate	Very loud	Moderate	Quiet	Very loud	Moderate
COAT COLOUR	Black	Brown	Caramel	Caramel	Black	Brown
HAIR LENGTH	Long	Moderate	Long	Short	Moderate	Long
SMELL	High ability	Moderate	Low	Low	Moderate	High
SIGHT	Moderate	Moderate	Moderate	High	High	Low
HEARING	High ability	Moderate	Moderate	High	High	Moderate
SPEED	Moderate	Fast	Fast	Fast	Low	Moderate
ENDURANCE	Low	Moderate	High	Moderate	High	Low

Results

Copy and complete the following table.

TRAIT	PUPPY 1	PUPPY 2	PUPPY 3
Trainability			
Temperament			
Bark			
Coat colour			
Hair length			
Smell			
Sight			
Hearing			
Speed			
Endurance			

Discussion

1. Were all three puppies identical? Suggest a reason.
2. Which puppy best suited your original needs? Explain your answer.
3. If you were to breed the dogs for another generation, which puppies would you select to be the parents? Explain your answer.
4. Are your puppies a new species? Explain your answer.

Conclusion

Explain how selective breeding can affect the survival of a species.

2.8 EXPERIMENT

Selecting for sickle cell anaemia

Aim

To examine how malaria selects for sickle cell anaemia.

Materials

- 75 dried red kidney beans (These are the sex cells carrying 'H', the unaffected normal haemoglobin allele.)
- 25 white beans (These are the sex cells carrying 'h', the affected sickle cell allele.)
- 5 containers
- Coin or counter (for flipping heads or tails)
- Permanent marker

Method

1. Place all the beans in a container and mix them thoroughly. This container represents the total 'gene pool' of your population.
2. Label the remaining containers:

   HH: No sickle cell disease

   Hh: No sickle cell disease

   hh: Sickle cell disease

   Dead
3. Without looking, randomly select two beans from the gene pool. This represents the two alleles that are present in a baby of the next generation.
4. Flip the coin to determine if the baby catches malaria. Heads means the baby is infected; tails means it does not become infected. Use the following table to determine if the individual lives or dies.

ALLELES PRESENT (BEAN COLOUR)	PRESENCE OF SICKLE CELL ANAEMIA?	HEADS – INFECTED WITH MALARIA	TAILS – NOT INFECTED WITH MALARIA
HH (red – red)	No sickle cell anaemia Susceptible to malaria	Die Place in Dead	Live Place in HH
Hh (red – white)	No sickle cell anaemia Resistant to malaria	Live Place in Hh	Live Place in Hh
hh (white – white)	Sickle cell anaemia	Die Place in Dead	Die Place in Dead

5. Repeat steps 3 and 4 until the gene pool is empty.
6. Record your results in the table below.
7. Place all the survivors in HH and Hh back into the gene pool and continue breeding for a second generation.
8. Combine the class results to ensure that you have a large sample size.
9. Determine the percentage of each allele present in each generation from the following formulas:

   Percentage of H alleles present

   $$= \frac{\text{number of red kidney beans}}{\text{total number of beans}} \times 100$$

   Percentage of h alleles present

   $$= \frac{\text{number of white beans}}{\text{total number of beans}} \times 100$$

Results

Copy and complete the following table.

Surviving alleles

	NUMBER OF RED KIDNEY BEANS (H)	NUMBER OF WHITE BEANS (h)
Generation 1	75	25
Generation 2		
Generation 3		

Discussion

1. What trends did you notice for the percentage of 'H' (normal) alleles present in the gene pool?
2. What trends did you notice for the percentage of 'h' (sickle cell) alleles present in the gene pool?
3. The hh combination is deadly and people with this are likely to die before reproducing. Why has the 'h' allele not been removed from the population completely?
4. If people with sickle cell anaemia were able to survive and reproduce, what would you expect to happen to the percentage of people carrying the 'h' allele in the population?

Conclusion

How does malaria select for carriers of sickle cell anaemia?

3.3 EXPERIMENT

Reactivity of metals

Aim

To compare the reactivity of various metals by observing their reaction with hydrochloric acid.

Materials

- 2 M hydrochloric acid
- Detergent
- 0.5 cm pieces of magnesium, aluminium, iron, zinc and copper
- Steel wool
- Test tubes and test-tube rack
- Ruler
- Timer
- Bench mat

Method

1 Clean the surface of the magnesium with a piece of steel wool.

2 Place the magnesium into a test tube.

3 Add 3 drops of detergent to the test tube.

4 Add 2 cm of hydrochloric acid to the test tube. Set the timer for 5 minutes and record your observations, including the height of the foam produced, in a results table like the one below.

5 Repeat the process for the remaining metals.

6 Record your observations over 30 minutes.

7 This equipment can be left set up overnight to observe any further changes.

Results

Copy and complete the following table.

METAL	OBSERVATIONS	HEIGHT OF FOAM (cm)
Magnesium		
Aluminium		
Iron		
Zinc		
Copper		

Discussion

1 Which metal was the most reactive?

2 Which metal was the least reactive?

3 Why were the metals cleaned with steel wool first?

4 Why was detergent added to the test tubes with the hydrochloric acid?

5 What properties would you think the most reactive metal would also exhibit?

6 Is there any link between the reactivity of the metals and where they are located in the periodic table?

Conclusion

What do your know about the reactivity of metals?

CAUTION: Wear protective gloves and safety glasses throughout this experiment.

Identifying patterns in the periodic table

What you need

> A3 sheet of paper
> Pens
> Highlighter pens

What to do

1 On an A3 sheet of paper, make a copy of the periodic table up to element 20. Leave a gap for the block of transition metals. Ensure that the size of the box for each element will fit the information you will need to insert, as detailed below. (Chlorine has been completed in step 5 as an example.)

2 Colour hydrogen red, metals blue, noble gases purple, other non-metals green, and use the different colours to shade in the metals, the noble gases, hydrogen, the non-metals other than the noble gases and hydrogen, and the metalloids. Place a suitable key under your periodic table.

3 Identify the elements that will not gain or lose electrons in a reaction because their uncharged atoms are already very stable. Beneath them, write:
   > 'Already a stable structure'.
   > 'Does not form an ion'.

4 Identify the elements that will not gain or lose electrons in a reaction, because this would require them to gain or lose more than three electrons. Beneath them, write:
   > 'Needs to gain or lose more than three electrons for a more stable structure'
   > 'Does not form an ion'.

5 Complete the box for each of the other elements listed, except for the metalloids and hydrogen, by stating how many electrons the element needs to gain or lose to achieve a more stable structure, and hence what charge its ion should have, like the example of chlorine. Information for chlorine:
   > Chlorine (Cl)
   > Needs to gain one electron
   > Charge on ion = 1–

Discussion

1 What patterns do you notice in your entries for the alkali metals?

2 What patterns do you notice in your entries for the alkaline earth metals?

3 What patterns apply to all the metals listed?

4 What patterns do you notice in your entries for the halogens?

5 What patterns do you notice in your entries for the group 16 elements?

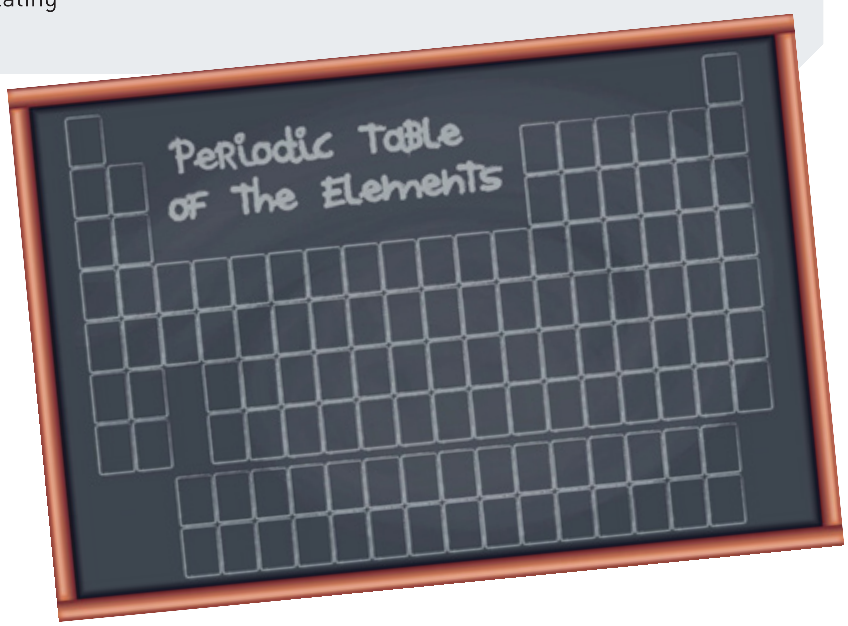
6 What patterns apply to the non-metals, except for hydrogen and the noble gases?

7 In general, what do you expect to happen when a metal atom and a non-metal atom meet? Which groups of non-metals will not react in this way? Discuss.

8 Predict what might happen if a:
   a potassium atom and a fluorine atom meet
   b calcium atom and an oxygen atom meet.

   You can illustrate your predictions by drawing shell diagrams of the atoms and showing what happens in the reaction.

9 Suggest why hydrogen and the metalloids were not considered in this activity.



3.5
EXPERIMENT

Aim
To investigate the electrical conductivity of two ionic compounds as a solid and in aqueous solution.

Materials

- Large sodium chloride crystals
- Coarse sea salt crystals
- Small Petri dish
- 4 V battery or other 4 V DC power source
- Ammeter
- Wires with alligator clips
- 2 graphite electrodes
- 3 × 100 mL beakers
- Large spatula
- Glass stirring rod
- Paper towel

Conductivity of ionic compounds

Method

1. Set up the electrical circuit as shown in Figure 9.8. Have your teacher check that it is correct before proceeding. Ensure that you know how to use the ammeter and its scales correctly.

Figure 9.8 Experimental set-up.

2. Using the spatula, place the largest sodium chloride crystal onto the Petri dish, then touch each end with an electrode, making sure that the two electrodes do not touch each other. Does the crystal conduct electricity? If it doesn't appear to, connect the wire to the more sensitive scale on the ammeter. Does a reading register now? Record your result.
3. In a 100 mL beaker, place half a large spatula of sodium chloride crystals and add 50 mL of water. Stir to dissolve the crystals.
4. Place the electrodes into this solution, again ensuring they do not touch each other. Does the solution conduct electricity? If it doesn't appear to, connect the wire to the more sensitive scale on the ammeter. Does a reading register now? Record your result.
5. Turn off the power supply and rinse the electrodes with fresh tap water, then dry them with a paper towel.

Inquiry

What if large coarse sea salt was used?

1. Write a hypothesis for your question.
2. What is your independent variable?
3. What is your dependent variable?
4. List three variables that you will need to control. How will you control them?
5. Record your observations in a table.

Results

Devise a simple table or spreadsheet in which to record your results.

Discussion

1. Sea salt is a mixture of different ionic compounds, including sodium chloride. What can you conclude about the ability of solid ionic compounds to conduct electricity, whether they are pure or mixed together?
2. What effect does dissolving an ionic compound in water have on its ability to conduct electricity?
3. To conduct electricity, a substance must have charged particles that can move about. Suggest an explanation for your findings.
4. The melting point of sodium chloride is 801°C, so it is not practical to melt it in the school laboratory. Predict whether molten sodium chloride would conduct electricity and justify your answer.

Conclusion

What do you know about the conductivity of ionic compounds?

Ionic compounds

Ionic compounds are those formed from the bonding of ions. Consider sodium chloride, which is produced when sodium and chlorine meet and react. In this compound, the metal sodium is present in the form of positively charged ions (Na^+) and the non-metal chlorine is present as negatively charged ions (Cl^-). Notice that the:

> metal is named first and its name is not changed
> non-metal is named second and the end of its name is changed from -ine to -ide.

This obeys the following standard naming convention.

> The positively charged ion (cation) in the compound is written first and keeps the name of the metal from which it was formed.
> The negatively charged ion (anion) in the compound is written second. The end of the name of the non-metal from which it formed is replaced with -ide.
> Some transition metals can form more than one ion. In these cases, a Roman numeral is used to show the charge on the ion. For example, copper forms two ions: one with a 1+ charge and one with a 2+ charge. These ions are called copper(I) and copper(II) ions, respectively.

The names and formulas of some common ions are listed in Table 9.1.

Table 9.1 Formulas of some common ions

CATIONS		ANIONS	
NAME	**FORMULA**	**NAME**	**FORMULA**
Lithium	Li^+	Fluoride	F^-
Sodium	Na^+	Chloride	Cl^-
Potassium	K^+	Bromide	Br^-
Magnesium	Mg^{2+}	Iodide	I^-
Calcium	Ca^{2+}	Oxide	O^{2-}
Aluminium	Al^{3+}	Sulfide	S^{2-}
Silver	Ag^+	Nitride	N^{3-}
Zinc	Zn^{2+}		
Copper(II)	Cu^{2+}		
Iron(II)	Fe^{2+}		
Iron(III)	Fe^{3+}		

The formula for sodium chloride is NaCl, whereas the formula of magnesium chloride is $MgCl_2$. The formula NaCl means that the cations and anions are present in a ratio of 1 : 1. That is, for every Na^+ ion present in a sodium chloride crystal, there is one Cl^- ion present. The formula $MgCl_2$ means that the cations and anions are present in a ratio of 1 : 2. That is, for every Mg^{2+} ion present in a magnesium chloride crystal, there are two Cl^- ions present. This is necessary to achieve an overall neutral charge.

We can use this principle to determine the formula of an ionic compound. First, use Table 8.1 to list the formulas of the cations and anions present. Then, work out the simplest ratio they need to be in so that the total positive charge and total negative charge are equal.

Example

1 What is the formula for iron(II) oxide?
> The ions are Fe^{2+} and O^{2-}.
> Because the charges 2+ and 2– are equal, the ions only need to be in a ratio of 1 : 1.
> Therefore, the formula is FeO.

2 What is the formula for silver sulfide?
> The ions are Ag^+ and S^{2-}.
> Because the charges are 1+ and 2–, the ions need to be in a ratio of 2 : 1 (making it a total of 2+ and 2–).
> Therefore, the formula is Ag_2S.

Your turn

Write the formulas for:

a lithium bromide
b iron(III) chloride
c sodium nitride
d aluminium oxide.

Modelling covalent molecules

Aim

To model the sharing of electrons in covalent molecules.

What you need

- Molecular modelling kits (or use different coloured marshmallows and toothpicks)

What to do

1. Choose three different colours to represent carbon, hydrogen and oxygen.
2. For each of the molecules shown in the results table:
   a. state the numbers of each atom
   b. make and draw a model of the molecules
   c. draw the number of electrons in the valency shell of each atom including the shared electrons.

Results

Copy and complete the following table.

MOLECULE	ATOMS PRESENT	NUMBERS OF EACH ATOM	DRAWING OF MODEL	ELECTRON DOT DIAGRAM
H_2				
H_2O				
CH_4				
CO_2				
$CHCl_3$				

Discussion

1. What type of bond occurs between a metal and a non-metal?
2. What type of bond occurs between two non-metals?
3. What is a valency shell?
4. What is meant by the term 'sharing electrons' in covalent bonds?

Conclusion

What do you know about covalent bonds?

3.7 CHALLENGE

Modelling alloys

Aim

To compare the properties of model alloys.

What you need

- 4 different colours of plasticine (35 g)
- Sand (12 g)
- Newspaper
- Balance
- Magnifying glass

What to do

1. Weigh 2 g of sand onto the newspaper.
2. Roll and work one of the plasticine colours until it is soft and malleable. Roll it out into a 0.5 cm layer.
3. Sprinkle the sand onto the plasticine and roll it over the sand until the sand is evenly spread through.
4. Repeat steps 2 and 3 with 4 g and 6 g of sand.
5. Work and shape the four pieces of plasticine until they are at room temperature.
6. Form each shape into a cylinder of the same size and length.
7. Hold the ends of a plasticine cylinder firmly and pull firmly apart.
8. Repeat the pull test for each plasticine cylinder.
9. Use the magnifying glass to examine the broken ends of the cylinder.

Results

Record your observations in an appropriate table.

Discussion

1. Which 'alloy' was most malleable (able to be rolled out easily when cold)?
2. Which 'alloy' was most ductile (able to be drawn out into a wire easily)?
3. Which 'alloy' was most brittle (snapped quickly)?
4. Did the amount of sand in the 'alloy' affect the size of the largest fracture surface? Explain your observation

Conclusion

How does the alloying of metal affect its properties?

4.1 EXPERIMENT

Aim

To determine if mass is conserved in a chemical reaction

Materials

- Sodium bicarbonate
- Vinegar
- Balloon
- Balance
- Measuring cylinder
- 2 conical flasks
- Watch glass
- Spatula

Comparing mass before and after a chemical reaction

Method

PART A

1. Copy the results table for Part A to record your results.
2. Weigh 2.0 g of sodium bicarbonate onto a watch glass.
3. Add 20 mL of vinegar to a flask.
4. Ensure the balance is reading zero. Weigh the vinegar and flask. Record this mass (*M*1).
5. Predict whether the mass of the flask and vinegar after the reaction with the sodium bicarbonate will be more, the same or less than the initial mass.
6. Add 2.0 g of sodium bicarbonate (*M*2) to the flask containing the vinegar and swirl until the bubbling stops.
7. Weigh the flask after the reaction has stopped. Record the final mass (*M*3).

PART B

1. Copy the results table for Part B to record your results.
2. Weigh 2.0 g of sodium bicarbonate onto a watch glass.
3. Add 20 mL of vinegar to a flask.
4. Ensure the balance is reading zero. Weigh the vinegar, flask and a balloon. Record this mass (*M*1).
5. Predict whether the mass of the flask, vinegar and balloon after the reaction with the sodium bicarbonate will be more, the same or less than the initial mass.
6. Add 2.0 g of sodium bicarbonate (*M*2) to the flask and quickly stretch the opening of the balloon over the neck of the flask to collect gas.
7. Weigh the flask, with the balloon still attached, after the reaction has stopped. Record the final mass (*M*3).

Results

Results for Part A

MASS OF FLASK AND VINEGAR (*M*1)	MASS OF SODIUM BICARBONATE (*M*2)	TOTAL MASS BEFORE REACTION (*M*1 + *M*2)	MASS AFTER REACTION (*M*3)

Results for Part B

MASS OF FLASK, VINEGAR AND BALLOON (*M*1)	MASS OF SODIUM BICARBONATE (*M*2)	TOTAL MASS BEFORE REACTION (*M*1 + *M*2)	MASS AFTER REACTION (*M*3)

Discussion

1. Compare the initial and final masses for each part of the experiment.
2. Is this what you expected? Explain why or why not.
3. What gas was produced?
4. What was the purpose of the balloon?
5. How could the design of this experiment be improved?

Conclusion

Do you think that mass was conserved in this chemical reaction?

Modelling chemical equations

You will need

- Paper bags
- Model atom kit (or laminated squares labelled oxygen (O) atom, carbon (C) atom, hydrogen (H) atom)
- Felt-tipped pen

PART A

What to do

1. Each paper bag represents a molecule. Create a molecule of oxygen (O_2) by placing two oxygen 'atoms' in a paper bag. Write 'O_2' on the bag.
2. Use two paper bags and four model hydrogen atoms to create two molecules of hydrogen (H2). You have now created the reactants in the chemical reaction: $2H_2 + O_2 \rightarrow 2H_2O$
3. Label the two remaining paper bags 'H^{2}O'. Take the model atoms out of the reactant bags and place them in the product H_2O bags. Are there enough atoms to fill the H_2O bags?

Discussion

1. Why were there more molecules/bags of hydrogen than oxygen?
2. What would happen if one more molecule of oxygen was added to the reaction? Could it react?
3. How does this model reaction conserve mass?

PART B

What to do

1. Use new bags and the model atoms to create two molecules of methane (CH_4).
2. How many molecules of oxygen (O_2) would you need to turn these methane molecules into carbon dioxide (CO_2) and water (H_2O)?

Discussion

1. How many molecules of oxygen did you need to balance this equation?
2. How many molecules of carbon dioxide and water were you able to create with two methane molecules?
3. Write the word equation for this reaction.
4. Write the balanced chemical equation for this reaction.

4.3A
EXPERIMENT

Aim

To produce water by direct synthesis.

Materials

- Magnesium ribbon
- Dilute hydrochloric acid (1 M)
- 2 test tubes and test-tube rack
- Rubber stopper
- Wooden splint
- Matches

Direct synthesis with a 'pop'

Method

1 For this reaction, you require a test tube containing hydrogen gas. The easiest way to produce this is to place three 1 cm lengths of magnesium ribbon in a test tube and add 10 mL dilute hydrochloric acid (Figure 9.9).

Figure 9.9

2 Place the other test tube (make sure it is dry) upside down over the top of the first test tube so that any hydrogen gas produced enters the second test tube (Figure 9.10).

Figure 9.10

3 After 15 seconds, place a rubber stopper over the end of the second test tube to trap the hydrogen gas – you now have a test tube of hydrogen gas.

4 Place the sealed test tube containing the hydrogen gas into the test-tube rack.

5 Light the wooden splint. Remove the rubber stopper and carefully hold the burning splint close to the top of the test tube.

6 Observe the reaction that occurs and examine the inside of the test tube closely.

Results

Record your observations in an appropriate format.

Discussion

1 What evidence was there that water was formed in the reaction?

2 Write a chemical equation for the reaction that occurred, ensuring that no atoms are created or destroyed in the process.

3 Why do you think that heat was required to start the reaction?

4 Apart from synthesis, in what other ways could this reaction be classified? (Hint: Think about the energy involved in this reaction.)

Conclusion

What do you know about the direct synthesis of water?

CAUTION: Wear protective clothing and safety glasses throughout this experiment. Avoid contact with hydrochloric acid.

4.3B
EXPERIMENT

Decomposing a carbonate

Aim
To use heat to decompose copper(II) carbonate to produce copper oxide and carbon dioxide.

Materials
- Copper(II) carbonate
- Copper(II) oxide
- Calcium carbonate powder
- Pyrex (high-strength) test tube
- Test-tube holder
- Bunsen burner
- Matches
- Spatula

Method
1 Describe the appearance of copper(II) carbonate and copper(II) oxide.
2 Place one spatula of copper(II) carbonate into the test tube.
3 Hold the test tube at an angle of approximately 45° and gently heat the bottom of the test tube by moving it carefully in and out of a Bunsen burner flame (Figure 9.11).

Figure 9.11

4 Carefully observe the changes that occur.

Results
Record your observations in an appropriate format.

Discussion
1 What evidence is there that copper(II) oxide was formed in the reaction?
2 What evidence is there that a gas was given off in the reaction?
3 Write a chemical equation for the reaction that occurred, including state symbols.
4 Apart from decomposition, what other ways could this reaction be classified?

Conclusion
What do you know about the decomposition equations?

Further investigation
How could you redesign this experiment to provide evidence that it is carbon dioxide gas that is produced in the reaction? Write an experimental method, including labelled diagrams, and list any additional equipment you will need. Show your design to your teacher and, if it is safe, try your method using copper(II) carbonate and then repeat using calcium carbonate.

CAUTION: Wear safety glasses throughout this experiment. Make sure that the open end of the test tube is facing in a safe direction while heating.

4.3C EXPERIMENT

Aim

To use electricity to produce copper metal from copper(II) sulfate.

Materials

- Copper(II) sulfate
- 100 mL beaker
- Stirring rod
- Spatula
- DC power supply
- 3 leads
- 12 V globe and globe holder
- Wires with alligator clips
- 2 carbon rods

Electrolysis

Background

Copper sulfate ($CuSO_4$) is an ionic substance containing copper(II) ions (Cu^{2+}) and sulfate (SO_4^{2-}) ions.

Method

1. Add one spatula of the copper(II) sulfate to the beaker and half fill it with water.
2. Stir until the crystals are all dissolved.
3. Set the power supply to a maximum of 6 V and connect the circuit as shown in Figure 9.12.

Figure 9.12

4. Touch the carbon rods together to check the circuit works and then place the carbon rods in the beaker with a 1 cm gap between them.
5. Hold the rods in place for 30 seconds and observe any changes that occur.
6. Turn off the power supply.

Results

Record your observations in an appropriate format.

Discussion

1. What evidence was there that copper was formed in the reaction?
2. Considering the structure of the copper sulfate, describe the:
   - role of the water in the process
   - role of the electric circuit
   - reason that the copper was only found on one of the carbon electrodes.
3. Do you think that a usable amount of copper could be produced this way? If not, what changes would need to be made to the set-up to produce more copper?

Conclusion

Was this a synthesis or decomposition reaction? Provide evidence from your results to support your answer.

CAUTION: Wear safety glasses throughout this experiment. Do not let the carbon rods touch when they are in the beaker. Ensure that liquid does not contact the power source at any time.

4.4 EXPERIMENT

Acid titrations

Aim

To compare the reactions of a strong acid, hydrochloric acid, and a weak acid, ethanoic acid, (common name acetic acid).

Materials

- Dropper bottles containing:
  - 0.1 M hydrochloric acid (HCl)
  - 0.1 M ethanoic acid (acetic acid) (CH_3COOH)
  - 0.1 M sodium hydroxide (NaOH)
  - 1 M hydrochloric acid (HCl)
  - 1 M ethanoic acid (acetic acid) (CH_3COOH)
  - universal indicator solution
- pH colour chart
- Small pieces of magnesium ribbon
- 4 test tubes and test-tube rack
- Dropping pipette
- Matches

Method

PART A

1. Draw up a table to record each test and the results for each acid.
2. Place 2 mL of 0.1 M hydrochloric acid in one test tube and add 2 drops of universal indicator solution. Record the colour of the indicator and the corresponding pH from the colour chart.
3. Repeat step 2 with 0.1 M ethanoic acid, using a fresh test tube.
4. To the first test tube add 0.1 M sodium hydroxide drop by drop, counting the drops, until the solution is neutral (i.e. pH = 7).
5. Repeat step 4 with ethanoic acid.

PART B

1. Add 2 mL of 1 M hydrochloric acid to a fresh test tube.
2. Add a small piece of magnesium ribbon to the test tube and invert a clean test tube over the top so there is only a small gap between the test tubes.
3. Record your observations.
4. Lightly touch the base of the bottom test tube. Record your observations of the temperature of the mixture.
5. When the reaction has ceased, light a match and hold it just inside the inverted test tube. Do you hear a loud popping sound? This is evidence of hydrogen gas being produced.
6. Repeat steps 1–6 with 2 mL of 1 M ethanoic acid.

Results

Record your results in an appropriate table.

Discussion

1. When you tested the pH of the two acids, you used the same concentration (0.1 M).
   a. Why were they compared at the same concentration?
   b. Why did they have a different pH?
   c. What can be concluded about the strength of ethanoic acid compared with the strength of hydrochloric acid?
2. Compare the number of drops of sodium hydroxide used to neutralise each acid. Is this what you expected? Explain using your results.
3. Write a balanced equation for each neutralisation reaction.
4. The pop test is the standard test for hydrogen gas. The 'pop' sound is a mini-explosion due to the combustion of hydrogen gas in air, which is a very exothermic (heat producing) reaction. The equation for the reaction is:

   $$2H_2(g) + O_2(g) \rightarrow 2H_2O(l) + \text{energy}$$

   a. Did your tests confirm that hydrogen gas was produced?
   b. Was there a difference in how fast the reactions with the two different acids occurred? If so, suggest why.
5. Write a balance chemical equation for the reaction between the two acids and the magnesium ribbon.

Conclusion

1. What do you know about neutralisation reactions?
2. What do you know about reactions between metals and acids?
3. What do you know about the difference between strength and concentration of acids?

CAUTION: Wear a laboratory coat, gloves and safety glasses throughout this experiment. Most of the substances used in this experiment need to be handled with care.

4.5 EXPERIMENT

Precipitation reactions

Aim

To determine which compounds form precipitates and write equations for the reactions occurring.

Materials

- Plastic document sleeve
- Dropper bottles containing 0.1 M solutions of:
  - Group A: calcium nitrate ($Ca(NO_3)_2$), copper(II) nitrate ($Cu(NO_3)_2$), magnesium nitrate ($Mg(NO_3)_2$), silver nitrate ($AgNO_3$), copper(II) sulfate ($CuSO_4$),
  - Group B: sodium chloride ($NaCl$), sodium hydroxide ($NaOH$), sodium sulfate (Na_2SO_4), sodium carbonate (Na_2CO_3)

Method

1 Draw up a large table as shown here with group B solutions listed across the first row and group A solutions in the first column as shown here:

	$NaCl$	$NaOH$	Na_2SO_4	Na_2CO_3
$Ca(NO_3)_2$				
$Cu(NO_3)_2$				
$Mg(NO_3)_2$				
$AgNO_3$				
$CuSO_4$				

2 Make a second copy of your results table on a piece of A4 paper and place this table into the plastic document sleeve. Place this on the laboratory bench. This now becomes your working area for the experiment and you will add drops of the solutions to corresponding cells on the results table, which is now protected by the plastic sleeve.

3 Place 1 drop of each of the group A solutions in each cell of the results table in the correct row.

4 Add 1 drop of each of the group B solutions to the drops of the group A solutions in the correct columns.

Results

1 Record whether a precipitate forms, as well as its appearance, on your other copy of the results table.

2 Use Table 4.2 (page 98) to help you answer the following questions. For each precipitate formed:

a identify the ions that have combined to form the precipitate and write the formula of the ions

b write the formula of the precipitate

c write a word equation for the reaction.

Discussion

1 The sets of compounds tested included a range of anions: NO_3^-, OH^-, CO_3^{2-}, Cl^-, SO_4^{2-} and Br^-. Of these, which:

a did not form any precipitates?

b only formed precipitates with one or two cations?

2 The sets of compounds tested included a range of cations: Na^+, K^+, Ag^+, NH_4^+, Cu^{2+}, Ca^{2+} and Mg^{2+}. Of these, which:

a did not form any precipitates?

b formed precipitates with only one or two anions?

3 Did the precipitation reactions you observed match those predicted from Table 4.2? Discuss why or why not.

4 Write balanced chemical equations for the reactions between:

a silver nitrate and sodium chloride

b iron(III) chloride and sodium hydroxide.

5 Why is it important not to touch the tip of the dropper bottles on the top of the solution already on the plastic sleeve?

6 What other factors may affect the outcome of these precipitation reactions?

Conclusion

What do you know about predicting precipitation reactions?

4.6 EXPERIMENT

Aim

To observe the oxidation of wire wool.

Materials

- Wire wool
- 9 V battery
- Crucible
- Bench mat
- Balance
- Small spatula

Combustion of wire wool

Method

1 Make a small ball out of the wire wool and place it in the crucible.

2 Record the weight of the crucible and wire wool.

3 Place the crucible in the centre of the bench mat.

4 Quickly touch both terminals of the 9 V battery to the wool and then pull them away (Figure 9.13) (If the wool sticks to the battery, use a small spatula to separate them.)

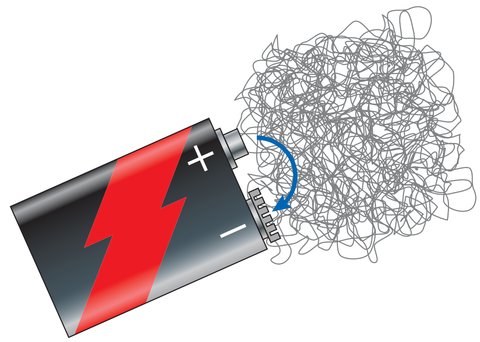


Figure 9.13

5 Write your observations of the reaction.

6 When the wire wool has stopped reacting, weigh the crucible and contents a second time.

Results

Record your masses and observations in an appropriate table.

Discussion

1 Was this reaction an exothermic or endothermic reaction?

2 Was there any change in the mass of reactants and products? Explain your observation.

3 Write a worded equation for this reaction.

4 Write a balanced chemical reaction for this reaction.

Conclusion

What do you know about the oxidation of wire wool?

CAUTION: Wear a laboratory coat and safety glasses throughout this experiment. The wire wool becomes very hot. Use a non-flammable bench mat. Do not touch the wool until it has cooled.

4.7
EXPERIMENT

Polymerisation of casein

Aim

To form polymers of casein monomers.

Materials

- 100 mL full cream milk
- 5 mL ethanoic acid (acetic acid) (CH_3COOH)
- Bunsen burner
- Tripod
- Thermometer
- Gauze mat
- Bench mat
- Spatula
- Filter paper
- Funnel
- Beaker
- Conical flask

Milk contains a protein called casein. When milk is heated and mixed with an acid, such as the ethanoic acid in vinegar, the casein monomers bond with each other to form long polymers. Before the Second World War, casein plastic was used to make buttons, beads and jewellery.

Method

1. Place 100 mL of milk in a beaker and heat it over the Bunsen burner until it is above 49°C.
2. Remove the milk from the Bunsen burner and place it on the bench mat.
3. Add 5 mL of ethanoic acid to the milk. The milk will separate into curds.
4. Place the filter paper in the funnel and filter the casein polymer curds from the whey.
5. Weigh the casein polymer you obtained.
6. Mould the casein plastic into a shape of your choice.

Inquiry

Choose one of the following questions to investigate.

- What if low-fat milk was used?
- What if more vinegar was used?
- What if less vinegar was used?

Answer the following questions in relation to your inquiry.

1. Write a hypothesis for your question.
2. What is your independent variable?
3. What is your dependent variable?
4. Name three controlled variables and explain how you will control them.

Results

Record your observations and measurements in a table.

Discussion

1. What are the reactants used?
2. What are the products produced?
3. What changes have taken place?
4. Is the polymer you created a thermoplastic or thermoset plastic? How could you test this?
5. State a use for this polymer and what properties make it suitable for that use.

Conclusion

What do you know about polymerisation?

4.8A EXPERIMENT

Aim

To investigate the effect of temperature on reaction rate.

Materials

- 0.001 M potassium permanganate solution
- 0.005 M oxalic acid solution
- Test tubes
- Stopwatch
- 250 mL beaker
- 10 mL measuring cylinders
- Safety glasses
- Kettle or access to hot water
- Thermometer

Effect of temperature on reaction rate

Method

1. Construct a hypothesis for your experiment.
2. Write a method for conducting the experiment.
3. This experiment can be performed using a water bath to warm or cool specific amounts of the two solutions to the required temperature before they are mixed. Once mixed, leave the test tube containing the reaction mixture in the water bath while you measure the reaction time. (The reaction is finished when the purple colour of the potassium permanganate disappears.)
4. Consider what different temperatures you will use, how the temperature will be measured, what volumes of solutions should be used and how the results will be best presented.
5. Follow the steps and perform the experiment.

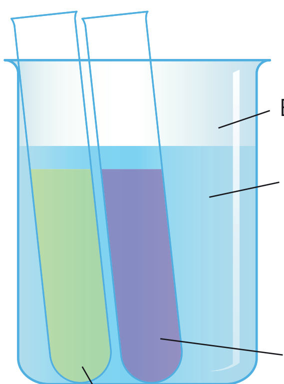


Figure 9.14 A water bath can be used to control the temperature of the solutions.

Hint: Potassium permanganate is toxic to the environment. Try to minimise the amounts used in this experiment.

Conclusion

Write a conclusion for your experiment that includes a discussion of your hypothesis based on the data from the experiment and an evaluation of the methods used to produce these data.

CAUTION: Wear protective gloves, a laboratory coat and safety glasses throughout this experiment. Avoid contact with the potassium permanganate solution and oxalic acid solution.

4.8B
EXPERIMENT

Factors affecting reaction rate

Aim

To investigate the rates of a reaction between hydrochloric acid and calcium carbonate.

Materials

- 30 g small marble chips (calcium carbonate) of similar size
- 20 mL of 0.5 M hydrochloric acid (HCl)
- 20 mL of 1.0 M HCl
- 20 mL of 2.0 M HCl
- Electronic balance
- Stopwatch
- 25 mL measuring cylinder
- 3 × 100 mL conical flasks

Method

1 Place a conical flask on the electronic balance and tare the balance so it reads zero. Weigh approximately 10 g of identical-sized marble chips into the flask.

2 Using a measuring cylinder add 20 mL of 0.5 M HCl to the conical flask still sitting on the electronic balance. Immediately tare the balance once so that it returns to zero briefly, and start the stopwatch. The numbers on the balance will move into negative readings from zero, as gas is given off.

3 Record in your results table the mass loss in grams at 30 seconds, 1 minute and then every minute until 8 minutes.

Inquiry

Choose one of the following questions to investigate.

- What if the marble chips were smaller?
- What if the acid was more concentrated?

Answer the following questions in relation to your inquiry.

1 Construct a hypothesis for your experiment.

2 What independent variable are you investigating?

3 How will you measure your dependent variable?

4 Name three variables that you will control. How will you control them?

5 Write you method step by step and check it with your teacher.

6 Is this experiment safe?

7 What personal protective equipment will you need?

8 How will you record your results? Will the results be quantitative or qualitative?

Results

Copy and complete the following table and plot a graph of the mass loss by minutes.

DEPENDENT VARIABLE	30 s	1 min	2 min	3 min	4 min	5 min	6 min	7 min	8 min

Discussion

1 Write a balanced chemical equation for the chemical reaction.

2 Describe the relationship between your independent variable and dependent variable as shown by your graph.

3 Is the hypothesis supported by the results?

4 Name two possible sources of error in your experiment. How could you improve the quality of the evidence that was obtained in the experiment?

Conclusion

Write a conclusion of your experiment that includes a general statement that summarises the evidence that supports your hypothesis.

CAUTION: Wear protective gloves, a laboratory coat and safety glasses throughout this experiment. Avoid contact with the acid solutions because they are corrosive. If acid comes into contact with your skin, wash it with water immediately.

4.9 EXPERIMENT

Using a catalyst

Aim

To investigate the effect of adding a catalyst to a reaction. The reaction used in this experiment is the decomposition of hydrogen peroxide:

$2H_2O_2(aq) \rightarrow 2H_2O(l) + O_2(g)$

Materials

- Hydrogen peroxide (H_2O_2) solution (10 mL)
- Manganese dioxide (MnO_2) powder
- Test tubes and test tube stand
- Spatula

Method

1. Place 5 mL of hydrogen peroxide solution into two separate test tubes.
2. Allow one of the tubes to stand; add a small amount of manganese dioxide to the other test tube using a spatula.
3. Observe and describe the changes that occur in the two test tubes.

Results

Record your observations in an appropriate format.

Discussion

1. Was there any evidence of reaction in the test tube in which manganese dioxide was not added?
2. Would you say that the manganese dioxide acted as a catalyst in this reaction? Justify your answer.

Conclusion

What do you know about how catalysts affect the rate of a reaction?

CAUTION: Wear protective gloves, a laboratory coat and safety glasses throughout this experiment. Avoid contact with hydrogen peroxide.

Using computer simulations

Scientists can't always find answers to big questions by doing experiments. Often the risks are too great or the experimental method is outside the limits of current technology. Answers to problems like this can sometimes be found using computer simulations.

A computer simulation takes an established pattern and extends it to make a prediction about further events. A simulation is a type of model and, just like other models, it isn't always accurate, but it is the best possible inference or answer to a big question that cannot be tested in any other way. Computer simulations can also be used for experiments that require a lot of repetition that would take a scientist a long time to complete manually, or to infer data about places we can't go to, such as other planets or below the crust of our own planet.

Scientists know that the Earth's mantle is 2800 km thick and that the temperature near the point where the crust and mantle meet is approximately 500°C. Your job is to find out the temperature of the mantle at its deepest point: 2800 km below the Earth's surface.

1 Enter the information from the following table into a spreadsheet program, such as Microsoft Excel or similar.

DEPTH UNDER MANTLE (km)	TEMPERATURE (°C)
100	500
200	598
300	696
400	794
500	892
600	990

2 Create a scatter graph of this information using the graphing function of the computer program. Make sure that temperature is on the *y*-axis and depth is on the *x*-axis.

3 Extend the data in the table until you reach a 'Depth under mantle' of 2800 km. Do this by using the 'fill handle' tool (select the cells in the Excel worksheet and click and drag the small square that appears in the lower right corner of the selection).

4 Update your graph to represent this new data.
   - Does the temperature at a depth of 2800 km match the information you have read above? Explain why there is a variance.
   - The process you have just followed only works for 'linear' data, which is data that increases or decreases at a constant level. Suggest another experiment you have conducted this year that you could have completed by this process.
   - Similar modelling is conducted using data about weather and climate. What predictions would scientists want to make with regard to weather and climate? Why would these predictions be useful?

More complex computer simulations are also available to process much more complicated, or non-linear, data.

5.2 EXPERIMENT

Testing phosphorus

Aim
To determine if phosphorus is present in a variety of detergents.

Materials
- Variety of detergents
- Phosphorus testing kit
- Test tubes and test-tube rack
- Measuring cylinder
- Distilled Water

Method
1 Add 9 mL of distilled water to a test tube.
2 Add 1 mL of detergent to the test tube.
3 Follow the instructions of the phosphorus testing kit to determine if there is phosphorus present in the detergent.
4 Repeat steps 1–3 with the remaining detergents.

Results
Record your observations in an appropriate table.

Discussion
1 What detergents contained phosphorus?
2 Why do living organisms need phosphorus?
3 Why are high levels of phosphorus in waterways a problem?
4 Check the labels on the detergents in your home. What phosphorus-containing detergents do you use regularly?

Conclusion
What do you know about the phosphorus cycle?

5.3 EXPERIMENT

Make your own clouds

Aim
To simulate the process of condensation.

Materials
- Ice cubes
- Water
- Bench mat
- Tripod
- 250 mL beaker
- Gauze mat
- Evaporating dish
- Matches
- Bunsen burner
- Safety glasses

Method
1 Set up the apparatus as shown in Figure 9.15 (except the evaporating dish and ice).
2 Heat the water in the beaker until it boils.
3 Turn the gas off and place an ice-filled evaporating dish on top of the beaker.
4 Carefully observe what happens.

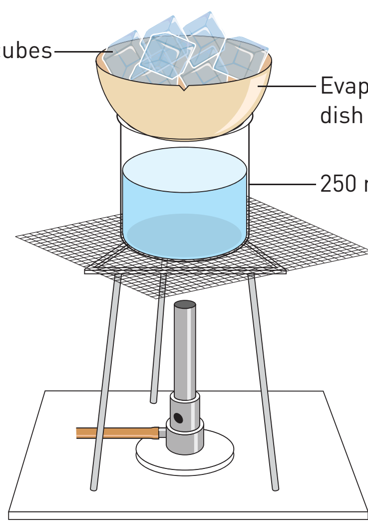


Figure 9.15 Experimental set-up.

Results
Include your observations in an appropriate format.

Discussion
1 What action produced water vapour?
2 What happened to the water vapour?
3 In which of the Earth's spheres would you find water vapour?
4 Why is the condensation of water important to the biosphere?

Conclusion
What do you know about the importance of water condensation in the Earth's spheres?

Making a simple barometer

What you need

- Glass jar
- Rubber balloon
- Rubber band
- Straw
- Sticky tape
- Sheet of thick paper with a scale marked on it

What to do

1. Cut a section from the balloon large enough to cover the opening of the jar.
2. Secure the rubber balloon over the jar with the rubber band.
3. Tape the straw onto the balloon.
4. Place the paper with the scale near the end of the straw and mark on the scale where the straw is.
5. Check the position of the straw on the scale over a few days. Mark each position of the straw (Figure 9.16).

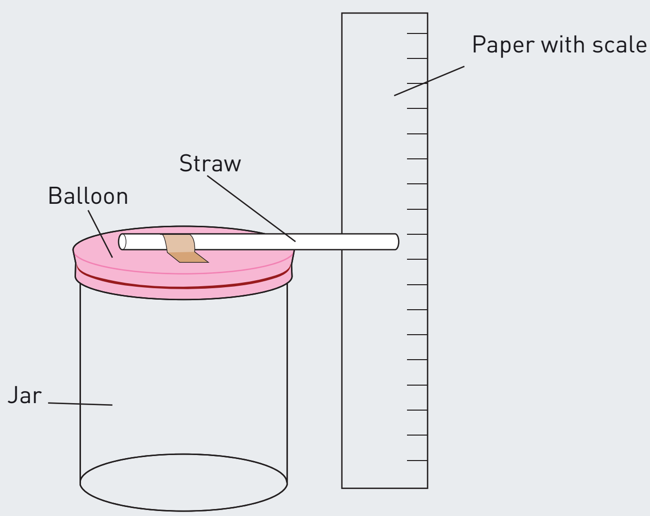


Figure 9.16 Experimental set-up.

Discussion

1. What happened to the rubber balloon as the outside air pressure changed?
2. What happened to the position of the straw against the scale? Why was this?
3. Use the particle model of air to explain why the rubber balloon gets pushed in or out of the jar by the surrounding air.
4. This 'barometer' will also respond to changes in temperature in addition to changes in air pressure. Explain why.

5.4 CHALLENGE

Modelling a carbon sink

This activity may be demonstrated by your teacher.

What you need

- Dry ice
- 100 mL water
- Universal indicator
- 200 mL beaker
- Piece of netting
- Watch glass that covers the top of the beaker
- Sticky tape
- Wooden or plastic tongs

What to do

1. Place the water in the beaker.
2. Add 5 drops of universal indicator to the water.
3. Place the netting over the top of the beaker and push down the centre slightly. This will provide a pouch to suspend the dry ice above the water. Use sticky tape to hold the netting in place.
4. Place a piece of dry ice in the netting and place the watch glass over the top of the beaker.
5. Observe any colour changes in the water.

Discussion

1. What happened to the solid dry ice?
2. Describe any changes you noticed in the water.
3. What was the final pH of the water?
4. Provide an explanation for the changes you noticed.
5. What is a carbon sink?
6. How could you use this demonstration to explain the consequences of increased carbon dioxide levels in the atmosphere?

CAUTION: Dry ice is frozen carbon dioxide (–79°C). Do not touch the dry ice with your fingers or metal objects. Use wooden or plastic tongs. Do not seal dry ice in any container as the gas expands rapidly.

5.5A
EXPERIMENT

What factors affect a greenhouse?

Aim

To determine which surfaces of the Earth absorb energy and radiate it as heat and so are likely to contribute most to the warming of the atmosphere.

Materials

- 3 cups of dark soil
- 3 cups of white sand or perlite
- White paint and brush
- Water
- 6 identical clear, empty 600 mL soft-drink bottles with labels removed
- 6 one-hole rubber stoppers with thermometers inserted that fit securely into the bottle top or data-logging equipment using long steel temperature probes with Blu Tack to secure the probe in place
- 6 plastic containers at least 11.5 cm in diameter at the top (e.g. margarine containers)
- Funnel
- Sunlight or one 150 W floodlight bulb
- Portable reflector lamp
- Stand to support the lamp set-up (retort stand and clamps)

Method

1. Work as a group and label the bottles A, B, C, D, E and F. Paint the upper one-third of bottles B, D and F white to represent cloud cover.
2. Use a funnel to fill the base of bottles A and B with dark soil, bottles C and D with white sand or perlite, and bottles E and F with room-temperature water. Ensure that you use the same depth (5–7 cm) in each bottle.
3. Put the thermometers inserted in the rubber stoppers into the bottle tops. Ensure that the bulbs are just above the top of the dirt, water, perlite/sand. If the bulbs are below the base, they may record the heat absorbed directly by the soil or water, which will affect your data. You want to measure the temperature of the air (atmospheric). If using a data-logger temperature probe, secure and seal into the top of the bottle with Blu Tack.
4. Record the initial baseline atmospheric temperature of each bottle in a table.
5. If it is a sunny day, take your bottles outside and record the temperatures of each bottle in a table every 2 minutes for at least 20 minutes. Alternatively, set up the 150 W light source on a stand facing down. Place the bottles underneath the light source approximately 15 cm away from the lamp. It is important that all bottles receive equal light. Depending on your light source, you may be only able to do two bottles at a time. If this is the case, ensure the two bottles have the same base; for example, dirt.

Results

Predict which bottle will get hottest and justify your prediction. Draw a graph of time (in minutes) versus temperature to record your observations.

Discussion

1. Compare the graphs for the different bottles. Describe the differences. What do these graphs indicate?
2. Which situation produced the lowest temperature? Which situation would lead to the least heating of the atmosphere?
3. Suggest some possible explanations for your results.
4. Explain how this experiment demonstrates the effect of the oceans and dark and light surfaces on air temperature.
5. If the deserts are increasing and ice is melting, exposing dark soil, what effects would you expect these changes to have on atmospheric temperature?

Conclusion

Summarise your key findings from this experiment.

5.5B
EXPERIMENT

Aim

To observe the effect of melting sea and sheet ice on global sea levels.

Melting ice and its effect on sea levels

PART A: SEA ICE

Sea ice is floating ice, like the ice found in icebergs. Design an experiment that shows the effects of melting sea ice on water level (e.g. an ice cube floating on water).

PART B: SHEET ICE

Sheet ice is ice resting on land. Approximately 98% of Antarctica is covered by sheet ice and the Antarctic ice sheet is one of two polar ice sheets. Design an experiment that shows the effects of a melting ice sheet on water level (e.g. an ice cube resting on clay).

Results

Present your results for each experiment in an appropriate format.

Discussion

1 How did the water level change as the sea ice melted?
2 How did the water level change as the sheet ice melted?
3 Provide an explanation for any differences you observed.

Conclusion

Will melting sea ice or melting sheet ice have the greater effect on sea levels? Why?

5.6
CHALLENGE

Salt water density

What you need

- Salt
- Water
- Measuring spoons
- Food colouring (4 different colours)
- Test tube and test-tube rack
- 4 × 200 mL beakers
- Pipette

What to do

1 Add 150 mL of water to each beaker. Label the beakers 1–4.
2 Add 1 teaspoon of salt to beaker 2 and mix thoroughly.
3 Add 2 teaspoons of salt to beaker 3 and mix thoroughly.
4 Add 3 teaspoons of salt to beaker 4 and mix thoroughly.
5 Add a different food colour to each beaker of salt and water.
6 Use the pipette to add 2 cm of salty water from beaker 4 to the bottom of the test tube.
7 Carefully use the pipette to add 2 cm of the salty water from beaker 3 so that it runs down the sides of the test tube. Be careful not to mix the two solutions.
8 Repeat the previous step with beaker 2 and then beaker 1 so that you achieve a test tube with different coloured layers.

Discussion

1 What is density?
2 Which is denser, the solution in beaker 1 or beaker 4? Provide evidence from your results to support your answer.
3 Relate your results to the movement of water in ocean currents.

Using a star chart

Planispheres or star charts are very useful maps for locating various stars in the night sky. A sky chart can be easily downloaded each month from www.skymaps.com. A sky chart and calendar are given on page 1, whereas page 2 has various notes and explanations about the objects you can see.

What you need

> A copy of this month's sky chart (Make sure you click on the southern hemisphere option.)

What to do

1. Read the instructions on how to use the sky chart. These are printed around the outside of the circular chart, along with other useful information about the chart.
2. Find the south celestial pole (SCP), which is marked a few centimetres above south on the chart. This is just a place in the sky; there is no star nearby. Over the course of a night, the stars appear to rotate about this point. In the northern hemisphere, the North Star is located at the north celestial pole (NCP) and so it is used in navigation to find north.
3. Look at the bottom right-hand corner of the chart, which gives a key to the symbols on the chart. The star magnitudes give the brightness of the stars as viewed from the Earth.
   - Can you see that Sirius is the brightest star in the sky?
   - Which star is the second brightest?
   - Which is brighter, Alpha or Beta Centauri?
   - Use your star chart to observe the night sky. How many stars and constellations can you identify? Report back to your class.

6.1 CHALLENGE

Modern-day Australian astronomers

Two prominent astronomers currently practising in Australia are Penny Sackett and Brian Schmidt (Figure 9.17).

Figure 9.17 Brian Schmidt and Penny Sackett.

Your task

Below are some jumbled facts about these two scientists. Carry out some research to help you match the facts to the correct scientist. Answer any questions below and add any other interesting or up-to-date facts about each person. Find some images to go with your information.

- Conducted major research into extrasolar planets. (What are these?)
- Headed the SkyMapper project. (What is this?)
- Was a member of the High-Z SN search team. (What did this team do?)
- Served on the Board of Directors of the Giant Magellan project. (What is this?)
- Born in 1967 in the USA.
- Has worked as a science reporter for *Science News*.
- Born in 1956 in the USA.
- Made a major scientific breakthrough in 1998. (What was it?)
- Worked as Director of the ANU Research School of Astronomy and Astrophysics. (When?)
- Worked mainly with exploding stars called supernovas.
- Appointed as the Chief Scientist of Australia. (When?)
- Been jointly awarded the US$1 million Shaw prize for astronomy. (When and why?)

6.2 CHALLENGE

Understanding parallax

What you need

- Whiteboard
- Whiteboard marker

What to do

1. Position a student in front of the class approximately 2–4 metres in front of the whiteboard (if possible).
2. Write a series of numbers across the whiteboard at the same height as the student.
3. Ask each member of the class to decide which number is in line with the student.

- Why do most members of the class see a different alignment of the student and the numbers on the whiteboard?
- Relate this activity to the night sky. What do the numbers represent? What does the student represent? What do the members of the class represent?
- How would the results of this demonstration be different if the student stood approximately 30 cm in front of the whiteboard?

6.2 EXPERIMENT

Calculating the distance to the Sun

Aim

To determine a value for the distance from the Earth to the Sun using a pinhole screen and to compare this with the known value.

Materials

- Metre ruler
- Retort stand (about 76 cm in height)
- Clamp
- Coat hanger
- Sticky tape
- Needle or pin
- 2 × A4 sheets of paper
- Calculator
- Sun visible in the sky

Theory

This experiment uses ratios to determine the distance from the Earth to the Sun. If you know the distance from the pinhole to the image of the Sun, the diameter of the Sun's image and the diameter of the Sun, you can calculate the unknown – the distance to the Sun.

You will use the following symbols:

- length from pinhole to Sun's image, L_i
- distance to the Sun, L_S
- diameter of Sun's image, d_i
- diameter of the Sun, d_S

You can write an equation using these four quantities. Try writing this equation or ask your teacher for help. It can be written in either fraction or ratio form.

Method

1. Wrap a sheet of A4 paper around the coat hanger and tape securely into place to form a screen.
2. Make a tiny pin hole in the centre of the screen covering the coat hanger.
3. In the centre of the other sheet of paper, draw two lines approximately 7 mm apart and measure the distance as accurately as possible. It doesn't matter if they are not 7 mm apart, but measure them as carefully as possible and record this value.
4. Tape the A4 paper with the two lines to the top of the base of the retort stand, making sure that the two lines are centred on the base horizontally.
5. Clamp the pinhole screen horizontally so it is facing the screen on the base of the stand and is about 40 cm away from the base.
6. Go outside and point the screen with the pinhole at the Sun. Adjust the position of the pinhole screen along the rod so that the circle of light from the Sun through the pinhole falls exactly between the two lines you drew on the base of the retort stand. The circle of light has to also fill the two lines by just touching both lines.

Results

1. Measure and record the distance between the two lines on the screen. This is d_i in the equation.
2. Measure and record the distance between the two screens in millimetres. This is L_i in the equation.
3. The accepted value of the diameter of the Sun, d_S, is 1 392 000 km.
4. Use the equation to perform a calculation based on the measurements to determine a value for L_S.

Discussion

1. The correct value for the distance to the Sun is approximately 149 600 000 km. Work out the difference between L_S and this value. Call this value the difference.
2. Divide the difference by the correct value and multiply by 100. This converts it to a percentage and is called the percentage error. Round it off to the nearest whole number.
3. What factors contributed to this error? (Hint: Which measurements were not exact?)

Conclusion

Write a conclusion for this experiment that relates the findings to the aim. Mention the size of the percentage error and comment about how the experiment could have been modified to reduce the errors.

6.4 CHALLENGE

Exploring the Doppler effect

What you need

- Source of sound that can be spun on a rope (known as a Doppler effect apparatus)

What to do

1. Switch on the sound source and spin it around, making sure no one is in its path (see Figure 9.18).
2. Listen carefully to the pitch of the sound.

Discussion

1. What happens to the pitch of the sound as the Doppler effect apparatus spins around?
2. When is the pitch higher? When is it lower?
3. Relate this demonstration to the red shift and blue shift that are seen with starlight.

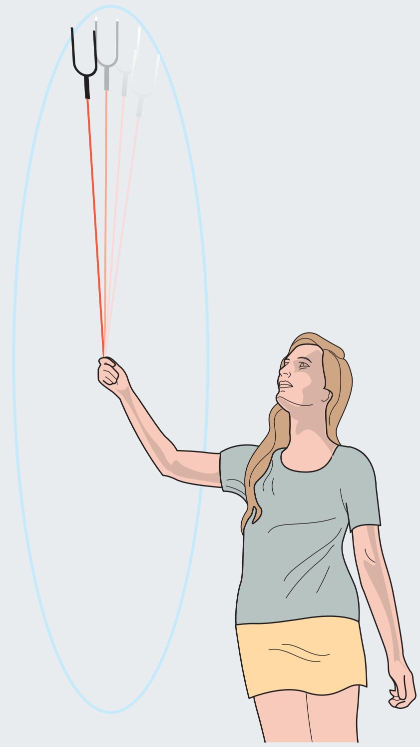


Figure 9.18 Using the Doppler effect apparatus.

6.4 EXPERIMENT

Investigating emission spectra

Aim

To investigate the light emitted by various elements by spectroscopy.

Materials

- Spectroscope
- Discharge tubes for different elements – hydrogen, helium and neon
- Power supply for discharge tubes

Method

1. Connect the equipment and darken the room.
2. Aim the spectroscope at the discharge tube and observe the emission spectrum.
3. Repeat for each tube.

Results

Record the position and colour of the emission lines for each element. Present the results in a table.

Discussion

1. Each element has a distinct emission spectrum. How is this used to identify the elements present in the universe?
2. If the light from a distant nebula had lines missing from its spectrum, what would that mean?

Conclusion

How does the light emitted from different elements vary?

6.5
CHALLENGE

The expanding universe

What you need

> Balloon
> Permanent marker
> Tape measure

What to do

1 Use the ruler to mark three crosses on the side of the balloon 1 cm apart. Mark the centre cross as the origin (O).
2 Inflate the balloon. Measure the distance of each cross from the origin (O).

Discussion

1 How far has each cross moved?
2 Predict what would happen to the distance between the crosses if you added more air into the balloon.
3 Relate the movement of the crosses to the expansion of the universe.

7.1
CHALLENGE

Bringing graphs to life

Working in pairs, act out the position–time graph in Figure 9.19.

What you need

> Clear space (maybe outside)
> Tape measure
> Stopwatch
> Masking tape
> Marker pen

What to do

1 Lay out a 4 metre piece of masking tape on the floor and mark it at intervals of 1 metre.
2 Rehearse the motion shown in Figure 9.19 by discussing it with your group and even doing a walk-through rehearsal.
3 Start the stopwatch and try to match your motion to the graph. The person timing you will give you feedback on how you went.
4 Swap roles and repeat the activity until everyone in your group has had a turn.
5 Repeat the activity with another piece of masking tape on the floor going 4 metres in the opposite direction.

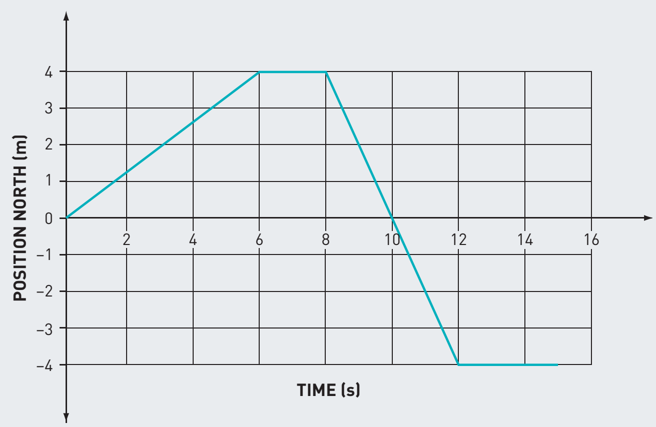


Figure 9.19

Discussion

1 How did your group perform in this task?
2 What difficulties did you have in demonstrating the motion?
3 Draw your own position–time graph and try to act out the motion. How did you go this time?

7.2A EXPERIMENT

Aim

To learn how a ticker timer operates and to use it to produce a speed–time graph.

Materials

- Ticker timer
- Scissors
- Power supply
- Graph paper
- 2 electrical wires
- Glue
- Ticker tape
- Carbon circles
- Ruler

The ticker timer

Method

1 Connect the ticker timer to the AC terminals of the power supply using the two electrical wires (Figure 9.20).

Figure 9.20

2 Thread a 30 cm length of ticker tape through the slots in the ticker timer. Turn on the power and pull the tape through the timer. Examine the tape to see if the dots are clear (Figure 9.21).

Figure 9.21

3 If the dots are too faint, adjust the equipment by increasing the voltage of the power supply. A new carbon disc may be required if this doesn't solve the problem. It can also help to loosen or tighten the screw holding the 'arm' of the ticker timer.

4 Repeat with a 1 m length of ticker tape. As you pull the ticker tape through, adjust your pulling speed so that there is a very slow section, a medium speed section and a very fast section, in any order.

Results

1 Start your analysis by finding the first clear dot. Number this dot '0'. Count along another five dots and rule a line right through the middle of the fifth dot. This gives a five-'gap' section of tape. The gap between successive dots is 0.02 seconds, so five gaps equals 5×0.02 or 0.1 seconds.

2 Divide the rest of your tape into five-gap sections by ruling lines through the middle of every fifth dot.

3 Number the sections of your tape and cut along the lines.

4 Glue each section of tape onto your graph paper, side by side, to form a column graph.

5 Add axes to your graph (speed on the *y*-axis and time on the *x*-axis) and work out a scale for each axis (see the hint below).

Discussion

1 Why does the length of each tape column indicate the speed?

2 How could you work out the average speed of each section?
(Hint: Average speed = distance ÷ time)

3 Why is it only the 'average' speed?

4 Design another experiment you could do using a ticker timer. Ask your teacher for permission to carry out your experiment.

Conclusion

What information can you determine using a ticker timer?

7.2B
EXPERIMENT

Using a motion sensor

Aim

To become familiar with the operation of a motion sensor and to use it to produce motion graphs.

Materials

- Motion sensor
- Dynamics trolley
- Laptop computer
- Cardboard reflector

Method

1. Connect the laptop to the motion sensor and open the appropriate software for your motion sensor on the laptop.
2. Position the motion sensor several metres in front of the dynamics trolley and push the trolley towards the sensor. (You may need to attach a cardboard reflector to the front of the trolley to reflect the signal from the motion sensor back to the sensor.) Ensure the trolley does not contact the motion sensor.

Results

Analyse the data on the laptop to produce a position–time graph (and speed–time graph and even an acceleration–time graph if possible).

Discussion

1. Can you work out what each graph is showing you?
2. How well did the graphs represent the actual motion of the trolley that you witnessed?
3. Design another experiment you could perform with the motion sensor.
4. Evaluate this experiment compared with Experiment 7.2A in which you used the ticker timer. Which measuring instrument did you prefer and why?

Conclusion

What information do the graphs created by a motion sensor tell you?

7.3
CHALLENGE

Measuring acceleration by timing or using a motion sensor

SAFETY: Never drop objects from high places without looking below to make sure the area is clear. Never drop objects off buildings or bridges.

What you need

- Ball
- Stopwatch
- Tape measure
- Motion sensor

What to do

1. Measure how long it takes to drop a ball from one storey in seconds (*t*).
2. Measure the distance the ball fell in metres (*h*).
3. For more accuracy, or as a comparison, you could use a motion sensor connected to a computer to measure the acceleration directly.
4. Use the results to determine the acceleration due to gravity in units of m/s^2. The formula that describes this situation is: $h = \frac{1}{2}at^2$
5. Rearrange the formula to make *a* (acceleration) the subject and substitute your values for *h* and *t*. The resulting value for *a* is the acceleration due to gravity (although it usually has the symbol *g*), which should be 9.8 m/s^2 near the Earth's surface, although we often round it off to 10 m/s^2 for calculations.
   - How close to 9.8 m/s^2 were your results?
   - Can you account for any differences?

Challenge: You may like to make several different measurements and plot them as an h–t^2 graph on your calculator. If you do a regression fit to the data, the gradient is h/t^2, which is $\frac{1}{2}g$. Double the gradient to get an average value for *g*.

7.4A
CHALLENGE

Make an accelerometer

What you need

- Small glass jar and lid
- Paperclip
- Short length of cotton
- Sticky tape
- Water

What to do

1 Tie one end of the cotton to the paperclip.
2 Stick the other end of the cotton to the underside of the lid so the paperclip hangs vertically inside the jar without touching the bottom.
3 Fill the jar with water and screw the lid on.
4 Test your accelerometer by pushing it slowly along a table, then speed it up, move it at constant speed and finally slow it down.
5 Take your accelerometer with you in the car, bus or train and observe the position of the cotton and paperclip when the vehicle:
  - starts moving
  - slows its movement
  - travels at constant speed in a straight line.

Discussion

1 Why does the paperclip resist moving when the jar starts moving?
2 Why does the paperclip keep moving forwards when the jar comes to a rest?
3 What happens to the paperclip when the jar is moving at a constant speed?
4 How do our own bodies tell us we are accelerating, decelerating or travelling around a corner?

7.4B
CHALLENGE

How do you like your eggs?

What you need

- 2 eggs in their shells – one fresh and one hard-boiled, but no indication of which is which (Note: Use half-full water bottles if egg allergies are a concern.)

What to do

1 Spin both eggs on a flat surface.
2 Stop the eggs gently by placing your finger momentarily on top of the spinning egg, then release the egg by lifting your finger off it. Does it stay stopped or keep spinning?

Discussion

1 How does the egg's motion after you release your finger help you to predict whether the egg is hard-boiled or fresh? Open the shells (over a rubbish bin or sink) to see if you are correct.
2 Think about the inside of the egg and the motion of the shell and the egg itself while it is spinning. Think also of Newton's first law. Describe what you did in terms of inertia.

7.5A

EXPERIMENT

Aim

To investigate the addition of vectors using three spring balances.

Materials

- 3 spring balances (0–10 or 0–20 N are best)
- 2 rubber bands
- Graph paper
- Masking tape

Resultant forces

Method

1 Test to see that each spring balance reads zero with no force exerted on its hook. (This is known as checking the 'calibration'.) If not, adjust it so it does.

2 Tape a piece of graph paper to the bench and draw a large dot in the centre of the paper.

3 Tie one rubber band to the centre of the other to create three 'loops' with a knot in the centre.

4 Hook each spring balance onto the loops lying flat on the paper and position the knot so that it stays directly above the dot on the graph paper (Figure 9.22).

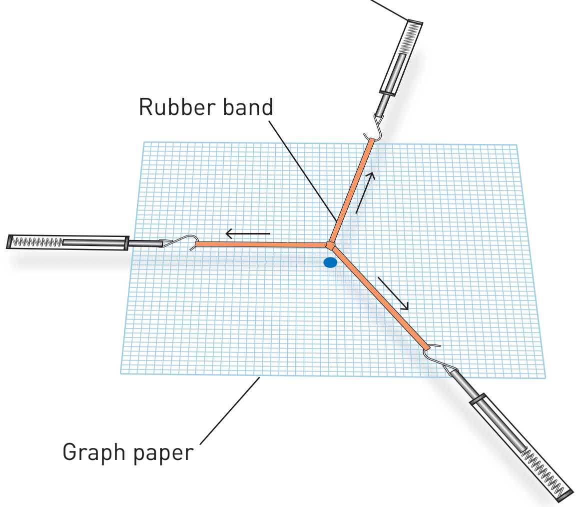


Figure 9.22

5 Pull on the spring balances in different directions so that the knot stays directly over the dot.

6 Record the force reading on each spring balance and draw the direction of the force on the graph paper. This can be done by drawing a line directly below the rubber bands.

7 Repeat the experiment twice more using different-sized forces and different directions.

Results

1 Drawing a force diagram: Remove the graph paper and create a force diagram by choosing an appropriate scale (usually 1 cm = 1 N) and drawing the three forces acting from the dot in the correct directions. The forces are drawn as lines with arrowheads. The direction of the arrowhead shows the direction of the force. The length of each line should show the size of each force.

2 Drawing a vector diagram: To convert the force diagram into a vector diagram, leave one of the force arrows in position where it is, then 'slide' the other two force arrows so that all three join head to tail with each other. When all three forces are added, determine the net force by drawing a line from the start to the end and head-to-head and tail-to-tail. This shows the result of the three individual vectors, which should be very small or even non-existent if you did the experiment correctly.

Discussion

1 What is the difference between a force diagram and a vector diagram?

2 What does 'net force' mean?

Conclusion

What is the net force on a stationary object? Explain.

7.5B EXPERIMENT

Accelerating masses

Aim

To determine the relationship between mass and acceleration.

Materials

- Dynamics trolley
- String
- Mass hanger and brass 50 g masses
- Several 1 kg masses
- Desk-mountable pulley wheel with clamp
- Electronic balance
- Motion sensor or stopwatch
- Tape measure or ticker timer
- Power supply
- Ticker tape
- Cushioning material

Method

1 Clamp the pulley wheel to the edge of the desk. Try to arrange the largest height above the floor as possible (Figure 9.23).

Figure 9.23

2 Attach one end of the string to the dynamics trolley and the other end to the mass hanger, carrying a total of approximately 200 g of mass (Figure 9.24).

Figure 9.24

3 Hang the masses over the pulley so they can pull the trolley along as they fall to the floor. Place the cushioning material under the weights to reduce impact.

4 Record the motion of the trolley as the masses fall, by using a motion sensor, timing with a stopwatch or recording the motion on ticker tape (Figure 9.25).

Figure 9.25

5 Successively add 1 kg masses to the trolley and repeat your measurements several times.

Results

1 Determine the acceleration of the trolley for your method.

2 If you used a motion sensor, use software (see Experiment 7.2B) to determine the acceleration directly or from the gradient of a velocity–time graph.

3 If you used a stopwatch, calculate the acceleration as (2 × the distance travelled ÷ time squared).

4 If you used a ticker timer, use the 'every fifth dot method' as per Experiment 7.2A to divide the tape into sections. Determine the speed of each section by dividing the distance covered by 0.1. Plot a speed–time graph and determine the acceleration from the gradient of the graph.

5 Plot a graph of acceleration versus total mass. This should give a truncated, or inverse, graph.

Discussion

1 How did increasing the mass on the trolley affect the acceleration of the trolley?

2 Relate your experiment to a real-life example.

Conclusion

What is the relationship between mass and acceleration?

7.6 EXPERIMENT

Aim

To examine the action and reaction of a balloon rocket.

Materials

- Balloon
- Drinking straw
- Sticky tape
- Fishing line
- Timer
- Measuring tape

What if forces were changed on Newton's rocket?

Method

1. Thread the fishing line through the straw.
2. Tie the ends of the fishing line to two fixed points across the room.
3. Inflate the balloon and hold it shut. Measure the diameter of the balloon.
4. Use the sticky tape to tape the inflated balloon to the straw (Figure 9.26).
5. Release the end of the balloon and measure the distance the balloon travels and the time it takes to come to a complete stop.
6. Reinflate the balloon to the same diameter. Repeat step 5.
7. Determine the average speed of the balloon.

Results

Record your results in an appropriate table.

Discussion

1. Why does the balloon move forwards?
2. Draw a picture of the balloon rocket with all the forces that are acting on it.
3. Describe the action and reaction that occurs in the balloon rocket.
4. How would you expect the average speed to change if the balloon was inflated less? Explain.

Conclusion

Describe how Newton's third law applies to your balloon rocket.

Inquiry

Choose one of the following questions to investigate.

- What if the amount of air in the balloon was increased?
- What if a string with more friction was used?

Answer the following questions in relation to your inquiry.

1. What is the independent variable?
2. What is the dependent variable?
3. List three variables you would need to control and how you will control them.
4. Write a hypothesis for your experiment.
5. Use force diagrams to explain the science behind your hypothesis.

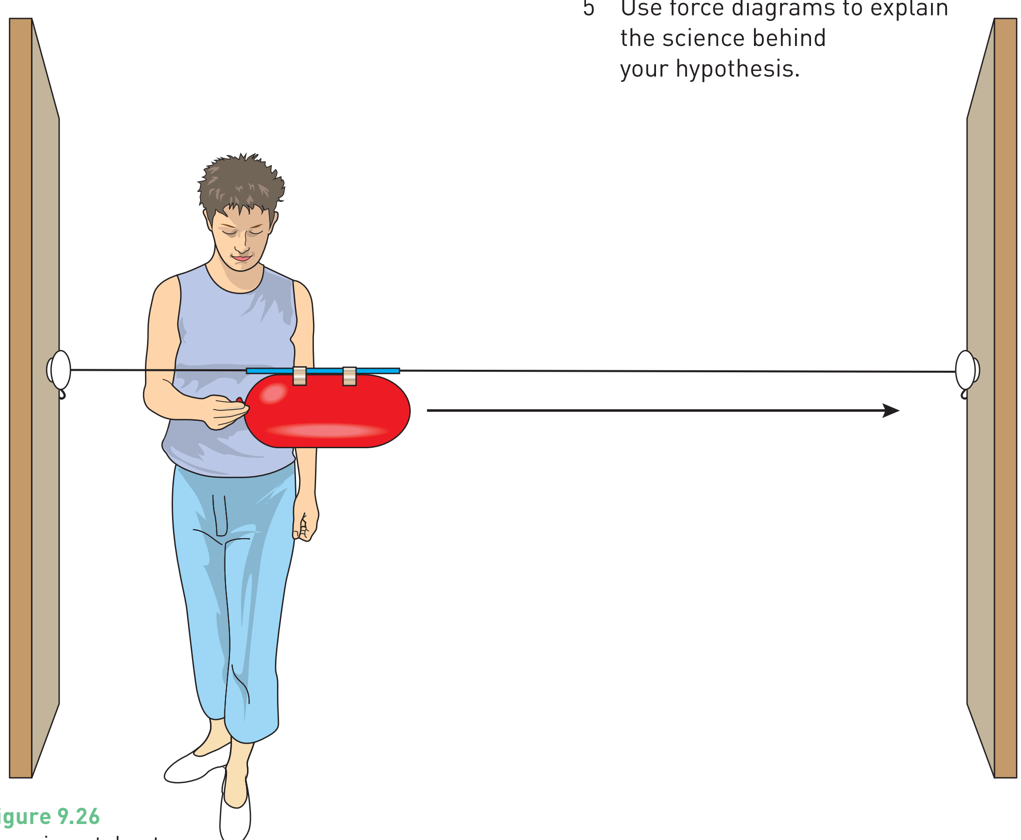


Figure 9.26
Experimental set-up

7.7 EXPERIMENT

Colliding trolleys

Aim

To investigate whether total momentum is conserved during a collision.

Materials

- 2 dynamics trolleys
- Metre ruler
- Ruler
- Several 1 kg masses to add to the trolleys
- 2 rubber bands tied together that will stretch to 20 cm quite easily
- Level benchtop
- Piece of A4 paper
- Masking tape

Method

1 Attach the piece of A4 paper to the benchtop with masking tape. Rule two parallel lines on the paper, 20 cm apart (Figure 9.27).

Figure 9.27

2 Link the two trolleys with the rubber bands (Figure 9.28).

Figure 9.28

3 Pull the trolleys apart and hold them with their front ends on the two lines (Figure 9.29).

Figure 9.29

4 Release the trolleys. The trolleys will accelerate towards each other and collide at the same time. How far the trolleys travel in a given time is proportional to their relative velocities. Determine where the trolleys collide and mark the collision point on the paper.

5 Measure the distance from one line to the collision point (d_1) and the same for the other line (d_2). Because the trolleys collide at the same time, there is no need to measure the times because the distances are proportional to the collision speeds.

6 Add various masses to one (or both) of the trolleys and repeat the experiment. Test approximately five different mass combinations.

Results

Record the following result headings in a spreadsheet or table.

- m_1 = mass of trolley 1 plus any 1 kg masses added (total in kg)
- d_1 (in m)
- $m_1 \times d_1$
- m_2 = mass of trolley 2 plus any 1 kg masses added (total in kg)
- d_2 (in m)
- $m_2 \times d_2$
- $(m_1 \times d_1) - (m_2 \times d_2)$

The final column gives a measure of the total momentum of the two trolleys just prior to the collision. The negative sign is used because the two trolleys are travelling in opposite directions and therefore one momentum is negative.

Discussion

1 When the trolleys are released, do they travel towards each other for the same period of time? Explain.

2 Is the magnitude of the force acting on each trolley the same? Explain.

3 If both trolleys come to a stop after the collision, what was the final total momentum of the 'system'? Explain.

4 According to the last column of results, what was the initial total momentum of the 'system'?

Conclusion

What did this experiment demonstrate about the total momentum before and after a collision?

8.1

EXPERIMENT

Aim

To determine the relationship between the elastic potential energy and kinetic energy of an elastic band.

Materials

- Metre ruler
- Elastic bands
- Tape measure
- Chalk
- Spring balance

What if an elastic band was stretched further?

Method

1 Use the chalk to place a mark on the ground. This is the starting point for your elastic band.

2 Hook one edge of the elastic band on the end of the ruler. Pull the rubber band back to the 10 cm mark on the ruler and let it go.

3 Measure the distance the elastic band moved.

4 Repeat steps 2 and 3 another three times (remembering the angle and height needs to be consistent with the first attempt) and average the distance the elastic band travelled.

5 Use the spring balance to determine the amount of force (N) needed to stretch the elastic band 10 cm.

Inquiry

What if the elastic band was stretched further?

1 What is the independent variable?

2 What is the dependent variable?

3 List three variables you will need to control and how you will control them.

4 Write a hypothesis for your experiment.

5 Explain the science behind your hypothesis.

Results

1 Draw an appropriate table for your experiment.

2 Draw a graph of the distance the elastic band was stretched against the distance the elastic band moved.

3 If $F = kx$ where F is the force needed to stretch the rubber band 10 cm (as measured by the spring balance) and x is 0.1 m, then what is k, the elastic constant for your elastic band?

4 Use the elastic constant you measured in step 3 to determine the amount of energy in the elastic band when you stretched it 10 cm. Remember to convert the cm into m.

Discussion

1 Describe the relationship between the distance the elastic band was stretched and the distance the elastic band moved.

2 Where did the initial energy come from to stretch the elastic band?

3 What type of energy did the elastic band have?

4 How much work was done when the elastic band was first stretched? ($W = Fd$)

5 If all the elastic potential energy was transformed to kinetic energy, how much kinetic energy did the elastic band have when it left the ruler?

6 What velocity did the elastic band have when it left the ruler? ($KE = \frac{1}{2}mv^2$)

Conclusion

What do you know about the energy in an elastic band?

CAUTION: Wear safety glasses at all times to prevent eye injuries.

Conservation in action

Analysis of a simple pendulum shows that it follows a similar pattern to dropping a mass.

What you need

- Simple pendulum made from a mass on the end of a length of string
- Retort stand
- Balance
- Tape measure

What to do

1. Hang the simple pendulum from the retort stand (Figure 9.30).
2. Lift up the mass and release it. As it swings, its GPE is converted into KE and back into GPE. The process continues until the pendulum finally comes to rest.
3. Measure how much GPE the pendulum mass had at the start before it was released by measuring its mass and starting height above the bench and using the GPE formula.
4. Allow the pendulum to complete 10 full swings (the release point is swing 0) and stop it at the end of its 10th swing. Hold the weight at the finishing height.
5. Measure the finishing height of the pendulum.

Discussion

1. Draw a picture of the pendulum at its highest point. What is its gravitational potential energy at this point?
2. Draw a picture of the pendulum at its highest point after 10 swings. What is its potential energy at this point?
3. How much energy was 'lost' to air friction each swing of the pendulum (divide by 10 swings)?
4. Work out the energy efficiency of the pendulum. Set out your calculations clearly and accurately.

Figure 9.30

Figure 9.31

8.3 EXPERIMENT

Thermal energy versus temperature

Aim
To investigate the difference between thermal energy and temperature

Materials
- Water
- Small iron weight
- Iron nail
- 2 × 100 mL beakers
- Bunsen burner
- Tripod
- Heatproof mat
- 2 thermometers
- Tongs

Method
1. Set up the experiment as shown in Figure 9.32.
2. Boil some water in a beaker.
3. Record the temperature in a table.
4. Using tongs, place the iron nail carefully in the beaker.
5. Continue to measure any changes in the temperature of the water after adding the iron nail.
6. Repeat steps 1–3 with the second beaker, this time using the small iron weight in place of the nail.
7. For each beaker, calculate the change in the temperature of the water when the metal object was added.

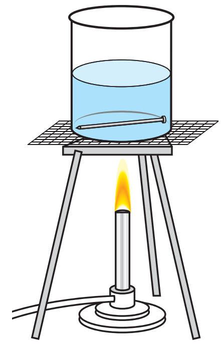


Figure 9.32 Experimental set-up.

Results
Include your results in a table.

Discussion
1. Which object, the nail or the iron weight, had the least change in water temperature? Use the difference between temperature and thermal energy to explain why.
2. Which object had the most thermal energy? Why?

Conclusion
What is the difference between thermal energy and temperature?

8.4 EXPERIMENT

Investigating heating by convection

Aim
To investigate heating water by convection

Materials
- Water
- Potassium permanganate crystals (or a few drops of food colouring)
- Bunsen burner
- Tripod
- Heatproof mat
- 600 mL beaker
- Dropper or pipette

Method
1. Set up the experiment as shown in Figure 9.33.
2. Fill the beaker with water. Put individual crystals of potassium permanganate on the bottom of the beaker, at the edge. Alternatively, add a drop of food colouring to the bottom of the full beaker using a dropper or pipette.
3. Heat the water gently over the Bunsen burner and observe the movement of the crystal. (If possible, use a small flame and no heatproof mat between the Bunsen burner and the beaker – you can do this with Pyrex beakers.)
4. Note the path that the coloured water takes from the burner to the top of the water and back down again.

Results
Draw a labelled diagram showing the movement of the coloured water.

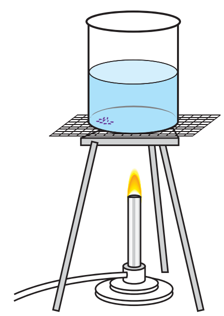


Figure 9.33 Experimental set-up.

Discussion
1. Describe the movement of the coloured water.
2. Why do you think the coloured water moved like this?
3. What was happening to the particles in the water when the water was being heated?

Conclusion
What do you know about heating water by convection?

GLOSSARY

A

absolute dating
a method that uses the amount of radioactivity remaining in the rock surrounding the fossil to determine its age

absolute magnitude scale
a scale for measuring the brightness of objects from the same distance

absorption spectrum
a spectrum with lines missing from the pattern; opposite of an emission spectrum because the element has absorbed its characteristic light wavelengths and removed them from the spectrum

acceleration
the rate of change of velocity; the rate of change of speed if the motion is in a constant direction

acceleration due to gravity
the acceleration of an object due to a planet's gravitational field; on Earth, $g = 9.8$ or $10\ m/s^2$

achondroplasia
a genetic (inherited) disorder of bone growth resulting in abnormally short stature and short limbs

adaptation
a characteristic or behaviour of a species that allows it to survive and reproduce more effectively

adenine
a nucleotide of DNA or RNA; complementary to thymine in DNA and uracil in RNA

alkali metal
an atom found in group 1 of the periodic table

alkaline earth metal
an atom found in group 2 of the periodic table

allele
a version of a gene. Each person inherits one allele from each parent

amino acid
a small molecule that makes up a protein

analogous structures
structures in organisms that perform the same function but are structurally different; result from convergent evolution

anion
a negatively charged ion

apoptosis
programmed cell death

apparent magnitude scale
a scale for measuring the brightness of an object when viewed from the Earth

artificial selection
when humans breed organisms that have desirable traits, increasing the likelihood of that trait occurring in the next generation

atmosphere
layer of gases that surrounds Earth and other planets

atomic number
the number of protons of an atom

autosome
a chromosome that does not determine the sex of an organism

B

Big Bang theory
the theory that the universe began from a hot, dense state at some time in the past, from when it has continued to expand and will continue to do so into the future

binary fission
a process of asexual reproduction used by bacteria cells (with no nucleus) to produce two similar sized daughter cells that are genetically identical

biodegradable
this means an object or a substance can be broken down by bacteria, fungi and other living organisms

biodiversity
the variety of life; the different plants, animals and microorganism and the ecosystems they live in

biosphere
the intersection between the atmosphere, hydrosphere and lithosphere

bivalent chromosomes
X-shaped chromosomes formed during DNA replication. Each strand of the bivalent chromosome is called a chromatid

black dwarf
a remnant formed when a white dwarf star cools and gradually fades away

black hole
a region in space of infinite density where gravity is so large that nothing can escape from it, including light itself

blue shift
apparent increase in frequency (towards the blue end of the spectrum) of light from galaxies that are moving towards the Earth

Bohr model
a way to represent the electrons of an atom in a series of shells around the atomic nucleus

C

carbon nanotube
a very small tube made by the careful arrangement of carbon atoms

carbon sink
any feature of the environment that absorbs and/or stores carbon

carbon tax
a tax levied on the carbon content of fuels used by businesses or homes

carbon trading scheme
the process of allowing a set limit of carbon credits to businesses that can then be traded

carrier
a person who has the allele for a recessive trait that does not show in their phenotype

catalyst
a substance that increases the rate of a reaction but is not used up in the reaction

cation
a positively charged ion

chromatid
one half of a bivalent chromosome

climate
weather conditions at a particular place over a long period of time based on the collection and analysis of large amounts of data

closed system
a system with a boundary that does not exchange any energy with its surroundings

cloud
a visible mass of condensed water in the atmosphere

co-dominant
this relates to two alleles of a gene that are both fully expressed in a heterozygote

collision theory
a theory that states the particles involved in a chemical reaction must collide in order to react

combustion
a reaction that involves oxygen and releases light and heat energy

complementary base
a nucleotide base that pairs with its partner nucleotide on the alternative DNA strand. Adenine pairs with thymine, cytosine pairs with guanine

concentrated acid
an acid solution with a high concentration of hydrogen ions

concentration
the number of active molecules in a set volume of solution

conduction
transfer of thermal energy involving direct contact with no movement of material

continental drift
the continuous movement of the continents over time

convection
transfer of thermal energy in a liquid or gas involving the movement of the material

convection currents
circular movement in liquids and gases caused by the rising of hot material

convergent evolution
the process whereby unrelated organisms evolve to have similar characteristics as a result of adapting to similar environments

Coriolis effect
the influence of the Earth's rotation on the direction of air or water movement

cosmic microwave background radiation
a form of electromagnetic radiation in the microwave spectrum left over from the formation of the Universe; evidence of the Big Bang theory

covalent bond
a bond formed when two or more atoms share electrons

cross-linked polymers
polymers in which long-chain molecules are attached to each other by ionic or covalent bonds, forming two- or three-dimensional networks

cyrosphere
part of the hydrosphere that is made up of frozen water

cytokinesis
refers to the division of the cell cytoplasm at the end of mitosis or meiosis, leading to the formation of two daughter cells

cytosine
a nucleotide of DNA or RNA; complementary to guanine

D

deceleration
slowing down; also known as negative acceleration

decomposition
a reaction that involves the breakdown of a compound into simpler substances

delocalised electron
an electron in a molecule that can easily move between atoms

deoxyribonucleic acid (DNA)
a molecule that contains all the instructions for every job performed by the cell; this information can be passed from one generation to the next

denitrifying bacteria
bacteria that return nitrogen to the atmosphere

diatomic molecule
a molecule that consists of two atoms

dilute
a small number of active molecules (such as acid) in a solution

diploid
a nucleus that contains two complete sets of chromosomes

diverge
two species can experience different selection pressures, and gradually become more different; may lead to the two species becoming reproductively isolated

dominant trait
a characteristic that needs only one copy of an allele to appear in the physical appearance of an organism

Doppler effect
the apparent change in wavelength (or frequency) when the source of the waves or the observer is moving; responsible for the red shift of distant stars

E

elastic potential energy
the energy possessed by stretched or compressed objects

elastomers
natural or synthetic polymers that have elastic properties, for example, rubber

electronic configuration
the arrangement of electrons in each electron shell surrounding an atom

element
a pure substance made up of one type of atom, e.g. oxygen, carbon

emission spectrum
the pattern of wavelengths (or frequencies) that appear as coloured lines in a spectroscope; it is unique to each element

enhanced global warming
the effect on the climate due to additional heat retained as a result of increased amounts of carbon dioxide and greenhouse gases released into the Earth's atmosphere by human activity

enhanced greenhouse effect
an increased level of global warming caused by the greenhouse effect of the atmosphere

entropy
the amount of energy in a closed system that is no longer available to be transformed

eutrophication
a process whereby excessive levels of phosphorus in waterways lead to the excess growth of algae and bacteria and an increased consumption of oxygen, suffocating fish and other aquatic animals

evolution
the gradual change in the genetic material of a population of organisms over a period of time

evolutionary relationship
refers to how two species or populations are related with respect to their evolutionary descent

F

first law of thermodynamics
the amount of internal energy of a thermodynamic system can change; increasing by the addition of heat, and decreasing through work being done

fossil
the remains or traces of an organism that once existed

fossilisation
the process of an organism becoming a fossil

frameshift
the process of moving the reading frame of codons through the addition or deletion of a nucleotide; usually results in a deformed protein

G

gene cloning
process that involves extracting and copying a specific gene from the genetic material (DNA) of an organism

gene flow
genes will flow from one generation to the next or one population to the next as different families or groups in the population choose partners and mate

gene pool
all the genes or alleles in the entire population

gene therapy
the treatment of disease by replacing faulty genes with normal genes in cells and tissues

genetic code
the sequence of nucleotides found in DNA that is inherited from parents

genetic engineering
process of modifying genes in some way

genetic mutation
a permanent change in the sequence of nucleotides in DNA

genotype
the combination of alleles for a particular trait

global warming
increase in the Earth's temperature due to the presence of certain human-made gases

gravitational potential energy
the energy possessed by objects raised to a height in a gravitational field

group
a vertical list of elements found in the periodic table that have characteristics in common

guanine
a nucleotide of DNA or RNA; complementary to cytosine

H

half-life
the time it takes for the radioactivity in a deceased organism to decrease by half

halogens
the group of elements found in group 17 of the periodic table

haploid
a nucleus that contains one complete set of chromosomes; usually found in a gamete

Hertzsprung–Russell diagram
a graph displaying star data with spectral class or star temperature on the x-axis and absolute magnitude on the y-axis

heterozygous
having two different alleles for a particular trait; a carrier for the recessive trait

homologous structure
a structure that is found across organisms with recent common ancestors and has a similar structure but a different function

homozygous
having two identical alleles for a particular trait

horizontal transfer
the transfer of genetic material (usually containing antibiotic resistance) between different bacteria

hydrocarbon
a molecule that contains only carbon and hydrogen atoms

hydrosphere
collection of all the Earth's water

hydrostatic equilibrium
a condition where the forces become balanced, resulting in some form of stability

I

inertia
the tendency of an object to resist changes in its motion while either at rest or in constant motion

ion
an atom that has gained or lost electrons, resulting in a negative or positive charge

ionic bond
a bond that forms between a negatively charged anion and a positively charged cation

ionic compound
a molecule that is formed by a negatively charged anion and a positively charged cation

isobar
a line drawn on a weather map that joins places of equal air pressure

isolation
the division of a population into two groups

K

karyotype
the arrangement of a complete set of chromosomes in pairs of decreasing size

kinetic energy
the energy possessed by moving objects

L

law of conservation of energy
a scientific law stating that the total energy in a system is always constant and cannot be created or destroyed

law of conservation of momentum
a scientific law stating that the total momentum in an isolated system does not change during a collision

linear polymers
sometimes called straight-chain polymers; consisting of long strings of carbon–carbon bonds. eg. polyethylene

lithosphere
outermost rocky layer of the Earth, consisting of the mantle and crust

light-year
the distance that light travels in 1 year

living fossil
an existing species of ancient lineage that have remained unchanged in form for a very long time

luminosity
the actual brightness of a star

M

magnitude
the size or extent of something

meiosis
the process that results in the formation of gametes with half the genetic material of the parent cell

metals
a collection of elements found on the left-hand side of the periodic table that are malleable, lustrous, ductile and highly conducting

metalloids
a small collection of elements that have a mixture of characteristics of metals and non-metals

mitosis
the process or replication that results in genetically identical daughter cells

molecular compound
a molecule that is formed through covalent bonding

momentum
the product of an object's mass and its velocity

monomer
a small molecule from which polymers are made

mutagen
a chemical or physical agent that causes a change in genetic material such as DNA

mutation
a change that occurs at the DNA level that may add, delete or rearrange genetic material

N

nanotechnology
the manipulation of individual atoms to form structures

natural greenhouse effect
the effect on the Earth's temperature due to water vapour and other gases present in small amounts in the atmosphere affect the Earth's radiation balance, resulting in a higher surface temperature

natural greenhouse gases
gases such as water vapour, carbon dioxide, methane, nitrous oxide, ozone and others which contribute to the greenhouse effect by affecting the radiation transfer through the atmosphere

nebula
a cloud of gas and dust in space

net force
the vector sum of all the forces acting on an object; also known as resultant force

neutralisation
a reaction in which an acid and a base combine to produce a metal salt and water

neutron star
a small, highly dense star, made mostly of neutrons

Newton's first law of motion
Newton's first law of motion states that an object will remain at rest and will not change its speed or direction, unless it is acted upon by an outside, unbalanced force

Newton's second law of motion
Newton's second law of motion describes how the mass of an object affects the way it moves when acted upon by one or more forces. It is often expressed as $F = ma$

Newton's third law of motion
Newton's third law of motion states that for every action, there is an equal and opposite reaction

nitrogen-fixing bacteria
bacteria that convert nitrogen from the atmosphere into various nitrogen compounds

noble gases
a collection of gaseous elements found in group 18 of the periodic table

non-disjunction
the failure of one or more chromosomes to separate and move to the end of the cell during meiosis; it can result in an abnormal number of chromosomes in the daughter cells

non-metals
a collection of elements that are found on the right-hand side of the periodic table

nova
a star showing a sudden large increase in brightness and then a slow fade away to its original state in a few months or years

nuclear fusion
a high energy reaction in which two lighter atomic nuclei fuse to form a heavier nucleus

nucleotide
a subunit of a DNA molecule

O

oxidation reaction
a reaction that involves the combination of oxygen with a fuel or metal

P

pedigree
chart showing the phenotypes for an individual and its ancestors, usually over several generations; also known as a family tree diagram

period
a horizontal list of elements found in the periodic table

periodic
the arrangement of elements into a table according to their chemical elements

permafrost
permanently frozen ground

phenotype
the physical characteristics that result from an interaction between the genotype and the environment

photolysis
the breakdown of a chemical substance by light, for example the breakdown of water into oxygen and hydrogen

phylogenetic tree
a branching tree-like diagram showing relationships between different taxonomic groups

planetary nebula
a glowing shell of gas formed when stars die

polyatomic ion
a charged ion that consists of two or more atoms bonded together

polymer
a long-chain molecule formed by the joining of many smaller repeating molecules (monomers) together

polymerisation
process of joining of smaller units (monomers) to form a long-chain molecule (polymer)

precipitate
an insoluble compound formed in a precipitation reaction

precipitation
the process of condensed water droplets falling as rain

precipitation reaction
a reaction product used to produce solid products from solutions of ionic substances

product
a substance formed as a result of a chemical reaction

protein
chain of amino acids; an essential part of ny cell

Punnett square
a diagram that is used to predict the outcome of breeding organisms

R

radiation
emission of energy from the nucleus of an atom as either particles or waves

reactant
a substance present at the start of a chemical reaction; also called a substrate

reaction force
the force acting in the opposite direction

reaction rate
how fast or slow a reaction proceeds

recessive trait
a characteristic that results from the inheritance of two identical alleles

red giant
a large, bright star with a cool surface that forms when a star like our Sun runs out of hydrogen fuel

red shift
the apparent decrease in frequency (towards the red end of the spectrum) of light from galaxies that are moving away from the Earth

ribonucleic acid (RNA)
a complementary copy of DNA that is able to carry to genetic message from the nucleus to the cytoplasm; contains uracil instead of thymine

S

scalar quantity
a quantity that only has size, for example, speed and distance

second law of thermodynamics
over time, energy is transformed from one form to another causing thermal energy to be produced and increasing the amount of entropy

selection pressure
environmental factors that affect an organism's ability to survive

sex chromosome
a chromosome that determines the sex of an organism

shell diagram
a diagram that shows the arrangement of electrons and electron shells in an atom

singularity
a point at which a function takes an infinite value, for example, in space-time when matter is infinitely dense, such as at the centre of a black hole

solution
a mixture of a solute dissolved in a solvent such as water

speciation
the process that results in the formation of a new species

spectator ion
an ion that does not take part in a chemical reaction

speed
the distance travelled per unit of time

stellar parallax
a change in the apparent position of a star against its background when viewed from two different positions

stem cell
a cell that can produce a number of different types of cells. Adult stem cells can produce a limited number of cell types (e.g. skin stem cells), whereas embryonic stem cells can produce multiple types of cells

strength
a strong acid readily releases a hydrogen ion in a chemical reaction; can also be used to describe the bond between different atoms

strong acid
an acid in which most of its molecules release hydrogen ions into solution

supernova
an explosive death of a star

synthesis
a reaction that involves the building up of compounds by combining simpler substances, normally elements

T

tectonic plate
a large layer of solid rock that covers part of the surface of the Earth; movement of tectonic plates can cause earthquakes

thermodynamic system
a quantity of matter that has a boundary around it

thermoplastic polymers
very long chain molecules that are usually solid at room temperature and melt when heated they can be remoulded easily

thymine
a nucleotide of DNA; complementary to adenine

transcription
the formation of complementary RNA from DNA

transition metal
the elements found in groups 3–12 of the periodic table

transitional fossil
a fossil or an organism that shows the intermediate state between an ancestral form and that of its descendants; also known as a 'missing link'

translation
the formation of a protein from RNA; occurs on a ribosome

U

uracil
a nucleotide of RNA; complementary to adenine

V

valence shell
the outermost electron shell in an atom that contains electrons

vector quantity
a quantity that has size and direction, for example, velocity and displacement

velocity
the vector quantity that measures speed in a particular direction

vestigial structure
a structure in an organism that no longer has an apparent purpose

W

water vapour
a gaseous form of water

weather
a snapshot of what the air and conditions are like in any one place on the Earth at any one time

weight
a measure of how much gravity is pulling on an object

white dwarf
a small, hot star that forms when a star such as our Sun runs completely out of fuel and slowly fades and cools

wind
the sideways movement of air as a result of lower density warm air rising through the atmosphere

work
occurs whenever an object is moved by a force

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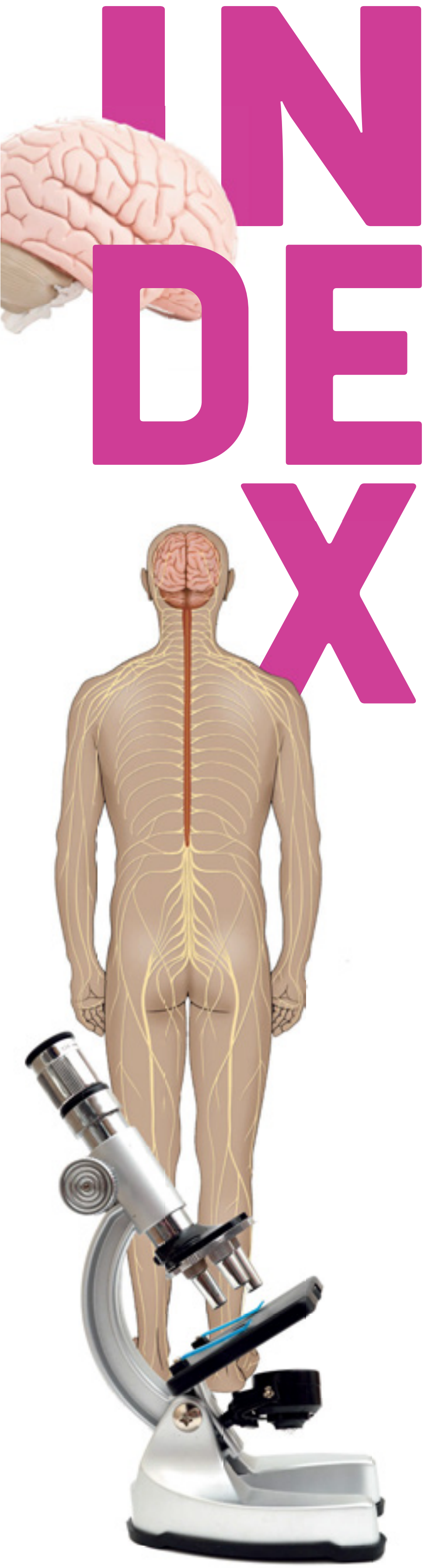

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