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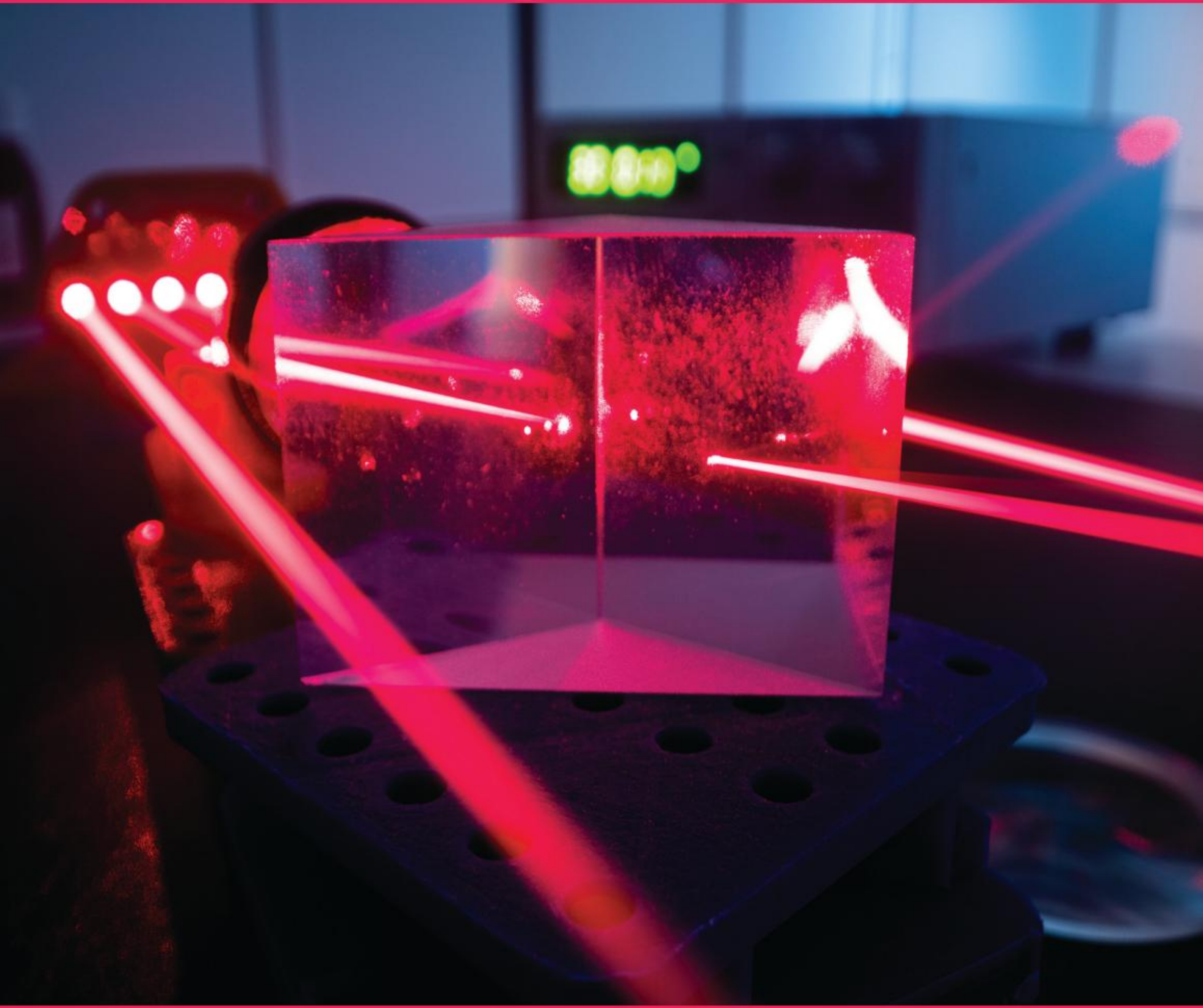
STUDY GUIDE

PHYSICS

YEAR 11 ATAR COURSE – UNITS 1 & 2

REVISED EDITION



Michael Lucarelli & Trevor Henderson

ACADEMIC
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WACE STUDY GUIDE

PHYSICS

YEAR 11 ATAR COURSE

Michael Lucarelli & Trevor Henderson

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About the Author

Michael Lucarelli is a science educator, author and publisher, who has held the position of Head of Physical Sciences in Western Australian Government senior high schools. Mike founded Academic Associates in 1990 and is the author of several successful educational resources.

Trevor Henderson has vast experience as a Physics teacher and Head of Department- Science with the Department of Education. This experience includes managing the implementation of major Year 11 and 12 Physics syllabus change in Western Australian schools.

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Their families for their patience, support and encouragement throughout the development of this book.

TO THE STUDENT

The purpose of this guide is to assist students in their preparation for tests and examinations in the new ATAR Physics course for Units 1 and 2. The structure of the topics will allow students to use the book throughout the year.

The guide closely adheres to the W.A. School Curriculum and Standards Authority ATAR syllabus. Essential theory is interwoven with revision exercises so that students will be able to actively review core theory and concepts.

Science Understanding

Essential core theory for each topic of Science Understanding is covered clearly and in detail. Illustrations and worked examples are used extensively to assist students in their learning. Throughout each chapter, questions and exercises are integrated with theory to help students clarify and consolidate their understanding of new concepts.

Review questions at the end of each chapter provide a wide range of problems. All questions and review exercises have detailed answers to provide students with immediate feedback and a means of enhancing their progress.

Trial Tests

Trial tests for each major topic provide an ideal means of self assessment. The style and structure of these tests is similar to that of the current WACE examination. They include sections on short response, problem solving and comprehension. The marks allocated for each of these sections also reflect the weightings used in the current SCSA examinations.

Physics is a most interesting and an enjoyable science to study. The practical work, in particular, holds a fascination for students. We hope that this study guide will help students to better understand the concepts they will encounter and to achieve greater success in the subject.

Michael Lucarelli and Trevor Henderson

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UNIT 2 – LINEAR MOTION AND WAVES

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UNIT 1

HEATING PROCESSES

1

SYLLABUS CHECKLIST

SCIENCE UNDERSTANDING – HEATING PROCESSES

- ☐ the kinetic particle model describes matter as consisting of particles in constant motion, except at absolute zero
- ☐ all substances have internal energy due to the motion and separation of their particles
- ☐ temperature is a measure of the average kinetic energy of particles in a system
- ☐ provided a substance does not change state, its temperature change is proportional to the amount of energy added to or removed from the substance; the constant of proportionality describes the heat capacity of the substance. This includes applying the relationship: $Q = m\ c\ \Delta T$
- ☐ change of state involves separating particles which exert attractive forces on each other; latent heat is the energy required to be added to or removed from a system to change the state of the system. This includes applying the relationship: $Q = m\ L$
- ☐ two systems in contact transfer energy between particles so that eventually the systems reach the same temperature; that is, they are in thermal equilibrium. This may involve changes of state as well as changes in temperature
- ☐ a system with thermal energy has the capacity to do mechanical work [to apply a force over a distance]; when work is done, the internal energy of the system changes
- ☐ because energy is conserved, the change in internal energy of a system is equal to the energy added by heating, or removed by cooling, plus the work done on or by the system
- ☐ heat transfer occurs between and within systems by conduction, convection and/or radiation
- ☐ energy transfers and transformations in mechanical systems always result in some heat loss to the environment, so that the usable energy is reduced and the system cannot be 100 percent efficient. This includes applying the relationship:

$$\mathit{efficiency}\ \ n = \frac{\mathit{energy\ output}}{\mathit{energy\ input}} \times \frac{100}{1}\ \%$$

1.1 HEAT

An atomic view of matter

The concept of heat is more easily understood by firstly considering the structure and nature of matter. In 1804, John Dalton first proposed the idea that tiny particles called atoms were the fundamental particles of nature. His atomic theory helped explain the experimental data available at that time and laid the foundations to our modern view of matter.

Some early evidence for the existence of atoms was discovered by Robert Brown in 1827 when he observed the motion of tiny pollen grains under a microscope. The pollen grains moved about in a random jiggling motion which we now refer to as **Brownian motion**. This motion is considered to be due to the action of rapidly moving atoms or molecules colliding with the pollen particles. The same effect can be observed when looking at smoke or soot particles under a microscope.

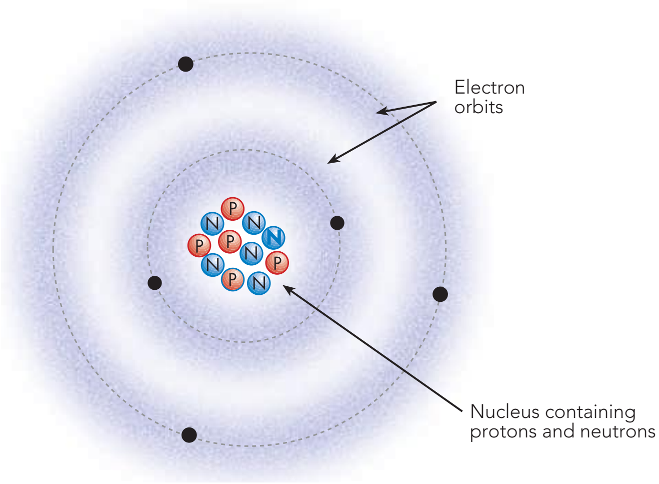


Figure 1.1 Rutherford-Bohr model of the atom. The atom's mass is concentrated in the tiny nucleus while the electron cloud occupies most of the volume. (See also chapter 2 on models of the atom).

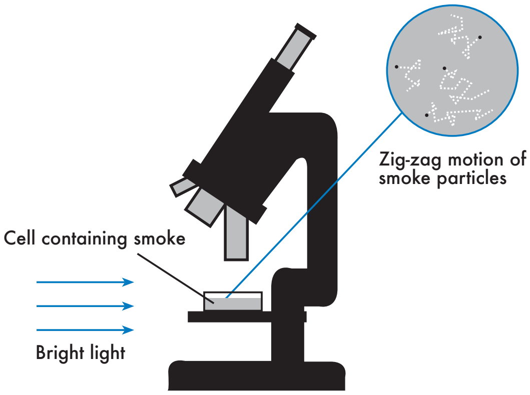


Figure 1.2 Brownian motion. The erratic zig-zag motion of the smoke particles is due to the random and rapid motion of air molecules colliding with them.

Kinetic theory of matter

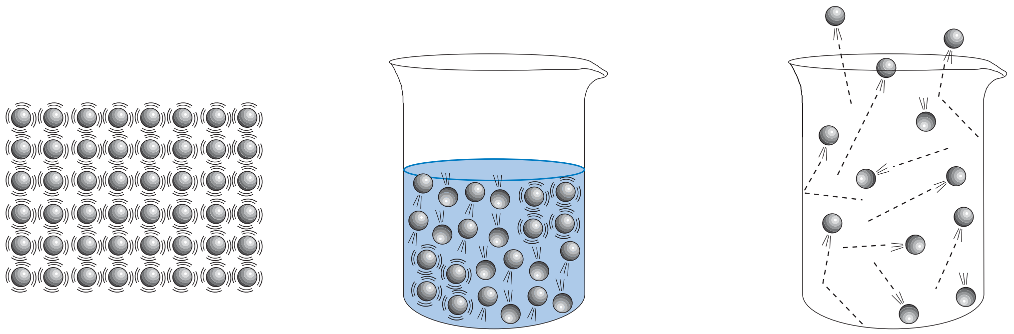
Many of the ideas involved in heating and cooling are more easily understood when explained in terms of the kinetic theory. Some of the basic assumptions of this theory are:

- all matter is made up of extremely small particles
- these particles are in constant random motion
- all collisions between these particles are elastic
- mutual attractive forces exist between particles.

In solids, the particles are held close together in a regular pattern by strong forces of attraction. The particles vibrate about fixed positions.

In liquids, the vibrating particles have sufficient energy to move from their fixed positions to other parts within the liquid. Liquids take the shape of their container.

In gases, the particles have sufficient kinetic energy to escape the attractive forces from other particles. Gases take up the complete volume of a container.



(a) **Solids:** particles vibrate about fixed positions. Solids have a definite shape.

(b) **Liquids:** particles are free to move within the liquid. Some particles escape the surface to form a vapour.

(c) **Gases:** particles move freely in all directions. Gases are compressible since there is a lot of space between particles.

Figure 1.3 Kinetic theory – solids, liquids and gases.

Heat and temperature

Heat and temperature are often confused as being the same thing. However, this is not the case. Although they are related, heat and temperature have distinctly different meanings. For example, the temperature of a hot cup of coffee is greater than that of a warm water bath, yet the energy required to raise the temperature of the water for the coffee is far less than that for the bath.

Temperature is used to describe how hot something is. Temperature scales, such as the Celsius scale, are used to indicate the level, or degree, of hotness. Temperature is a measure of the average random kinetic energy of the particles in a body. The faster the particles move, the greater the temperature.

Heat refers to the energy which is transferred from one body to another due to a difference in temperature. Bodies at high temperatures always lose heat to bodies at lower temperatures. The S.I. unit for heat is the Joule.

(a) **Hot drink:** the temperature is high since the average kinetic energy of particles is high. However, the heat that the hot drink can transfer to the surroundings is relatively low.

(b) **Warm bath:** the temperature is less than that of the coffee but the heat that the bath can transfer to the surroundings is greater.

Figure 1.4 Heat and temperature.

Question 1.1

Explain why it is incorrect to say that a body contains heat.

Heat and internal energy

The particles that make up a substance possess both kinetic energy and potential energy. The kinetic energy is dependent on motion while potential energy depends on the relative position of the particles. Hence the internal energy of a substance is the sum of all the individual kinetic and potential energies of its particles.

Heat, as we have already stated, is the energy which is transferred from a body at a higher temperature to another at a lower temperature.

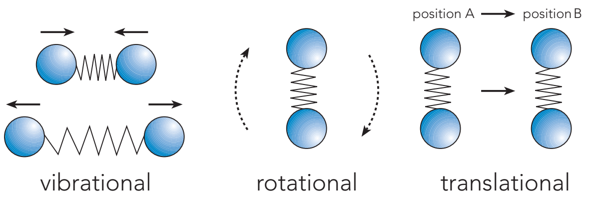


Figure 1.5 Kinetic energy (energy of motion). Types of motion for gaseous molecules. Note that atoms only have translational motion.

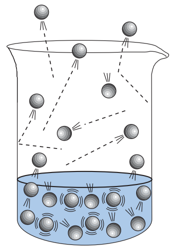


Figure 1.6 Potential energy (energy of position). Gaseous molecules that have overcome the forces of attraction within the liquid phase have a greater potential energy.

Question 1.2

A nail is heated in a bunsen burner flame and is about to be dropped into a beaker of water at room temperature.

(a) Which of the two substances (nail or water) would you expect to initially have:

(i) the highest internal energy? ______________________________

(ii) the highest average kinetic energy? ______________________________

(b) The hot nail is dropped into the water and allowed to cool. What happens to the average kinetic energy of the atoms in the nail and to the average kinetic energy of the molecules in the water?

Question 1.3

You are about to go for a swim at the beach where the water temperature is about 20°C. Assuming that your internal body temperature is 37°C:

(a) which body, yours or the ocean of water, contains the greatest amount of internal energy?

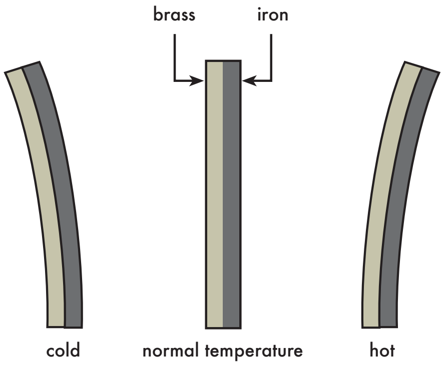
(b) In view of your answer to (a) explain why you always feel cold when you enter the water.

Thermal expansion

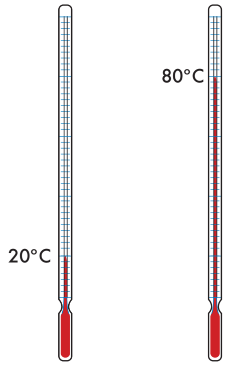
Whenever a substance is heated it will expand. Any increase in temperature will cause the particles to vibrate with more kinetic energy and move further apart. This is true for solids, liquids and gases, they expand when heated and contract when cooled. This thermal property of substances is useful in many everyday applications although there are also many situations where it can cause problems.

Expansion is least noticeable in solids. However the forces due to expansion are very large and can cause damage if not allowed for. Railway lines for example are not laid in one continuous strip but have small gaps to allow for movement due to changes in temperature. Similarly, concrete footpaths are laid in small sections separated by small gaps filled with a flexible rubbery material such as tar.

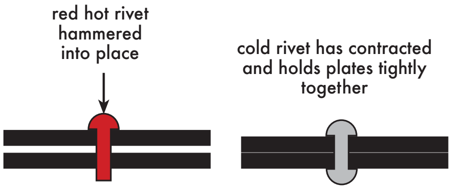
The fact that different solids expand at different rates is useful in designing a **bimetallic strip**. This device consists of two strips of different metals, say iron and brass, which are welded together. If the strip is heated one of the metals expands more than the other causing the bimetallic strip to bend. This device has many practical applications such as use as a **thermostat**.



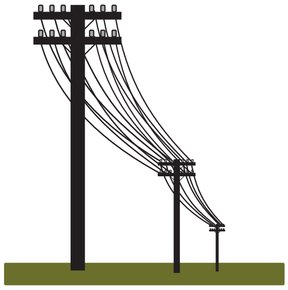
A bimetallic strip changes shape with a change in temperature. Brass expands more than iron.



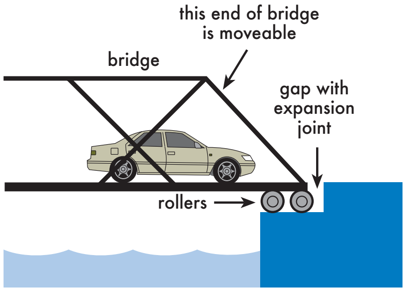
A thermometer works because the liquid in it expands when heated. The glass also expands but much less so.



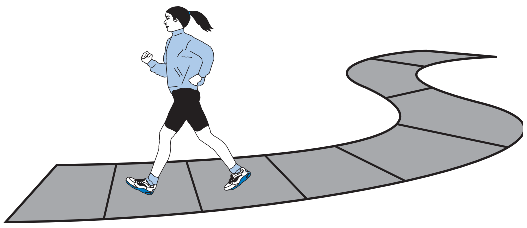
Rivets are used to hold plates of steel tightly together such as in shipbuilding.



Power lines always have some sag to allow for contraction during very cold weather. If too tight the wires would snap.



Bridges are given a gap at one end to allow for expansion.



Expansion gaps in concrete footpaths allow for expansion and contraction of the concrete.

Figure 1.7 Thermal expansion. There are many useful applications of thermal expansion as well as situations that must allow for its effects.

Measuring temperature

The most familiar method of measuring temperature is the use of liquid in glass thermometers. This is possible because of the fact that liquids expand when heated and do so to a greater extent than solids. All thermometers, in fact, make use of some property of a material which changes with a change in temperature. This could be a change in such properties as length, shape, electrical conductivity or colour.

Liquid in glass thermometers: These are based on thermal expansion as stated above. Mercury and alcohol are commonly used. Mercury responds to changes in temperature quickly and is suitable for higher temperatures (it is liquid between –39°C and 357°C). Alcohol has to be coloured to be seen (usually red) but is particularly suitable for low temperatures (it is liquid between –115°C and 79°C).

Bimetallic strips as thermometers: These are based on the fact that different metals expand at different rates. A metallic coil made up of two different metals (say iron and brass) will bend and curl appreciably with a change in temperature. This type of thermometer is often used in ovens since they are quite sturdy and can be easily adapted for temperature control as thermostats.

Resistance thermometers: The electrical resistance of metals or of thermistors will alter with temperature. When a metal such as platinum (sensor) is placed in a simple circuit with a battery, the current flowing will vary with temperature. An ammeter can be calibrated to give temperature readings.

These types of thermometers are very useful as they can be designed for a large range of temperatures, (–200°C to 1200°C) and are easy to read as a digital display.

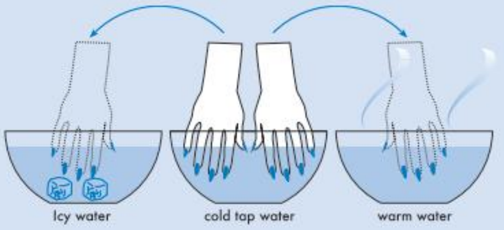
Thermocouple thermometers: If the junction of two different metals is heated a small voltage is developed. Wires of two different metals are joined together at two junctions. One junction is kept at a reference temperature (say freezing point), while the other acts as the sensor. These types of thermometers can be used to measure temperatures up to about 2300°C.

Infrared thermometers: These determine temperature by measuring the thermal radiation emitted by a body. Conveniently they are non-contact devices and can be designed for wide applications, such as the common ‘ear thermometer’ to hot furnace pyrometers.

Liquid crystal thermometers: Some liquid crystals change colour with a change in temperature. They are relatively convenient and safe to use but have a limited temperature range.

Question 1.4

Can your hands correctly sense temperature? Try this – place one hand into icy water and the other in fairly warm water. After one or two minutes place both hands in some tap water.



(a) Describe how each hand felt when placed in the cold tap water.

(b) Suggest an explanation for your observations in terms of heat transfer and temperature.

Temperature scales

To establish a temperature scale on a thermometer it is important to choose two easily reproducible temperature conditions called fixed points. In the Celsius scale these points are:

- lower fixed point
  - – melting point of pure ice
  - – 0°C (zero degrees Celsius)

- upper fixed point
  - – boiling point of pure water at standard atmospheric pressure (100 kPa)
  - – 100°C (100 degrees Celsius)

To calibrate an unmarked thermometer, it is necessary to place the thermometer firstly in melting ice and mark the 0°C point, and then in boiling water and mark the 100°C point. The rest of the scale can then be marked by dividing the space between the points into 100 equal divisions. Each division is a degree.

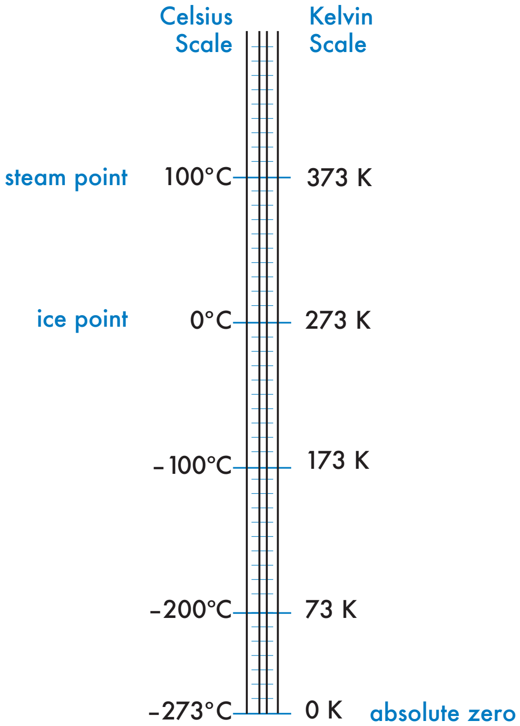
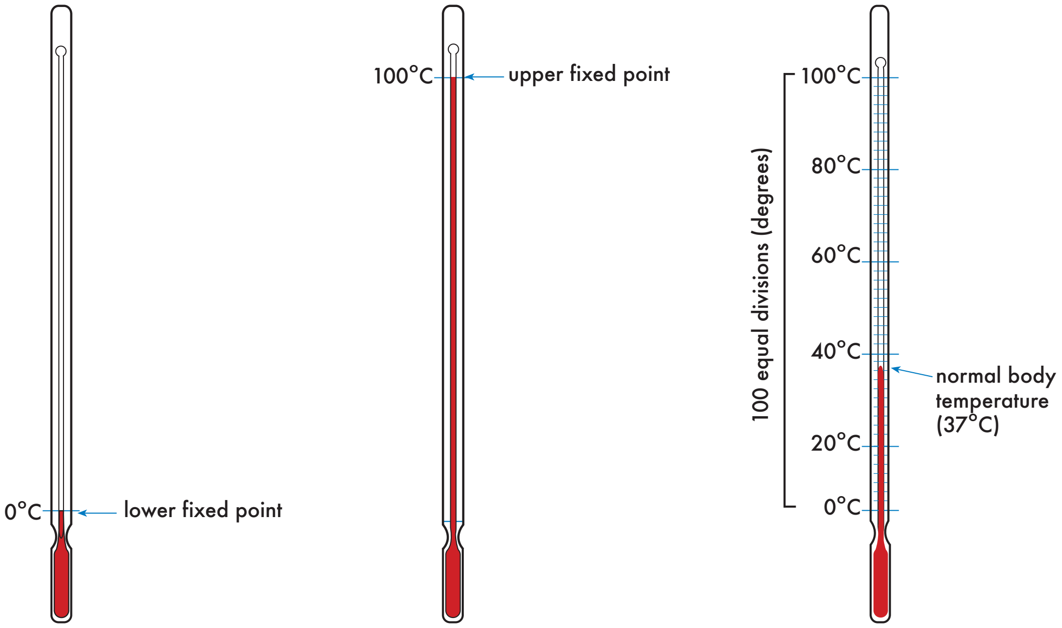


Figure 1.8 Comparing the Celsius and Kelvin scales.

In the Kelvin or absolute scale, the zero point is set at absolute zero (–273°C) with kelvin (K) divisions that are the same size as those on the Celsius scale. Absolute zero is the temperature at which a substance has the lowest possible internal energy. This occurs at exactly –273.15°C.

Note: Kelvin temperatures are not expressed as degrees, but simply kelvin.

$$K = {}^{\circ}C + 273$$



(a) An unmarked thermometer is placed in pure melting ice and the 0°C fixed point is marked.

(b) The thermometer is now placed in the steam directly above pure boiling water and the 100°C fixed point is marked.

(c) The distance between the fixed points is marked off into 100 equal divisions.

Figure 1.9 Calibrating a thermometer to the Celsius scale. The two fixed points are determined and marked on the thermometer. The distance between them is marked off into 100 equal divisions. Each division is one degree Celsius.

1.2 HEAT CAPACITY AND LATENT HEAT

Heat capacity

If we wish to increase the temperature of a body we need to apply heat. However, some materials are more difficult to heat up than others, that is, they have a greater heat capacity. Materials with large heat capacities can absorb and store more internal energy and when cooled, cool more slowly.

Specific heat capacity (c)

The specific heat capacity of a substance, c, is the amount of heat required to raise the temperature of 1.00 kg of that substance by 1.00°C. Water has a relatively high specific heat capacity, needing 4.18×10^3 joules of energy to raise the temperature of 1.00 kg by 1.00°C. This makes water an ideal substance to act as a coolant or for heat storage.

The amount of heat required to produce a temperature rise in a substance depends on:

- mass (m) – the greater the mass, the greater the heat required to increase the kinetic energy of all the particles.
- specific heat capacity (c) – substances with low specific heat capacities, such as copper and steel, require little heat to produce a temperature rise.
- temperature rise (ΔT) – the greater the temperature rise the greater the heat required.

To calculate the heat required to change the temperature of a substance the following relationship is used.

$$Q = m\,c\,\Delta T$$

Q = quantity of heat energy (J)
m = mass of substance (kg)
c = specific heat of substance (J kg^{-1} K^{-1})
ΔT = temperature change (K)

Table 1.1 Specific heat capacities of some common substances.

SPECIFIC HEAT CAPACITY (J kg^{-1} K^{-1})					
Water	4.18×10^3	Air	1.01×10^3	Copper	3.85×10^2
Alcohol	2.44×10^3	Aluminium	8.97×10^2	Mercury	1.40×10^2
Ice	2.10×10^3	Glass (Silica)	8.40×10^2	Human body	3.5×10^3
Steam	2.00×10^3	Iron	4.50×10^2	Brass	3.70×10^2

Worked Example 1.1

(a) A kettle is filled with tap water which is at a temperature of 22.0°C. If the mass of the water is 1.85 kg calculate the heat required to raise its temperature to 100.0°C.
(b) Discuss any assumptions you have made.

Q = ?
m = 1.85 kg
c = 4180 J kg^{-1} K^{-1}
ΔT = (100 – 22.0)°C

(a)
$$\begin{aligned} Q &= m\,c\,\Delta T \\ &= (1.85)(4180)(100 - 22.0) \\ &= 6.03 \times 10^5 \text{ J} \\ &= 6.03 \times 10^2 \text{ kJ} \end{aligned}$$

(b) Assuming no heat losses to the surroundings

Worked Example 1.2

(a) A home heater supplies 1.80 MJ of heat in 15.0 minutes to a room which contains 95.5 kg of air. Assuming that all of the heat was absorbed by the air only, find the rise in temperature in the room.

(b) What is the power rating of the heater? (That is, the amount of heat supplied per second).

(c) In reality, the temperature change in the room is unlikely to be as high as calculated. Explain.

$Q = 1.80 \times 10^6$ J
$m = 95.5$ kg
$c = 1.01 \times 10^3$ J kg^{-1} K^{-1}
$\Delta T = ?$
$t = 15.0$ min $= 900$ s
$P = ?$

(a)

$$Q = m\,c\,\Delta T$$

$$\therefore \Delta T = \frac{Q}{mc}$$

$$\Delta T = \frac{1.80 \times 10^6}{(95.5)(1010)}$$

$$= 18.7°\text{C}$$

(b)

$$Power = \frac{energy}{time}$$

$$= \frac{1.80 \times 10^6}{900}$$

$$= 2000 \text{ Js}^{-1}$$

$$= 2.00 \text{ kW}$$

(c) Much of the heat supplied by the heater will be absorbed by the walls and furniture. In addition to this, heat will be lost through the walls, floor and ceilings. Hence the temperature rise of the air in the room is likely to be much less than calculated.

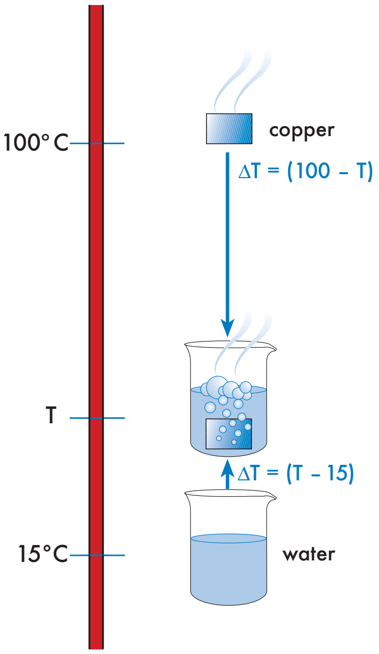
Thermal equilibrium

If you place a hot piece of metal into a beaker of cold water, heat from the metal will transfer to the water. The temperature of the water will rise and that of the metal will fall until thermal equilibrium is reached (assuming no heat transfer to or from surroundings).

In terms of kinetic theory we can say that the average kinetic energy of the atoms of metal has lowered and the average kinetic energy of the atoms of water has increased so that they are now both the same.

In reaching equilibrium we should note that:

- Heat lost (by metal) = Heat gained (by water)
- The final average kinetic energy of the particles of both substances is the same.



Worked Example 1.3

A 650 g block of copper metal is initially heated to 100°C (in boiling water), and then placed into 500 g of cold water at 15.0°C. Assuming that no heat is lost to the surroundings, determine the final temperature of the copper and water. It is best to do a simple sketch of the temperature changes involved in this problem. Assume that the unknown final temperature is T.

For copper:
$m = 650$ g
$c = 385$ J kg^{-1} K^{-1}
$\Delta T = 100 - \text{T}$

For water:
$m = 500$ g
$c = 4180$ J kg^{-1} K^{-1}
$\Delta T = \text{T} - 15.0°\text{C}$

Heat lost by copper $= m\,c\,\Delta T = (0.650)(385)(100 - T) = 25025 - 250.25T$
Heat gained by water $= m\,c\,\Delta T = (0.500)(4180)(T - 15) = 2090T - 31350$

Since Heat lost = Heat gained
$25025 - 250.25T = 2090T - 31350$
$2340.25T = 56375$
$T = 24.1°\text{C}$

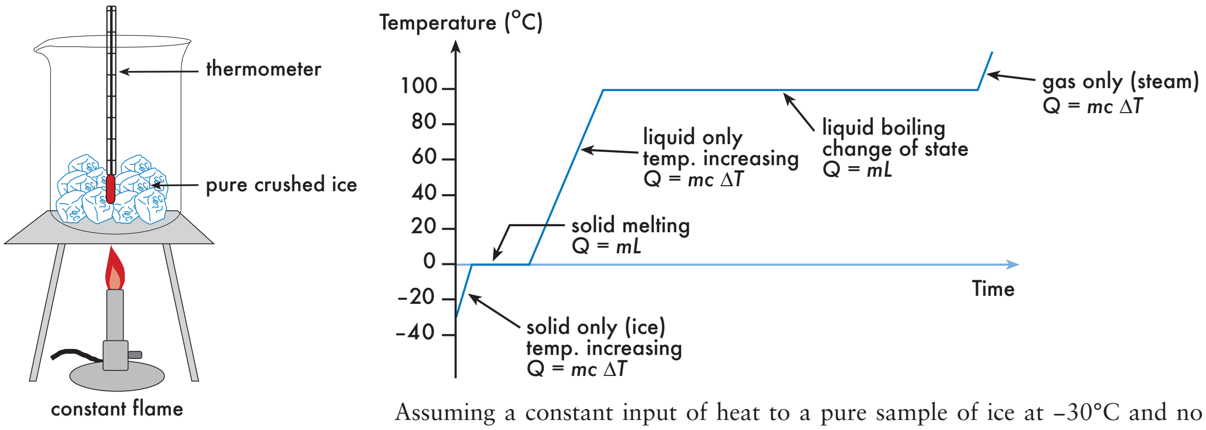
Hence the final temperature of the water and copper is 24.2 °C. (*This type of problem may not be required for your course*).

Change of state

Substances may exist as either solids, liquids or gases. If heat is applied to a substance then the usual result is an increase in its temperature, that is, an increase in the average random kinetic energy of its particles.

However, at particular temperatures, the applied heat causes a change of state. This change of state occurs without any change in temperature. The applied heat is absorbed by the particles as potential energy as they move further apart from each other.

The graph below shows the changes that occur as solid ice is heated at a constant rate until steam is formed.

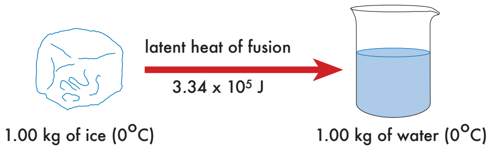


Assuming a constant input of heat to a pure sample of ice at −30°C and no loss of heat to the surroundings, we see that heat either causes a temperature change ($Q = m\,c\,\Delta T$), or a phase change ($Q = mL$). Note that the heat required to change water to steam is much greater than the heat required to change its temperature from 0°C to 100°C.

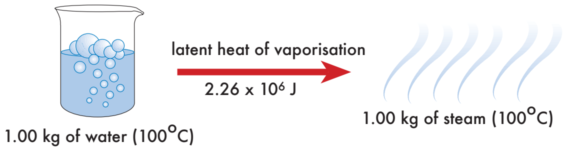
Figure 1.10 Heating curve for water.

Latent heat

As we have seen above, quite large amounts of heat are necessary to cause a change of state. And all this, without a change in temperature. This heat is referred to as latent heat (hidden heat). Latent heat varies for different substances.



The **specific latent heat of fusion** is the amount of heat required to change 1.00 kg of a substance from a solid to a liquid (or vice versa) without any change in temperature. For water the latent heat of fusion is 3.34×10^{5} J kg^{-1}.



The **specific latent heat of vaporisation** is the amount of heat required to change 1.00 kg of a substance from a liquid to a gas (or vice versa) without any change in temperature. For water the latent heat of vaporisation is 2.26×10^{6} J kg^{-1}.

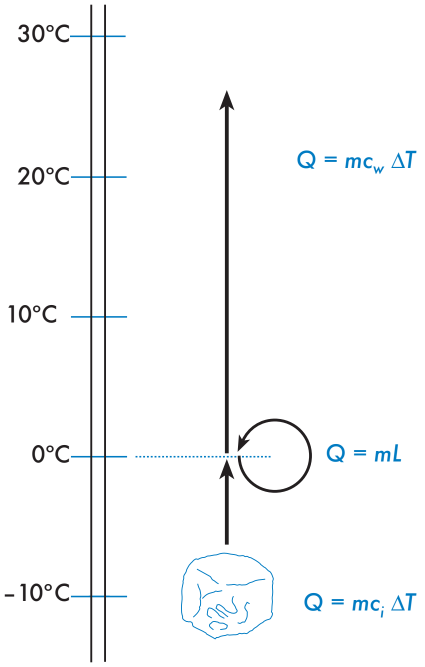
$$Q = mL$$

Q = quantity of heat required or given off (J)
m = mass of substance (kg)
L = specific latent heat (J kg^{-1})

Worked Example 1.4

Determine the amount of heat required to change 250 g of ice at −10.0°C to water at 25.0°C.

Again, it is a good idea to do a simple sketch of the changes involved as shown at right. There are three separate changes to consider.



- Heat required to change the temperature of the ice from −10.0°C to 0°C.

  $Q_1 = m\,c_i\,\Delta T$
  $= (0.250)\ (2100)\ (10)$
  $= 5.25 \times 10^3$ J
- Heat required to change the ice at 0°C to water at 0°C.

  $Q_2 = m\,L$
  $= (0.250)\ (3.34 \times 10^5)$
  $= 8.35 \times 10^4$ J
- Heat required to change the temperature of the water from 0°C to 25.0°C.

  $Q_3 = m\,c_w\,\Delta T$
  $= (0.250)\ (4180)\ (25.0)$
  $= 2.61 \times 10^4$ J

Hence total heat energy required:

$Q_T = Q_1 + Q_2 + Q_3$
$= 1.15 \times 10^5$ J

Worked Example 1.5

A basketballer attains a high metabolic rate during a game and much of the excess heat generated must be lost by sweating. During such a game Jessica develops excess heat at the rate of 800 W. If 90% of this heat must be lost by sweating, calculate the mass of sweat produced during a 10 minute session. Assume the latent heat of vaporisation of sweat to be 2.40 × 10⁶ J kg⁻¹.

$m = ?$
$L_v = 2.40 \times 10^6\ J\ kg^{-1}$
$t = 10\ min\ (600\ s)$
$P = 800\ W$

$$P = \frac{energy}{time} = \frac{Q}{t}$$

$$\therefore Q = \left(\frac{90}{100}\right)(P.t) = \left(\frac{90}{100}\right)(800)\ (600)$$

$$= 4.32 \times 10^5\ J$$

Also $Q = m\,L_v$

$$\therefore m = \left(\frac{Q}{L_v}\right) = \frac{4.32 \times 10^5}{2.40 \times 10^6} = 0.180\ kg$$

∴ mass of sweat = 180 g

Evaporation – a cooling effect

Evaporation of a liquid has a cooling effect. This explains why we can feel so cold if we stand around in wet clothes, particularly in a breeze. The evaporating water absorbs latent heat from our body and hence we feel cold.

Evaporation occurs to some extent at all temperatures. This is possible because not all the particles in a liquid have the same kinetic energy. Due to random collisions it is possible for some particles to have a much greater kinetic energy than others. Hence, if the fast moving particles are near the surface of the liquid they may be able to escape the attractive forces which are holding the other particles within the liquid. The loss of these particles from the liquid means that the average kinetic energy of the remaining particles is lowered. That is, the temperature is lowered.

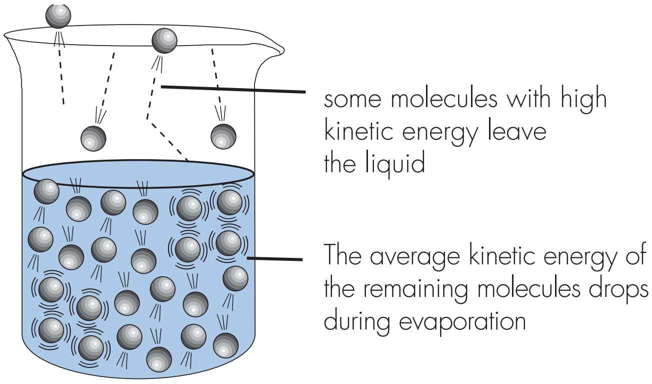


Figure 1.11 The cooling effect of evaporation. Fast moving particles near the surface of a liquid are able to escape. This causes the average kinetic energy of the remaining particles to be reduced, so reducing the temperature.

Controlling body temperature

The internal temperature of our bodies, or core temperature, is maintained at a fairly constant 37°C, even though the air temperature around us may vary. Except for extreme conditions, the body is able to control its core temperature by the following means:

Perspiration: If the surrounding air temperature is relatively high (say greater than 30°C) then the body is unable to effectively lose heat by the usual means of conduction, convection and radiation. Sweat produced by sweat glands however, is able to remove heat as it evaporates. In hot conditions a body may produce sweat at the rate of 1 Lh^{-1} with a consequent loss of heat at the rate of 670 W.

Humidity and lack of air movement can reduce the effectiveness of perspiration. If the air is fairly humid, evaporation is dramatically reduced and we feel sticky and hot. A breeze, on the other hand, assists evaporation by removing saturated air away from the body.

Controlling skin temperature: The body can reduce the blood flow to our skin and thereby lower the skin temperature. This minimises heat losses from the body's surface. The reduced blood flow also has the effect of making the skin develop 'goose bumps' and appear pale or blue.

Increasing metabolic rate: When we are cold, our natural reaction is to move about and stamp our feet as a means of increasing our body's internal energy. The body's own involuntary reaction is to shiver. Shivering is particularly effective and can provide body heat at a rate which is some four or five times as great as our normal metabolic rate.

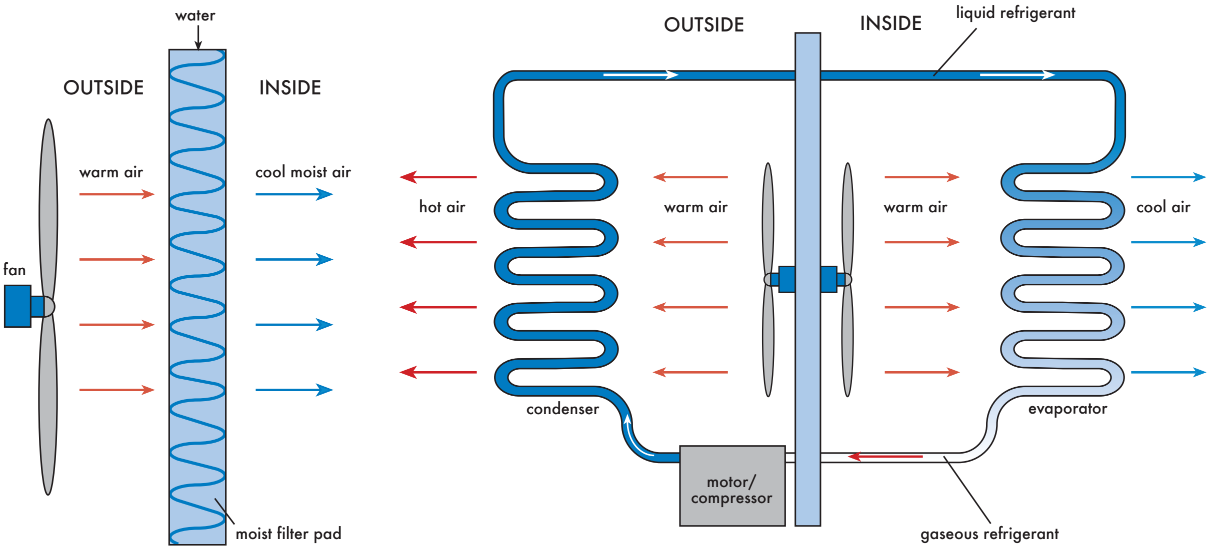
If temperatures are extreme, the body will not be able to maintain its normal core temperature of 37°C. High external temperatures are the most difficult to cope with since the body can only give up heat by perspiration under these conditions. If the core temperature increases to 42°C, **hyperthermia or heat stroke** will result. This is a dangerous condition and unless the body is cooled (e.g. with wet towels) then death may result. Very cold temperatures can also cause difficulties for the body, especially if associated with wind and water. Shivering and the reduction of blood flow to the skin may not be sufficient in maintaining normal internal body temperature. As this core body temperature falls, a condition known as **hypothermia** can occur. Unless appropriate action is taken, unconsciousness and death will occur.

Air conditioning and refrigeration

As liquids change to gases, latent heat is absorbed and a cooling effect is achieved. This is the basis for the function of air conditioning systems and refrigerators. The two types of air conditioners are evaporative and refrigerative.

Evaporative air conditioners: These operate very simply by using a fan to continuously draw air through a moist filter. The evaporating water creates a cooling effect. In hot weather, evaporation occurs even more readily and this type of air conditioning is both economical and effective. However, on hot humid days it does not work so well since evaporation is difficult.

Refrigerative air conditioners: These are essentially heat pumps although they still rely on the latent heat involved during phase changes. A liquid with a low boiling point, known as a refrigerant, is pumped through coils on the inside of the house and allowed to evaporate. Since heat is absorbed from the surrounding air a cooling effect is created. The refrigerant, which is now in the gaseous state, is compressed and allowed to condense back to a liquid in coils on the outside of the house. This causes heat to be given out to the surrounding air. This type of air conditioning is more expensive to run but is effective under all weather conditions. It also has the advantage that on cold days it can be operated in reverse so that cold air is pumped out and warm air in.



(a) Evaporative air conditioner. Warm air is forced through a moist filter. The evaporating water creates a cooling effect.

(b) Refrigerative air conditioner. The liquid refrigerant evaporates inside the evaporator coils and creates a cooling effect. The gaseous refrigerant is then compressed back to a liquid and heat is released through the condenser coils to the outside air.

Figure 1.12 Air conditioning systems.

Refrigeration: The home refrigerator is essentially a heat pump and works in the same way as refrigerative air conditioning. Fans, however, are not needed. The liquid refrigerant is constantly evaporated in the freezer coils inside the refrigerator and in so doing absorbs heat from the contents within. The compressor condenses the gaseous refrigerant on the outside of the refrigerator and the heat evolved is dissipated through metal cooling fins.

Before refrigerators were invented natural ice was commonly used for cool storage. Where available, the ice was collected and stored in large icehouses from where it could be distributed and sold. Homes typically would have iceboxes to store perishable food.

Artificial refrigeration developed in the late 18th century as vapour compression systems using gases such ammonia and sulphur dioxide. The early systems were large and somewhat dangerous and were mainly used commercially for the storage and transport, including shipping, of perishable goods.

Domestic refrigerators first became available in the early 20th century. However they were bulky, expensive and the gases used as refrigerants posed some danger. The use of Freon gas, a CFC, as a refrigerant in the 1930s, provided for more efficient designs and a safer alternative. However, this CFC has now been banned as it was later discovered that its use contributed to the depletion of the earth's ozone layer.

Question 1.5

On warm days people often use fans to help them keep cool even though the fans themselves do not cool the air. Explain why you feel cool. (Hint: Refer to page 12)

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Question 1.6

Water can evaporate at quite low temperatures, such as on a cold day. Describe two common occurrences that support this statement.

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Question 1.7

Hypothermia can occur at even moderately cold temperatures if the body is also exposed to wind and water. Explain.

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Question 1.8

Why are evaporative air conditioners not as effective on a humid day?

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Question 1.9

On a warm day young John decides to leave the refrigerator door wide open to help cool the room. What effect is this likely to have on the temperature of the room? Explain.

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1.3 HEAT TRANSFER

If a temperature difference exists between two bodies then heat will flow from the body at the high temperature to that at the low temperature. Heat can flow in three ways; conduction, convection and radiation.

Conduction

Conduction of heat occurs most easily in solids. It is the result of the transfer of kinetic energy from one vibrating particle within a material to another particle nearby. There is no net movement of particles. Essentially, particles that have high kinetic energies tend to share this energy as they collide with neighbouring particles. In this way heat is transferred throughout the material.

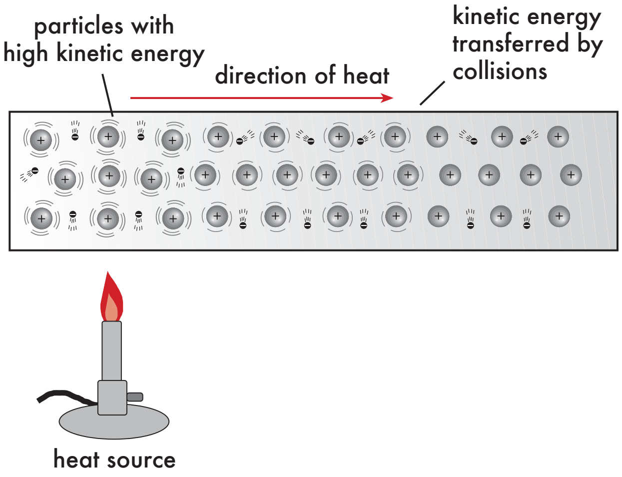

Figure 1.13 Conduction in a solid. Particles with high kinetic energies transfer some of their energy through collisions with neighbouring particles.

Convection

Liquids and gases are poor conductors of heat but they can readily transfer it by means of convection currents. These currents are possible since the density of fluids is dependent on temperature. When a fluid is heated, it expands, becomes less dense and therefore rises. Convection currents result as the cold and more dense fluid moves downwards to take its place.

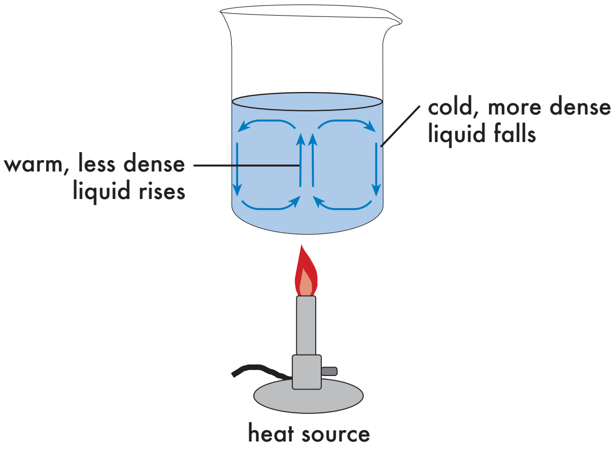

Figure 1.14 Convection currents in a liquid. Heat is transferred readily since the liquid is free to circulate.

Radiation

We are all familiar with the radiant energy given off by a simple bar heater but in fact all objects give off energy in the form of electromagnetic radiation. At common temperatures this radiation is mostly infra red (long wavelength) while at high temperatures visible light and ultraviolet radiation are also given off.

Radiation is the fastest means of heat transfer and a medium is not required. Heat transferred in this way behaves in a similar manner to light. It can travel through a vacuum, in straight lines, and can be reflected, refracted, absorbed or transmitted.

Figure 1.15 Heat radiation. Radiant heat is reflected by smooth shiny surfaces. It can be felt immediately the heater is turned on.

Conductors and insulators

There is great variation in the thermal conductivity of different materials. Some values are listed in Table 1.2. Metals are the best conductors of heat while non-metals are generally poor conductors and hence referred to as insulators. Liquids and gases are particularly poor conductors of heat, although as we have seen they can readily transfer heat by the action of convection currents.

Table 1.2 Thermal conductivities of some common materials. Metals are excellent conductors of heat, most other solid substances are poor conductors while air is an extremely poor conductor.

SELECTED THERMAL CONDUCTIVITIES ($Wm^{-1}K^{-1}$, 300 K) – APPROXIMATE VALUES					
Silver	430	Brick, concrete	0.8*	Wool	0.04*
Copper	400	Water	0.60	Air	0.023
Iron	80	Fat	0.25*	Felt	0.017*
Glass	1.0*	Wood	0.15*		

** Vary with composition.*

Rate of cooling

Hot bodies can lose heat by conduction, convection and radiation. A body's actual rate of cooling depends on many factors but the two most important ones are its surface area and the temperature difference between itself and its surroundings.

- The greater the *temperature difference* between an object and its surroundings, the greater the rate of heat loss. This is known as Newton's law of cooling (i.e. Heat loss rate $\alpha \Delta T$).
- The greater the *surface area* the greater the rate of heat loss. Extra area of contact simply allows more heat transfer. For example if hot coffee is placed into a saucer, it will cool more quickly due to the increased surface area. Similarly a warm sheet of aluminium foil will cool more quickly than a similar sheet that has been rolled into a ball.

Question 1.10

On a cool evening you are standing near a logfire to keep warm. Explain in terms of conduction, convection and radiation each of the following observations.

(a) Your face and hands feel the fire's warmth most readily.

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(b) The flames are always flickering and in a vertical direction.

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(c) You are able to hold quite comfortably a stick which is red hot at the opposite end.

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Thermal insulation

There are many everyday situations where it is important, and in some cases vital that we minimise heat transfer. Home insulation and the protection of our bodies from temperature extremes are two examples. In each case, effective insulation is achieved by minimising all means of heat transfer, that is, by minimising conduction, convection and radiation.

Home insulation

Good home insulation saves money on both heating and cooling costs. In summer, the insulation helps to keep the house cool by preventing heat entering the house while in winter the same insulation will minimise the loss of heat from the inside.

Materials used to build homes, such as bricks, wood and plasterboard all have low thermal conductivities. This reduces the conduction of heat.

Trapped air is an excellent insulator. This explains the effectiveness of bulk insulation such as fibreglass batts in the ceiling. The air trapped in the woolly like fibre prevents the transfer of heat. This is one of the most effective forms of extra insulation for a home, since 30%–40% of heat loss (or gain) occurs through the ceiling.

Double walls on the perimeter of a home provide an air cavity which reduces the conduction of heat between the outside and inside. This separation of the two external walls also prevents moisture from slowly seeping in.

The cavity between the walls may also have fibreglass insulation. This will further reduce heat transfer by preventing convection currents (draughts) or conduction. Sometimes shiny reflective foil is placed in the cavity. This reflects heat and minimises radiation.

Heat losses which can occur through convection currents can be minimised by using weatherseals and draught stoppers.

Double glazing of windows reduces heat transfer by conduction. The air gap between the two sheets of glass prevents the direct transmission of heat through the glass. The amount of heat passing through windows can be reduced by 50% in this way.

Carpets and curtains are also very effective insulators. These can reduce heat transfer through floor and windows by some 50%.

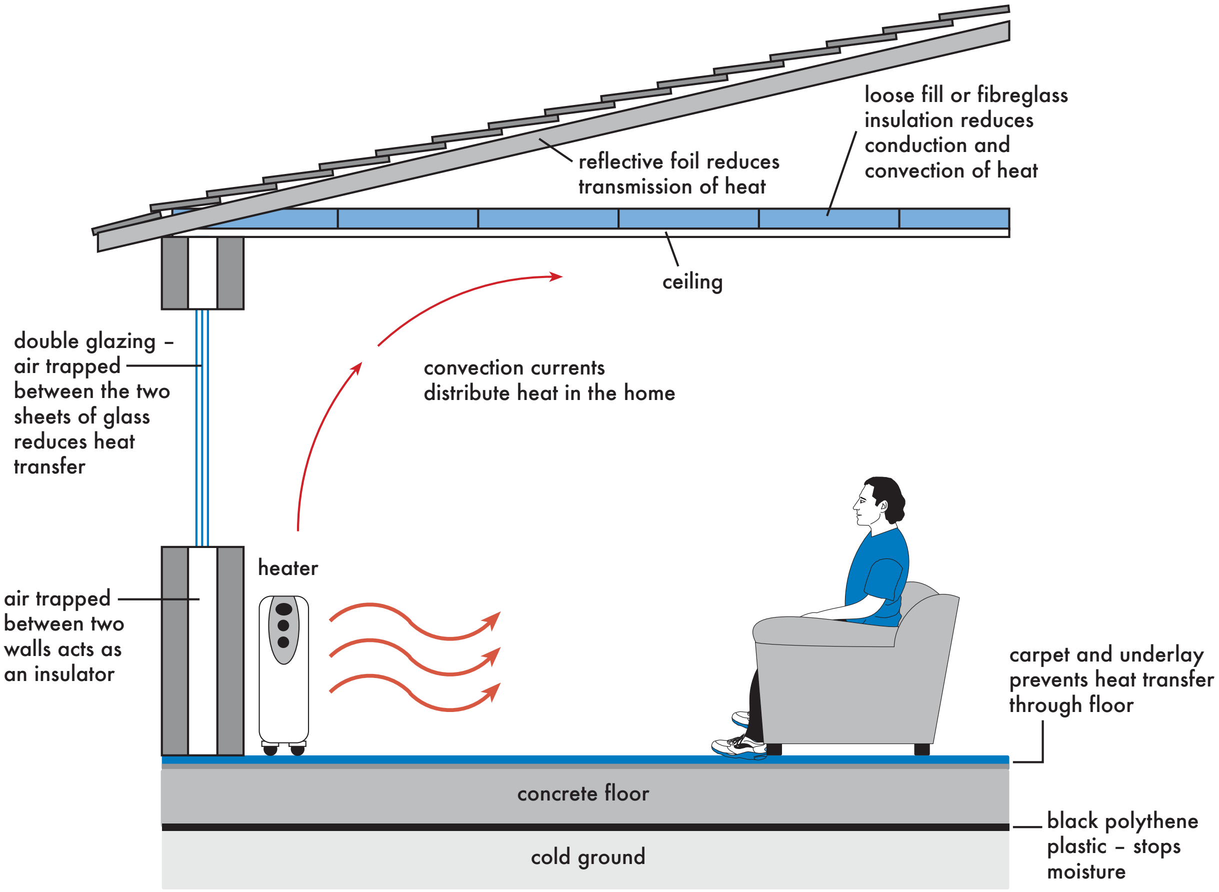

Figure 1.16 *Home insulation.*

Protection from heat and cold

Our bodies are most comfortable at temperatures around 25°C when only resting or doing light work. This is several degrees below the body's core temperature of 37°C. This difference in temperature is important as it allows the transfer of excess body heat to the surroundings and prevents overheating. However, temperatures are quite often not ideal and our bodies require protection from heat and cold.

Clothing provides us with the necessary insulation when it is cold or windy. The air trapped within and under our clothing is an excellent insulator since it has such low thermal conductivity. Appropriate clothing will allow humans to comfortably withstand outside temperatures of −40°C.

Clothing reduces heat loss by:

- **minimising conduction of heat** from the body. (Clothing materials are poor conductors and provide a thick barrier.)
- **minimising convection of heat** from the body. (This is especially important in windy conditions which would otherwise continually remove the warm air layer near the skin of our bodies.)
- **minimising radiation of heat** from the body. (The clothing essentially reduces the difference in temperature between the outside layer of the clothing and the environment. This dramatically reduces radiation losses.)

Clothing for wet weather needs to be waterproof. Since water is a much better conductor than air, clothing loses its insulating properties if it becomes wet. More importantly, the moisture quickly increases heat loss due to evaporative cooling. Combined with wind, this can have a very chilling effect.

Clothing designed for firefighters is both reflective and highly insulating. The reflective surface prevents much of the radiant heat from being absorbed by the clothing. The suit is also lined with heat resistant wool which prevents the conduction of heat.

The vacuum flask

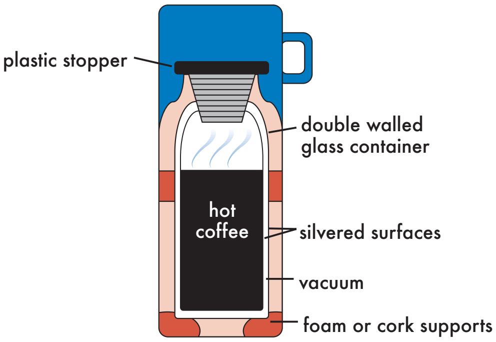

Figure 1.17 The vacuum flask.

A vacuum flask can keep liquids warm (or cool) by minimising heat losses in all possible ways. The flask consists of a double walled glass container with a vacuum between the walls. The vacuum prevents both conduction and convection between the glass walls. The heat that does radiate through the vacuum is mostly reflected by the highly silvered walls. The thin glass and plastic stopper conduct very little heat through the top. The stopper also prevents heat loss by evaporation or convection currents.

Question 1.11

Insulating materials such as carpet, polystyrene and foam all contain trapped air. What are the advantages of this feature?

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1.4 HEAT AND THE ENVIRONMENT

Solar energy

Although only a very tiny fraction of the energy radiated by the sun reaches planet Earth, this energy is sufficient in maintaining the planet's average surface temperature at approximately 15°C. Without the sun's energy, the earth would soon become cold and inhospitable due to the fact that it is itself radiating energy into space.

The Earth's temperature depends on the amount of solar energy it receives as well as the amount of energy it radiates back into space. If these energy quantities are not in balance the Earth will heat up or cool down over time. The Earth's temperature has been relatively constant over the years although there has been an increase of approximately 1°C since the beginning of last century. Most of this increase has occurred during the past fifty years or so. This increase in global temperature indicates that the energy lost to space by the Earth is somewhat less than that it receives from the sun.

Solar radiation consists mostly of visible light but also contains ultraviolet radiation. Most of this is absorbed by the ozone layer in the atmosphere. Visible light and infra-red radiation reach the Earth's surface. The diagram below (Figure 1.18) indicates how the suns energy is absorbed, reflected and radiated on reaching the Earth.

We can see that approximately 30% of the incoming radiation is reflected back into space by the atmosphere and Earth's surface. The remainder is absorbed, some 20% by the clouds and atmosphere and some 50% by the Earth's surface.

Hence only some 70% of solar radiation is actually absorbed by the Earth. This solar energy causes the warming of land, oceans and the atmosphere. Through a series of steps this energy is eventually radiated back into space in the form of long wave infra-red radiation. The heat that is radiated from the Earth's surface towards space is mostly, but not all, absorbed by the atmosphere and re-radiated back to Earth. This process and other similar heat exchanges occur continuously. Over time, however, the energy initially absorbed by the Earth is lost to space.

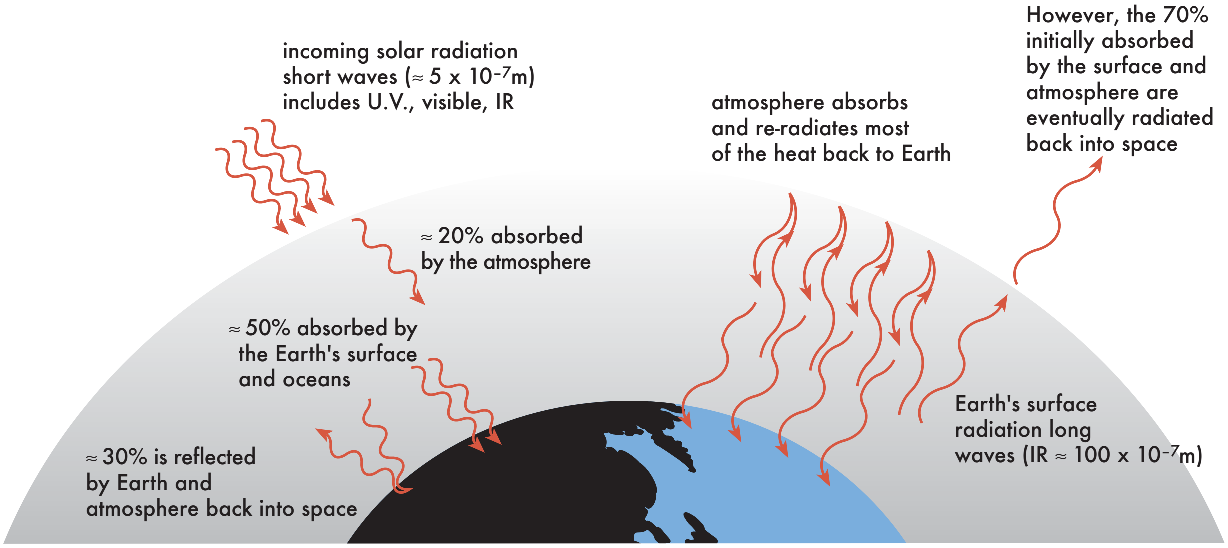

Figure 1.18 The Earth's energy budget – globally averaged. Solar energy received from the sun is mostly short wavelength radiation while that lost by the Earth is long wavelength infra-red radiation.

The greenhouse effect

The Earth is warm and hence it also radiates energy into space. In fact the Earth's surface radiates more heat than it directly receives from the sun. But since this heat is long wavelength infrared radiation, it is mostly absorbed by the atmosphere and much of it is re-radiated back to

Earth. This “trapping” of heat by the atmosphere, due mostly to the presence of water vapour, carbon dioxide and methane, is referred to as the greenhouse effect.

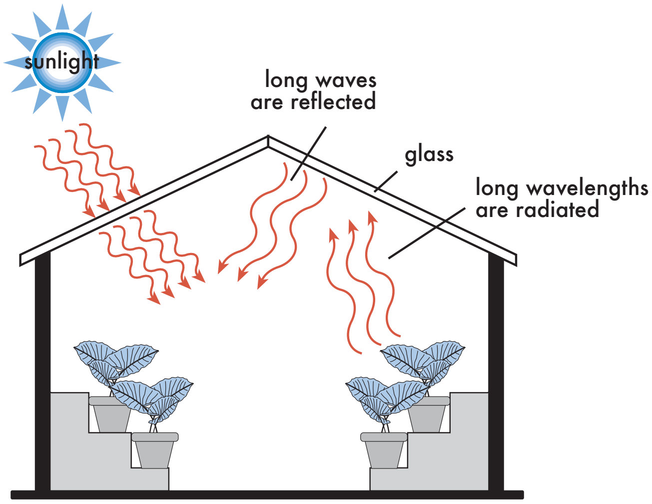

Figure 1.19 The greenhouse effect. Light from the sun passes easily through the glass and warms the interior. However, thermal radiation given off by the warmed interior cannot easily escape due to its longer wavelength.

Intensity of solar radiation

When the sun is directly overhead, the intensity of solar radiation is approximately 1360 Wm^{-2} as it reaches our upper atmosphere. The intensity at ground level on any particular part of the earth is always less than this due to the effect of the atmosphere and angle of the sun.

- **The atmosphere** always absorbs and reflects some solar radiation, particularly if cloudy or smoggy conditions exist. At higher latitudes, sunlight also has to travel through more atmosphere.
- **The angle of elevation** of the sun also reduces the intensity of radiation reaching the surface. The same energy is spread out over a larger area (see Figure 1.19), as well as being affected by its longer path through the atmosphere.

In Australia, the intensity of solar radiation on a clear summer’s day is typically over 900 Wm^{-2} during the middle of the day.

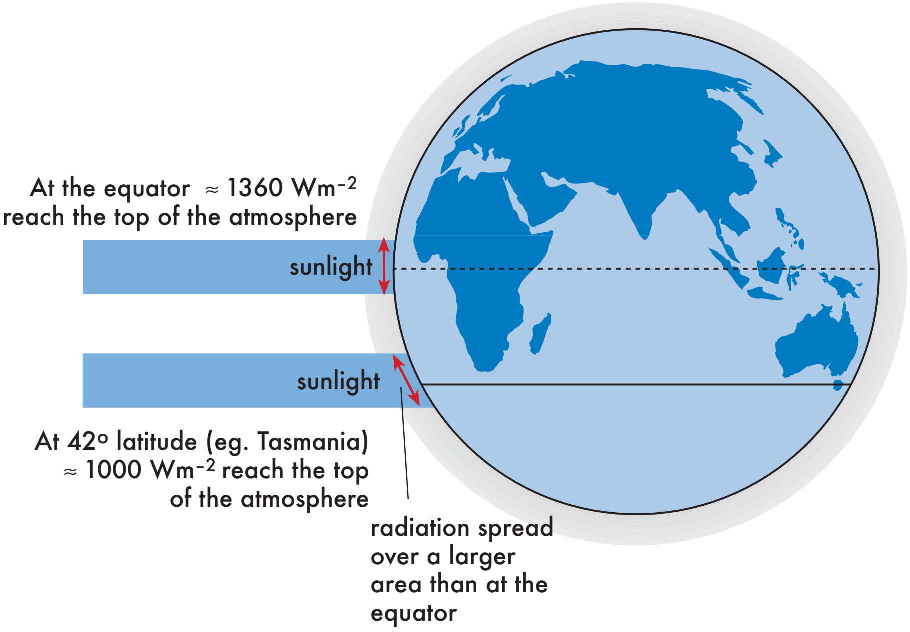

Figure 1.20 Intensity of solar radiation. At the top of our atmosphere the intensity is ≈ 1360 Wm^{-2} with the sun directly overhead.

Question 1.12

(a) Heat that the Earth radiates into space is of a much longer wavelength than that which it receives from the sun. Why is this?

(b) If the Earth's atmosphere absorbed a smaller amount of the long wave infrared radiation how would this affect the earth's temperature? Why?

Question 1.13

We know that it is much safer to sunbake in the late afternoon since the intensity of solar radiation is lower than the middle of the day. Give two reasons for this lower intensity.

Collecting solar energy

The Earth receives huge amounts of solar energy each day and it is totally free. In the city of Perth during summer this can be as high as 25 MJm^{-2} day^{-1}. If this solar energy can be collected efficiently it provides an environmentally friendly and relatively cheap source of power. Solar energy collectors can be designed to collect heat at either low or high temperatures.

- **Low temperature solar energy collectors** are the most common. Typically these consist of black absorbing panels which transfer their absorbed heat to water or air (see Figure 1.21). The heat is usually stored as hot water but it can also be stored in a bed of crushed rock below the home. Molten salts can also be used to store the heat (as latent heat). This latent heat can be released to warm cold water or air passed through pipes within the liquid salt.
- **High temperature solar energy collectors** generally concentrate radiant energy to a small area prior to its use. This is done with curved or parabolic reflectors. A variety of temperatures can be achieved, such as that needed to cook meat (solar barbecue) or to melt metals (solar furnace). A future application may be the use of large dish collectors which can drive steam engines or other devices and thereby produce electricity.

Solar hot water

Many Australian homes take advantage of the abundant solar energy available in our climate by installing solar hot water systems. These essentially consist of the following:

- **A solar collector** which absorbs the sun's radiant energy. Dark coloured materials are the best absorbers and hence copper metal with a flat black finish is commonly used. The fact that copper is a good conductor is important, since it is able to readily pass on the heat to the cold water. The solar collector is also glazed in order to reduce the heat loss from the collector by radiation.

  Flat plate collectors as shown in Figure 1.21 are the most commonly used. However, a more recent development has been the introduction of evacuated tube solar collectors. These are considered more efficient, particularly if there is no direct sunlight. A copper pipe runs through the centre of the evacuated glass tubes and the heated water is circulated to a storage tank by a slow flow pump.

- **An insulated storage tank.** Usually this is placed close to, and just above the collector panel. As the water in the collector pipes heats up it becomes less dense and is forced upwards by the downward movement of colder (and denser) water.

  Split systems can also be used by placing the hot water storage tank in a convenient ground location rather than on the roof. In this case a small circulation pump is required. The energy required to run the low wattage pump is offset by the reduced heat loss by having the tank in a more protected position and closer to the main areas of use.

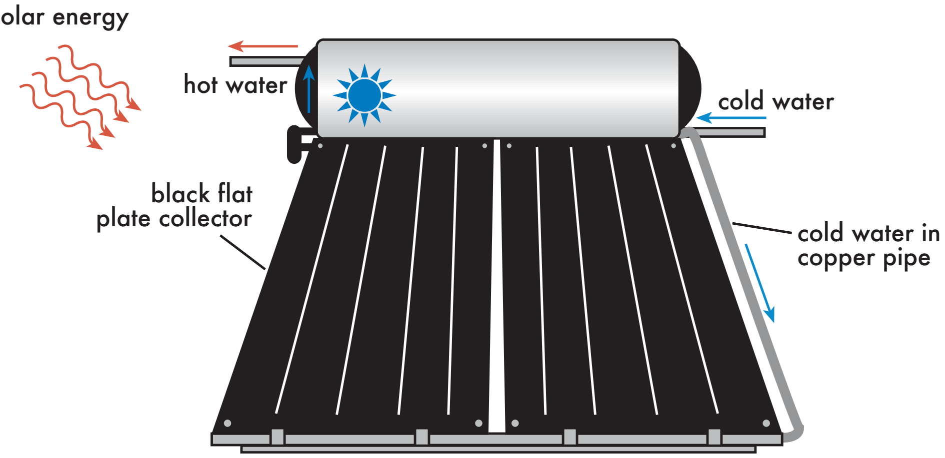

Figure 1.21 *Typical domestic solar hot water system.*

Solar pool heater

Solar hot water systems are commonly used to supply hot water for the house but the same principle can be used to heat the water in swimming pools during the colder months of the year. A solar pool heater can consist simply of a large area of black plastic pipe through which pool water circulates and collects heat. However, since the pool water is usually at a lower level than the solar panel a pool pump is used to force the warm water to mix with the cooler water in the pool.

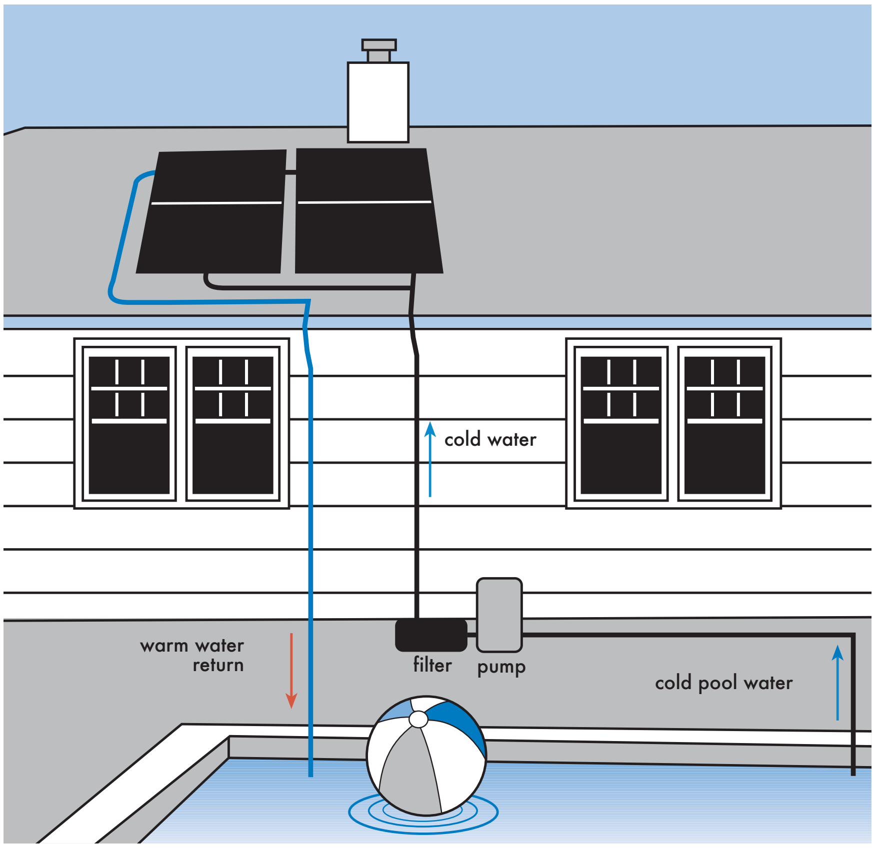

Figure 1.22 *Solar water heating for swimming pool.*

Useful energy and energy degradation

Useful energy is energy that can be easily transported and efficiently converted to other required forms. Fossil fuels and electricity are two important examples of useful energy forms. They are readily transportable and can be used for many practical purposes such as heating, lighting and running of machinery.

Whenever energy is transformed from one form to another, it is conserved, that is, it is not lost (Law of Conservation of Energy). However, when high grade energy is put to practical use, much of it is converted to less useful forms of energy or low grade energy.

The efficiency with which supplied energy is converted to useful energy is determined as follows:

$$\text{Efficiency} = \eta = \frac{\text{useful energy output}}{\text{total energy input}} \times 100$$

When petrol is used in a motor car for example, much of the stored chemical energy ends up as 'waste heat' released to the environment through hot exhaust gases and heat from the car. The air which is warmed by the engine contains energy which is no longer useful and is regarded as low grade energy. This conversion of high grade (useful) energy into low grade (less useful) energy is referred to as **degradation of energy**.

Since the Earth has only limited reserves of high grade energy sources it is important that these are conserved and used efficiently. Where possible use should be made of alternate energy forms such as solar, wind and tidal energy.

Worked Example 1.6

A motor car engine converts the chemical energy stored in petrol into heat and mechanical work. Typically, it converts 35 MJ of energy for each litre of petrol consumed. On average, for a particular car, 25 MJ of this energy is given up as heat losses, mainly through the radiator and hot exhaust gases. The remainder provides the mechanical energy to keep the car moving.

(a) Calculate the efficiency of this car in providing mechanical energy.

(b) Typically, due to other internal losses such as drive train friction, only 90% of the mechanical energy provided by the motor is available as power to the wheels. Calculate the overall efficiency of the car in providing energy of movement.

(c) The cars manufacturer quotes a fuel consumption of 12.0 L of petrol per 100 km. Calculate how much energy is supplied to power the wheels for each kilometre of travel.

(a) Efficiency = η = (useful energy output/total energy input) (100)

$$= \left(\frac{10}{35}\right)(100) = 28.6\ \%$$

(b) Efficiency = η = (energy converted to movement/total energy input) (100)

$$= \left(\frac{10}{35}\right)(100)\left(\frac{90}{100}\right) = 25.7\ \%$$

(c) Fuel energy input = $(35 \times 10^6)(12)$ per 100 km

= 420 MJ/100 km

= 4.2 MJ km

Energy supplied to wheels

$$= (0.257 \times 4.2)$$

$$= 1.1 \text{ MJ km}$$

Question 1.14

Diesel fuel, typically, contains 38 MJ of chemical energy per litre. The diesel engine in a particular family car is known to be 35% efficient. The fuel consumption is also given as 8.5 L per 100 km. Determine:

(a) How much useful energy is supplied to the car for every litre of fuel consumed?

(b) How much useful mechanical energy is supplied to the car over a 100 km trip?

(c) How much energy is lost as heat over a 100 km trip?

Question 1.15

Solar power cells are important energy converters. Their efficiency in converting solar energy to electrical energy has improved markedly through better technology. Typically, it can be 20% or a little higher.

Some solar panels with an efficiency rating of 21.5% are placed on the roof of a Perth home. Assume the intensity of solar radiation in Perth, on a typical summer day, to be 900 W per m^2. Determine:

(a) The maximum amount of solar energy that would fall, each hour, on 4 of these solar panels, if each panel has an effective area of 1.60 m^2.

____

(b) The maximum amount of electrical energy that could be supplied each hour by these solar panels.

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REVIEW QUESTIONS

Chapter 1: Heating Processes

1.1 Heat

1. Indicate whether each of the following is true or false. Alter any false statement so that they are true.
   (a) Heat refers to the energy which is transferred from one body to another.
   (b) The temperature of a body will increase when the average kinetic energy of the particles in that body decreases.
   (c) Thermal expansion due to an increase in temperature is most noticeable in solids.
   (d) A temperature of 100 K is greater than 100°C.
   (e) A substance has the lowest possible internal energy at absolute zero.

2. Distinguish between the terms:
   (a) heat (b) internal energy (c) temperature.

3. During a physics experiment David was heard to ask Melissa, "How much heat is possessed by that piece of lead?" Melissa replied, "It is not possible to determine the amount of heat possessed by the piece of lead."
   Explain why Melissa answered David in this way.

4. A gas oven is said to have sufficient heat at 170°C in which to place a batch of cakes. Is the term 'heat' used correctly here? Explain.

5. Rohan placed two identical pieces of lead, both at room temperature, one at a time and three minutes apart into a single beaker of water also at room temperature. Rohan thought that by doubling the amount of lead and therefore doubling the amount of internal energy possessed by the two pieces combined, the water temperature would change. Does the water temperature change?

6. If a material has a property that changes with temperature then it may be able to be used as a thermometer. List three different properties of materials which change with temperature.

7. Two types of thermometer are (a) a mercury-in-glass thermometer and (b) a platinum resistance thermometer. What property of each changes to enable it to measure temperature?

8. (a) List the fixed points for the (i) Celsius scale and (ii) Kelvin scale.
   (b) What do the fixed points for the Celsius scale represent?

9. Convert the following temperatures.
   (a) to Kelvin: (i) 37°C (ii) –20°C (iii) 114°C
   (b) to Celsius: (i) 180 K (ii) 293 K (iii) 350 K

10. Julie was carrying out an experiment using melting ice to determine the location of the ice point on a mercury-in-glass column. She took the precaution of using ice made of pure water. Why was it necessary for her to take this precaution?

1.2 Heat Capacity and Latent Heat

11. Indicate whether each of the following is true or false. Alter any false statement so that they are true.
    (a) When a substance is heated while in a solid phase there is an increase in the potential energy of its particles.
    (b) Substances with a low specific heat capacity require relatively more heat to increase their temperature.
    (c) Sweating during physical exercise helps to keep our body cool.
    (d) A refrigerator is essentially a heat pump.
    (e) As liquids change to gases heat is given off.

12. Cathy cooked a jam tart to have for dessert. Soon after removing the tart from the hot oven she ate a piece and was surprised to find that the jam appeared to be much hotter than the surrounding pastry and burnt the inside of her mouth.
    (a) Was the jam at a higher temperature than the pastry when the tart was removed from the oven? Why?
    (b) Explain why the jam burnt Cathy's mouth.

13. During a physics experiment, Andrew heated equal masses of water and paraffin oil which were contained in separate but identical containers. Both were heated by the same Bunsen burner for a period of 4 minutes. Predict which liquid Andrew would find to have the highest temperature after 4 minutes. Why?

14. A constant volume of hydrogen gas has a specific heat capacity of 14300 J kg^{-1} K^{-1}. Hydrogen gas is sometimes used in enclosed electrical generators. To what use do you think the hydrogen gas is being put in the generator?

15. 1.50 kg of water at 25.0°C is heated in an electric kettle for 2.00 minutes. If in this time the kettle supplies 3.00×10^5 J to the water calculate the temperature of the water after the 2.00 minutes interval.

16. A hot water system tank contains 150 L of water at a temperature of 20°C.
    (a) Determine the energy required to heat the water to 65.0°C
    (1 L water = 1 kg water).
    (b) If the heat is being supplied at a rate of 7.00×10^3 J per second, how long will it take to heat the water to 65°C?

17. Mark placed 50.0 g of iron with a temperature of 90.0°C into an insulated non-conducting container with 30.0 mL of water at 20.0°C. He then measured the new temperature of the water while doing his best to prevent heat entering and leaving the container. Calculate the final temperature of the mixture.

    ($c_{\text{iron}} = 4.50 \times 10^2$ J kg^{-1} °C^{-1})

18. If Mark repeats the experiment but uses an insulated 200 g aluminium calorimeter cup, also at 20.0°C, calculate the final temperature of the mixture.

    ($c_{\text{aluminium}} = 9.00 \times 10^2$ J kg^{-1} °C^{-1})

19. As a solid melts, the latent heat of fusion does not increase the kinetic energy (temperature) of the molecules. How is this heat supplied to the solid used?

20. A 3.00 kg metal electric kettle contains 1.00×10^3 mL of water and both are at room temperature (20.0°C). The kettle is switched on and left on for 10.0 minutes. How much water is left in the kettle if heat is supplied at 2.00×10^3 W? Ignore heat loss to the surroundings.

$c_{kettle} = 4.00 \times 10^2 \text{ J kg}^{-1} \text{ °C}^{-1}$
$c_{water} = 4.18 \times 10^3 \text{ J kg}^{-1} \text{ °C}^{-1}$
$L_{steam} = 2.26 \times 10^6 \text{ J kg}^{-1} \text{ °C}^{-1}$

21. During the half-time interval at a game of netball which was played on a warm day, Hannah found that although her arms and legs were sweaty, the gentle breeze made her feel cool. Is it actually the breeze alone which is cooling her body? Explain your answer.

22. Chelsea had a soft drink at room temperature. To cool the drink she could either add 50 g of cold water at 0°C or an equivalent mass of ice pieces also at 0°C. Which would be more effective in cooling the drink – the water or the ice? Give a reason for your answer.

23. Calculate the heat required to melt 50.0 g of ice at 0°C to water at 0°C.
($L_{ice} = 3.34 \times 10^5 \text{ J kg}^{-1}$)

24. A plastic insulated drinking vessel contains 300 mL of water at 20.0°C. If 50.0 g of ice at 0°C is added to the water, calculate the final temperature of the water. (Ignore any heat transfer between the mixture and the vessel.)

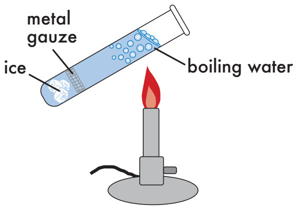
25. Steam at 100°C can cause a more severe burn to your arm than an equal mass of water at the same temperature. Explain why this is the case.

1.3 Heat Transfer

26. Indicate whether each of the following is true or false. Alter any false statement so that they are true.
    (a) Liquids and gases are poor conductors of heat.
    (b) Heat transfer by convection currents can only occur in gases.
    (c) Air is a very poor conductor of heat.
    (d) Radiation of heat is not possible through a vacuum.
    (e) Double glazing of windows reduces heat transfer by conduction.

27. Liquid sodium is used in some nuclear reactors as a coolant. What physical property of sodium enables sodium to be used in this way?

28. Explain how heat is conducted in gases, liquids and metals.



29. When Adrian applied the Bunsen burner as shown in the diagram he noticed that the water boiled while the ice, held down by gauze metal, only melted very slowly. How would you explain to Adrian why this occurs?

30. When the weather is cold birds can be seen fluffing up their feathers which can make them appear larger than they really are. Explain how doing this to its feathers can keep a bird warm.

31. A woollen coat does not supply heat to our body but can keep us warm on a cold day. Explain why the coat is able to keep us warm.

32. Modern brick homes have insulating material between the inside and outside walls. This has the effect of keeping the homes warm during winter. Explain why the homes keep warm.

33. Heat can be transferred through a liquid by both conduction and convection. How are the two processes different?

34. Motor bike engines have been designed with cooling fins to prevent them from overheating. In some models the fins are made vertical. Explain why they are made vertical.

35. Briefly describe how a vacuum flask, containing hot water, is designed to reduce heat loss on a cold day through the processes of conduction, convection and radiation.

36. When standing in front of a fire in an open fire place, which process of heat transfer is largely responsible for the warmth you receive?

37. Joan and Peta were walking to school one winter's morning. Joan was wearing woollen slacks and a woollen jumper but Peta, who had a phys. ed. class period one, was wearing a sports skirt and short sleeved top. A cold wind started to blow causing Peta to shiver but not Joan. Explain why the cold wind caused Peta to shiver but not Joan.

38. Many modern kitchens have a built-in alcove in which the refrigerator is placed. Explain why refrigerator manufacturers advise that if a refrigerator is placed in an alcove then an air gap of about 10 cm should be allowed for around the sides and top of the refrigerator.

1.4 Heat and the Environment

39. Indicate whether each of the following is true or false. Alter any false statement so that they are true.
    (a) Energy from the sun is mostly long wavelength radiation.
    (b) The intensity of solar radiation at ground level is lower at higher latitudes.
    (c) The Earth radiates energy into space.
    (d) Silver coloured materials are the best absorbers of heat.
    (e) Whenever energy is transformed from one form to another it is always conserved.

40. The intensity of solar radiation when it reaches the Earth's upper atmosphere is about 1360 Wm^{-2}. However the intensity at ground level for a city such as Perth (latitude 32°) is significantly less, typically 900 Wm^{-2} during the middle of a clear summer day.

    Explain clearly the two main reasons for this reduced intensity of solar radiation.

41. The greenhouse effect of our atmosphere is very important in keeping our Earth warmer than it would otherwise be. Explain what is meant by the greenhouse effect and how it is caused.

42. Regular petrol typically contains 35 MJ of chemical energy per litre. The engine in a particular family car is known to be 27% efficient and its fuel consumption is 9.5 L per 100 km. Determine:
    (a) how much useful energy is supplied to the car for every litre of fuel consumed.
    (b) how much useful energy is supplied during a 10 km trip.
    (c) how much energy is converted from the fuel over a 10 km trip.

43. Incandescent light globes have been shown to be only about 3% efficient in converting electrical energy into light energy. The general use of these type of globes has now been limited.

(a) How much light energy per second would be produced by a 60 W incandescent light globe?

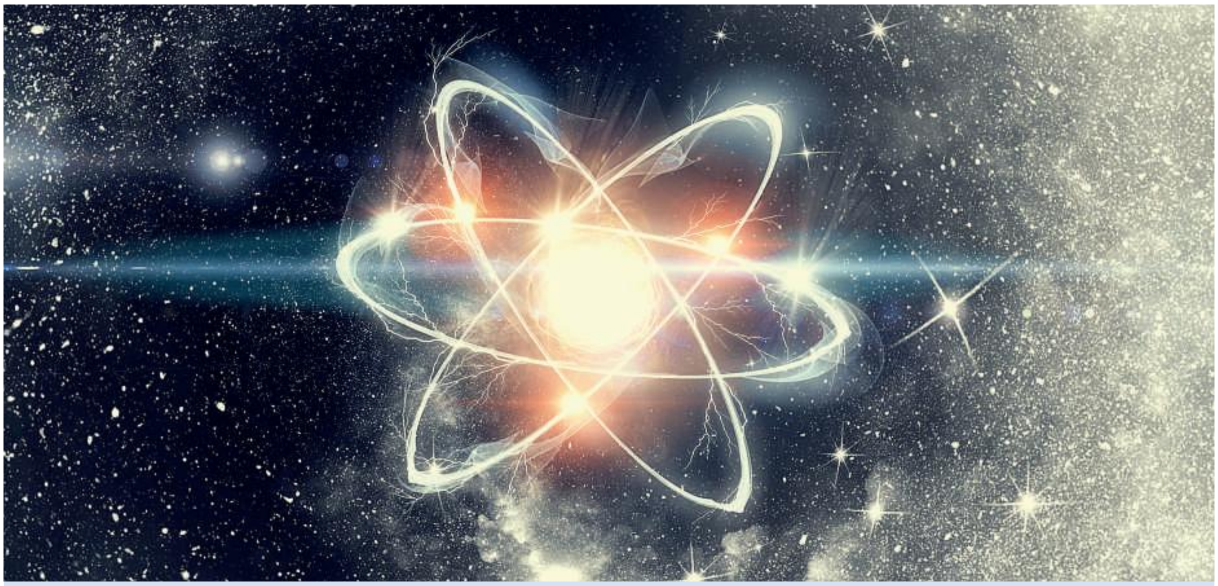
(b) Explain what happens to the remainder of the electrical energy used.

(c) Fluorescent light globes are rated as having 15% efficiency. Determine the wattage rating for a fluorescent globe producing the same amount of light as the 60 W incandescent globe.

44. In Europe, valleys between the very high snow covered mountains can receive very cold convection currents from the mountain slopes. Suggest how these convection currents may be formed.

IONISING RADIATION AND NUCLEAR REACTIONS

2



SYLLABUS CHECKLIST

SCIENCE UNDERSTANDING – IONISING RADIATION & NUCLEAR REACTIONS

- ☐ the nuclear model of the atom describes the atom as consisting of an extremely small nucleus which contains most of the atom's mass, and is made up of positively charged protons and uncharged neutrons surrounded by negatively charged electrons
- ☐ nuclear stability is the result of the strong nuclear force which operates between nucleons over a very short distance and opposes the electrostatic repulsion between protons in the nucleus
- ☐ some nuclides are unstable and spontaneously decay, emitting alpha, beta (+/-) and/or gamma radiation over time until they become stable nuclides
- ☐ each species of radionuclide has a half-life which indicates the rate of decay. This includes applying the relationship:

  $N = N_0 \left(\tfrac{1}{2}\right)^n$
- ☐ alpha, beta and gamma radiation have different natures, properties and effects
- ☐ the measurement of absorbed dose and dose equivalence enables the analysis of health and environmental risks. This includes applying the relationships:

  $\text{absorbed dose} = \frac{E}{m}, \quad \text{dose equivalent} = \text{absorbed dose} \times \text{quality factor}$
- ☐ Einstein's mass/energy relationship relates the binding energy of a nucleus to its mass defect. This includes applying the relationship:

  $\Delta E = \Delta mc^2$
- ☐ Einstein's mass/energy relationship also applies to all energy changes and enables the energy released in nuclear reactions to be determined from the mass change in the reaction. This includes applying the relationship:

  $\Delta E = \Delta mc^2$
- ☐ alpha and beta decay are examples of spontaneous transmutation reactions, while artificial transmutation is a managed process that changes one nuclide into another

☐ neutron-induced nuclear fission is a reaction in which a heavy nuclide captures a neutron and then splits into smaller radioactive nuclides with the release of energy

☐ a fission chain reaction is a self-sustaining process that may be controlled to produce thermal energy, or uncontrolled to release energy explosively if its critical mass is exceeded

☐ nuclear fusion is a reaction in which light nuclides combine to form a heavier nuclide, with the release of energy

☐ more energy is released per nucleon in nuclear fusion than in nuclear fission because a greater percentage of the mass is transformed into energy

2.1 RADIATION

What is radiation?

Our everyday environment contains many different forms of radiation. Often, the term radiation is immediately associated with danger yet many types of radiation are helpful and in some cases essential to our survival. Light and heat are two very familiar and useful forms of radiation while such things as x-rays and nuclear radiation are less well understood.

In order to understand and distinguish between the various forms of radiation it is best to consider the source from which they originate.

Electromagnetic radiation

Electromagnetic radiation includes radio waves, microwaves, infra-red, visible light, ultraviolet radiation, x-rays and γ-rays. This type of radiation is produced or caused by the excitation of electrons within atoms or the acceleration of charged particles.

Visible light results from the thermal excitation of atoms (such as in the filament of an old style light globe) and the movement of electrons between the energy levels of the atoms. The frequency (or colour) of the light produced depends on the energy given up by the electrons as they fall between different levels.

Radio waves were discovered in 1888 by Heinrich Hertz. He produced these waves by creating electric sparks. Modern radio transmitters produce radio waves by causing electric waves to oscillate up and down an antenna at very high frequencies (e.g. 720 kHz for ABC 720). Telecommunications such as TV, radio, and mobile phones all depend on some form of radio waves.

Microwaves are a higher frequency radiation than radio waves. They are produced by causing electrons to vibrate rapidly inside a small cavity by using a magnetron or klystron tube. Microwave radiation is used in microwave ovens and the operation of radar.

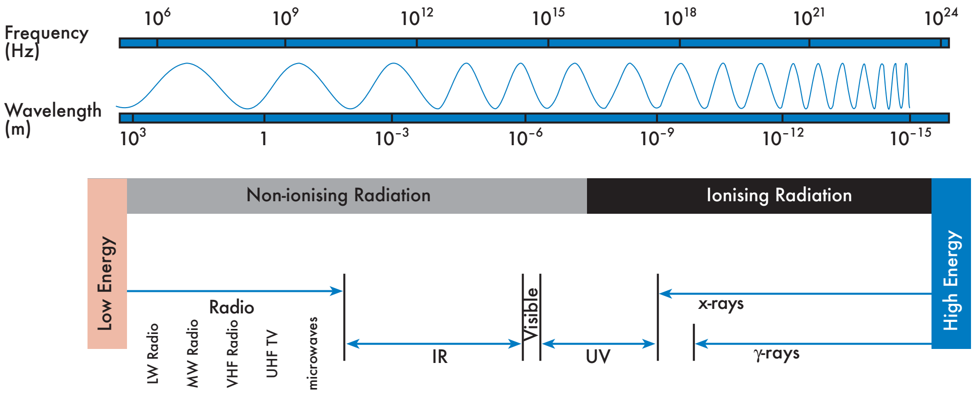


Figure 2.1 *The electromagnetic spectrum. Higher energy radiation, such as γ-rays, x-rays and some UV light have an ionising effect. Soft UV, visible, IR, microwaves and radio waves are non-ionising.*

X-rays were first discovered by Wilhelm Röentgen in 1895 while experimenting with a discharge tube. X-rays are high frequency electromagnetic waves which are produced when high speed electrons strike a metal target (usually tungsten) and rapidly decelerate. X-rays have important applications in both medicine and industry.

Gamma rays are caused by changes that occur within the nucleus of atoms. This type of radiation is considered as both nuclear and electromagnetic. Gamma rays consist of high frequency, high energy photons which can penetrate deeply into most matter.

Nuclear radiation

This type of radiation is the result of changes or disintegrations that occur spontaneously in the nucleus of some atoms. It was first discovered by Henri Becquerel in 1896 when he noticed that a uranium compound was able to expose a sealed photographic plate. Later work by Marie Curie and others found that elements like thorium and radium also gave off this type of radiation.

This was different to electromagnetic radiation since it was spontaneous and nothing had to be done to get it started. Neither could it be stopped by any chemical or physical means. Substances giving off this type of radiation were called *radioactive*.

Experiments carried out by Ernest Rutherford early this century showed that there were three different kinds of radiation given out by radioactive materials. He called these alpha (α), beta (β) and gamma (γ) radiation. Using magnetic and electric fields to investigate their properties, Rutherford established that alpha and beta radiation were actually charged particles while gamma radiation was similar to x-rays.

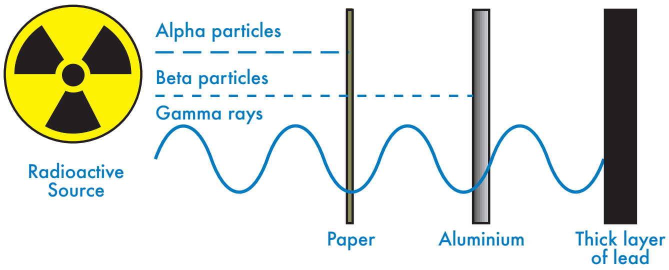


Figure 2.2 Penetrating power of α, β and γ radiation.

Alpha (α) radiation – Positively charged particles not very penetrating, easily stopped by a few cm of air or paper or the outer layers of human skin.

Beta (β) radiation – Negatively charged particles which can penetrate a few metres of air or a few mm of aluminium. It can penetrate about 2 cm of human flesh.

Gamma (γ) radiation – Similar to high energy x-rays. It consists of highly energetic photons that can penetrate most substances. Thick shields of lead or concrete can stop it.

Radiation in the environment

Natural radioactivity is an invisible part of our everyday environment and it has been so since the earth was formed. The major sources of this natural radiation are cosmic radiation from outer space and radiation from our own earth, the atmosphere, our food and our own bodies. In Australia, these contribute 1.5 mSv, or approximately half of our average annual radiation dose from all sources. These low levels of background radiation are not considered harmful. Artificial sources of radiation exposure are mainly from medical diagnostics. Their increased use and complexity has seen a marked increase in the average annual radiation dose in this area to 1.7 mSv.*

Cosmic radiation

Cosmic rays originate from deep in space. It is thought that they are caused by high temperature interactions that occur in the sun and other stars. These rays consist mainly of very energetic protons and gamma rays. When they collide with molecules in our atmosphere, they produce various forms of secondary radiation referred to as cosmic ray showers.

For Australians at sea level, cosmic radiation contributes some 20% of their natural radiation dose. At higher altitudes the level of cosmic radiation increases since there is less atmosphere to act as a protective blanket. Airline passengers for example would get a much higher exposure than at ground level. However, for the average airline passenger, this is not significant. A return trip from Perth to Europe for example, would only add about 0.1 mSv to their total natural radiation dose.

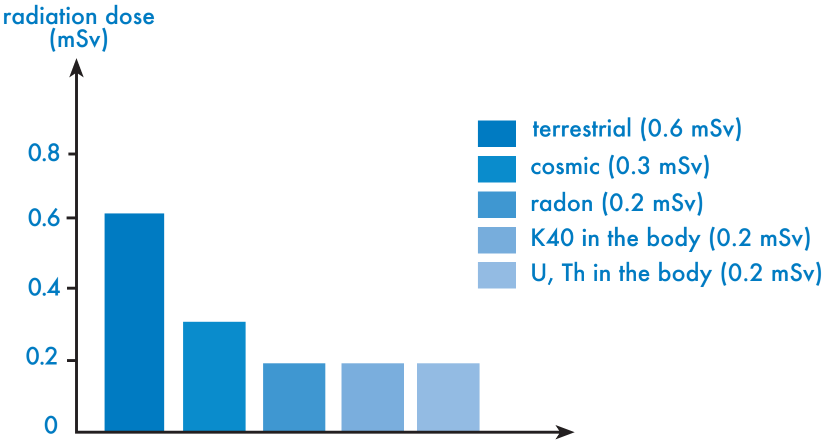


Figure 2.3 Average annual radiation dose from natural sources in Australia. This totals 1.5 mSv. Artificial sources, mainly medical, contribute a further 1.7 mSv to the average yearly radiation exposure.

Terrestrial and other natural radiation

Terrestrial radiation is emitted by radioactive materials present in the earth's crust, soil and building materials such as bricks and granite tiles. On average it contributes some 40% of our total natural radiation dose. Other sources of natural radiation come from the air we breathe, the food we eat and even our own bodies.

Radon gas occurs naturally in the atmosphere around us. It is the result of the radioactive decay of uranium-238, an element present in small quantities in many rocks. The radon gas itself is not a high health risk since it is breathed out as easily as it is taken in. However its radioactive daughter products, which are solids, can remain trapped inside our bodies.

The foods that we eat also contribute to our natural radiation dose. Potassium-40 is a common example. This radioactive isotope occurs as a very small percentage (0.01%) of the potassium taken into our bodies as an essential part of our diet.

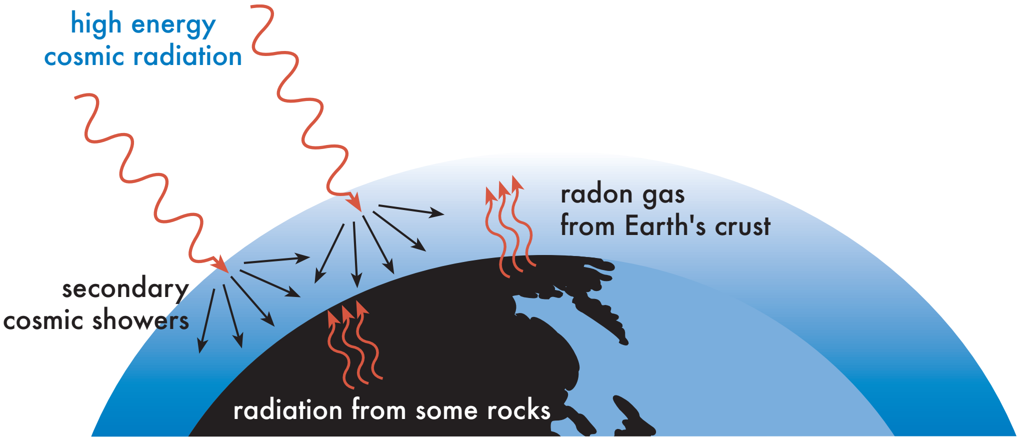


Figure 2.4 Natural sources of environmental radiation. Currently in Australia approximately half of a person's yearly dose of radiation comes from natural sources.

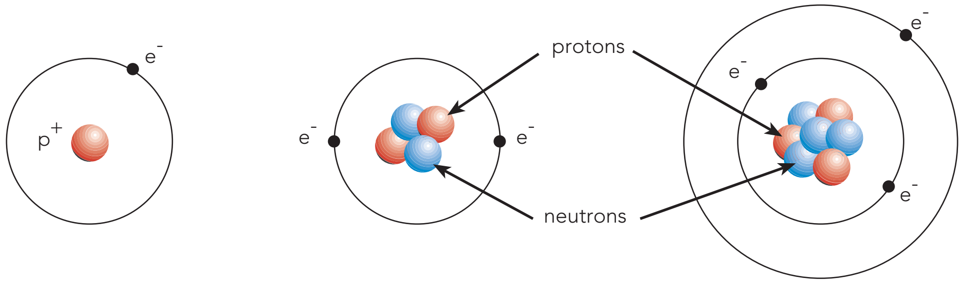
** See* www.arpansa.gov.au *for other and more current information.*

Models of the atom

To understand the nature of radioactivity we must firstly establish a model of the structure of atoms. Our modern concept of the atom is based on the work and theories of many scientists but in particular those of Ernest Rutherford and Neils Bohr.

During the earlier part of this century it was established that atoms have a dense positively charged centre (nucleus) surrounded by negatively charged particles (electrons). The Rutherford/Bohr model of the atom suggests that:

- atoms are mostly empty space
- nearly all of their mass is concentrated in the nucleus
- protons and neutrons have approximately the same mass and are located in the nucleus
- electrons move around the nucleus in specific orbits dependent on their energy
- all the neutral atoms of a given element have the same number of protons (+ve charge) and electrons (–ve charge)
- when atoms lose or gain electrons they become ions (that is, charged atoms).



(a) Hydrogen (${}^{1}_{1}H$) (b) Helium (${}^{4}_{2}He$) (c) Lithium (${}^{7}_{3}Li$)

Figure 2.5 Rutherford/Bohr model of the atoms of the first three elements.

Protons, neutrons and electrons

Protons, neutrons and electrons are the three elementary particles that make up atoms. Protons and neutrons (collectively called nucleons) are similar in mass and are 1836 times heavier than electrons. They are held together in the nucleus by very strong nuclear forces.

Electrons and protons carry equal and opposite charges (1.60×10^{-19} coulomb). It is the electrostatic attraction between these two particles which keeps the electrons in orbit around the nucleus.

Table 2.1 Protons, neutrons, electrons.

PARTICLE	SYMBOL	CHARGE (C)	MASS (kg)	MASS (u)*
proton	${}^{1}_{1}p$	$+1.60 \times 10^{-19}$	1.673×10^{-27}	1.0073
neutron	${}^{1}_{0}n$	neutral	1.675×10^{-27}	1.0087
electron	${}^{0}_{-1}e$	-1.60×10^{-19}	9.11×10^{-31}	0.00055

* *Atomic mass unit (u) = $\frac{1}{12}$ mass of a carbon–12 atom = 1.6605×10^{-27} kg*

Atomic number, Mass number

The **atomic number** (Z) of an atom is the number of protons in its nucleus. All atoms of the same element have the same atomic number. For neutral atoms this is also equal to the number of electrons.

The **mass number** (A) is the total number of protons and neutrons.

The atomic and mass numbers of different nuclides (nuclear species) are indicated as follows.

$${}^{A}_{Z}X$$

X = symbol of the element
A = mass number
Z = atomic number

Using this notation we can write for example:

${}^{1}_{1}H$ for hydrogen, ${}^{12}_{6}C$ for carbon-12, ${}^{235}_{92}U$ for uranium-235

Isotopes

All the atoms of a given element have the same number of protons but the number of neutrons may vary. Hence different forms of an element may have a different mass number (A). These different forms of the element are called isotopes.

Isotopes of a particular element are chemically similar since they have the same number of electrons. This makes them difficult to separate as they only differ slightly in mass and density.

Two common isotopes are ${}^{35}_{17}Cl$ and ${}^{37}_{17}Cl$. The chlorine-35 isotope has 18 neutrons in its nucleus while the chlorine-37 has 20 neutrons.

Some isotopes give off nuclear radiation because their nuclei are unstable. They are called **radioactive isotopes** or simply radioisotopes.

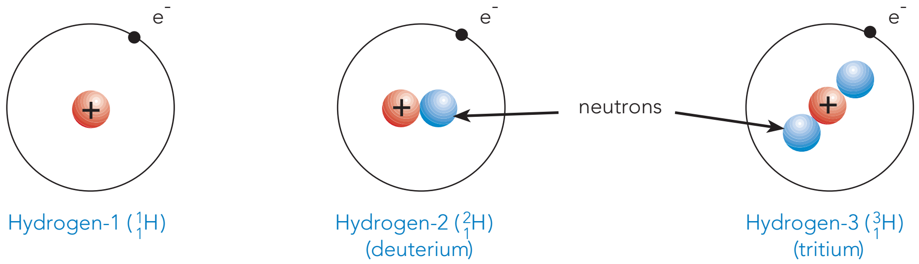


Figure 2.6 The three isotopes of hydrogen.

Radioactive decay

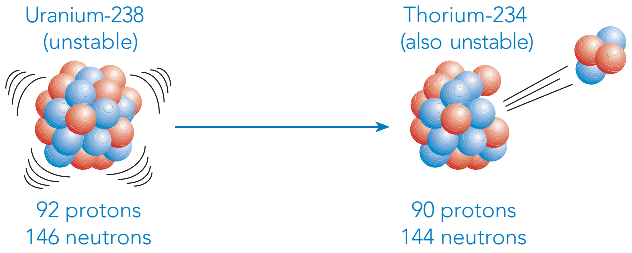
Many nuclei, particularly those of larger atoms, are unstable and break down into simpler nuclei. During this process of radioactive decay, three different forms of nuclear radiation may be released. These are alpha (α), beta (β) and gamma (γ) radiation.

Alpha particle decay

Alpha particles can best be described as helium nuclei. They consist of two protons and two neutrons and are emitted from the nucleus of unstable atoms at up to $\frac{1}{10}$ the speed of light. A common source of alpha radiation is that from uranium-238. In this process the uranium changes to a new element, thorium-234. We can represent this alpha decay as follows.

$${}^{238}_{92}U \rightarrow {}^{234}_{90}Th + {}^{4}_{2}He$$

Note that in this decay equation the mass numbers balance (238 = 234 + 4) and the atomic numbers balance (92 = 90 + 2).

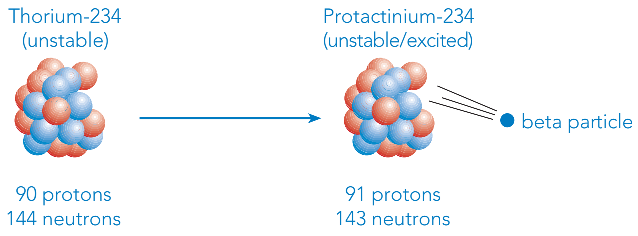


Beta particle decay

Thorium-234 is itself unstable and emits β^- particles from its nucleus. A β^- particle is a nuclear electron travelling at up to $\frac{9}{10}$ the speed of light. It appears that a neutron from the nucleus changes to a proton by emitting an electron (β^-) called a beta particle.

This can be represented as follows: $${}^{1}_{0}\text{n} \rightarrow {}^{1}_{1}\text{p} + {}^{0}_{-1}\text{e}$$

The decay equation for thorium-234 being: $${}^{234}_{90}\text{Th} \rightarrow {}^{234}_{91}\text{Pa} + {}^{0}_{-1}\text{e}$$



Gamma ray decay

When a nuclide undergoes either alpha or beta decay it is often left in an excited state, that is, with more energy than normal. The nucleus achieves a normal energy state by emitting a photon of energy. These photons have no mass or charge and therefore there is no change in the value of Z or A. The protons and neutrons are simply arranged in a different and more stable manner. The photons of energy emitted are high energy, high frequency radiation. They are referred to as gamma rays (γ).The emission of γ radiation from protactinium-234 can be represented as follows:

$${}^{234}_{91}\text{Pa}^{*} \rightarrow {}^{234}_{91}\text{Pa} + \gamma$$

(*excited state)

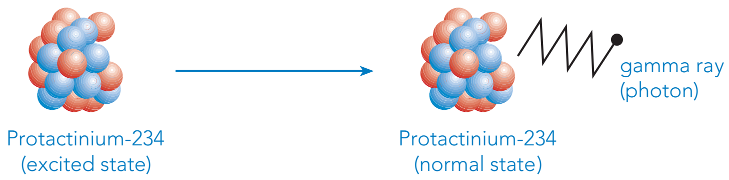


Table 2.2 Nuclear radiation – types and properties.

	α-particle	β^--particle	γ-ray
Description	helium nucleus	high speed electron	high energy photon $\lambda \approx 10^{-12}$ m
Symbol	$[{}^{4}_{2}\text{He}]^{2+}$ or ${}^{4}_{2}\propto$ or $\propto$	${}^{0}_{-1}\text{e}$	γ
Charge	+2 ($2 \times 1.6 \times 10^{-19}$ C)	–1 (-1.6×10^{-19} C)	0 (neutral)
Mass	Approx. 4 u ($\approx 4 \times 1.66 \times 10^{-27}$ kg)	Approx. 0.00055 u ($\approx 9.11 \times 10^{-31}$ kg)	0 (no mass)
Emission velocity	up to 10% speed of light	30–90% speed of light	c (speed of light) 3.00×10^{8} ms^{-1}
Penetration	few cm in air	1–2 mm metal foil	mostly stopped by lead or concrete
Ionising effect	strong	moderate	very little

Stability of nuclei

Protons and neutrons are held together in the nucleus by an attractive force known as the strong nuclear force. This force is able to overcome the weaker electrostatic repulsive force which exists between the positively charged protons.

The strong nuclear force between nucleons acts only over very short distances. This means that for very large nuclei distant nucleons are not able to attract each other strongly and hence the electrostatic forces trying to break the nucleus apart become more dominant. However the stability of larger nuclei is maintained by the greater proportion of neutrons within the nucleus.

- For light nuclei ($Z < 20$), stability occurs when the number of neutrons is similar to the number of protons.
- For heavier nuclei up to lead ($Z = 82$), stability is achieved by an increase in the proportion of neutrons to protons.
- Above $Z = 82$, the repulsive forces in the nucleus are not balanced by extra neutrons since the average distance between the nucleons is becoming too large. Hence all these very large nuclei are unstable.

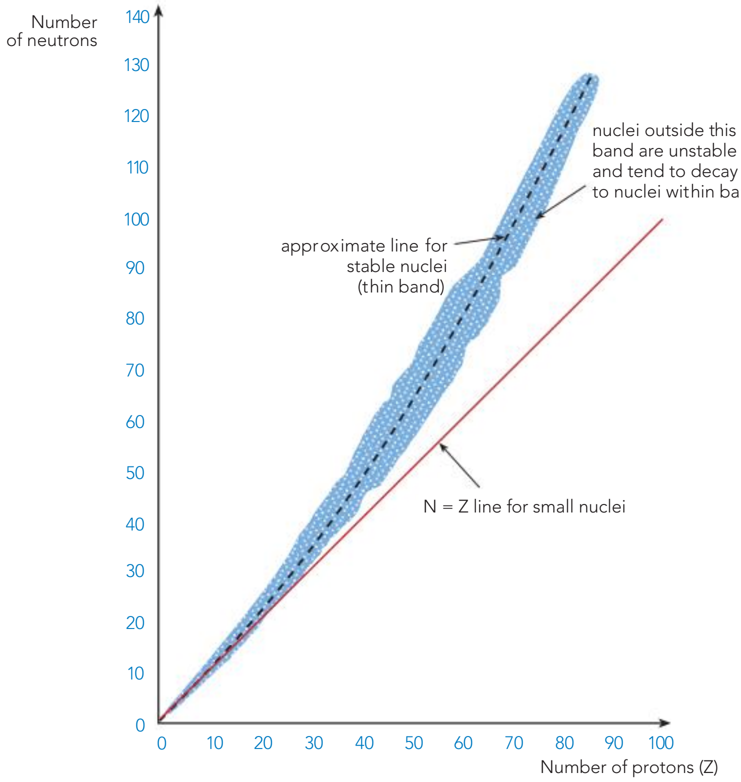


Figure 2.7 Approximate N-Z plot for stable nuclei.

Question 2.1

Complete each of the following decay equations and name the type of radiation emitted in each case.

(a) $^{232}_{90}\text{Th} \rightarrow {}^{228}_{88}\text{Ra} +$ ______________ ______________

(b) $^{24}_{12}\text{Mg}^{*} \rightarrow {}^{24}_{12}\text{Mg} +$ ______________ ______________

*excited state

(c) $^{3}_{1}\text{H} \rightarrow {}^{3}_{2}\text{He} +$ ______________ ______________

(d) $^{11}_{6}\text{C} \rightarrow {}^{11}_{5}\text{B} +$ ______________ ______________

Decay series

When an unstable nuclide decays (parent nucleus) the remaining nuclide (daughter nucleus) is also very often unstable. This radioactive daughter product itself decays to a granddaughter nucleus. The process continues until a stable nuclei such as lead-206 is formed. A particular set of decays is referred to as a decay series or radioactive series.

An important naturally occurring radioactive series is that which begins with U-238 and finishes with Pb-206. This series begins with the alpha emission from U-238 which produces Th-234. The early part of this series is as follows.

$$^{238}_{92}\text{U} \longrightarrow {}^{234}_{90}\text{Th} \longrightarrow {}^{234}_{91}\text{Pa} \longrightarrow {}^{234}_{92}\text{U} \longrightarrow {}^{230}_{90}\text{Th} \longrightarrow \ldots$$

An alpha decay causes the atomic number to be reduced by 2 and the mass number by 4. A β^- decay actually causes an increase in atomic number. The decay series can be indicated graphically as in Figure 2.8.

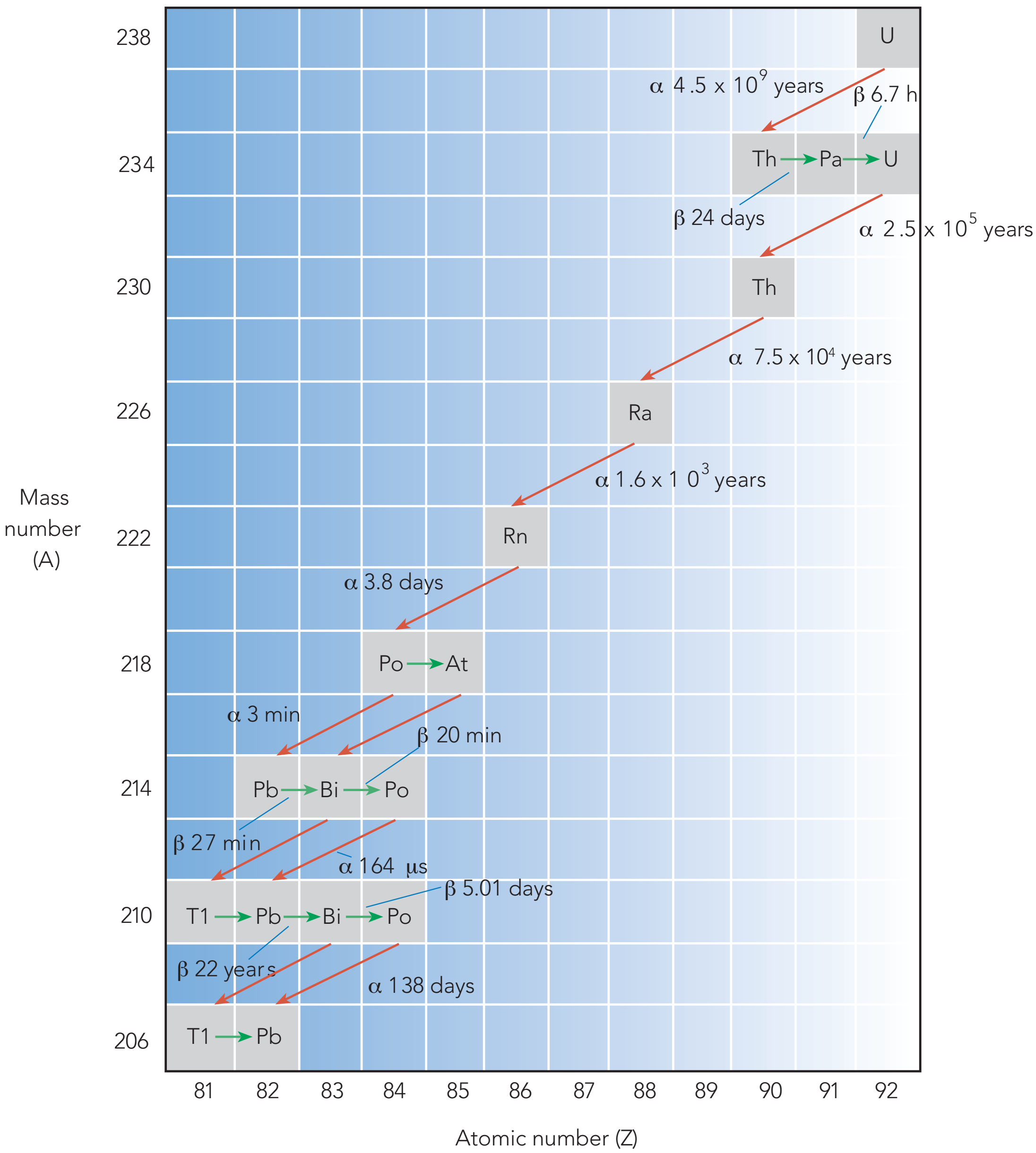


Figure 2.8 *The uranium decay series. Alpha (α) decays, indicated by the red arrows reduce the atomic number by 2 and the mass number by 4. The β decays, green arrows, actually cause an increase in atomic number. The many decays that occur, referred to as a decay series, end with the stable nucleus Pb-206.*

Detecting radiation

Radioactivity can be detected in a variety of ways, the most common being the use of a Geiger counter. It can also be detected by using photographic emulsions, electroscopes, cloud chambers or solid state detectors. In most cases this detection is made possible by the fact that α, β and γ radiation have an ionising effect.

Geiger counter: This consists of a Geiger-Müller tube operated at high voltage and connected to an amplifier and counter (see Figure 2.9). The mica window is sufficiently thin as to allow alpha particles as well as β and γ radiation to enter the tube. The radiation ionises the gaseous atoms and causes a temporary pulse of current between the central wire and the metal tube. This pulse is amplified and a click is heard through the loudspeaker. The counter records the number of pulses or counts per second.

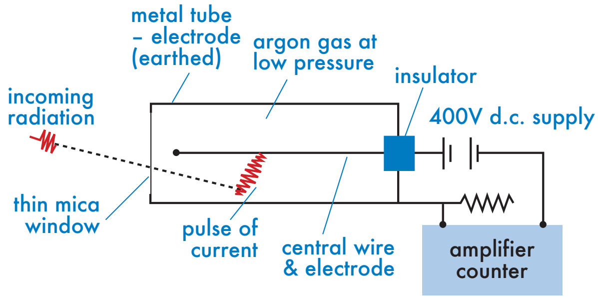


Figure 2.9 The Geiger counter. Incoming radiation causes argon gas atoms to become ionised. Temporarily, the gas conducts and a pulse is registered.

Cloud chamber: This device allows the tracks of charged particles to be seen. The container is filled with super-cooled alcohol vapour. As ionising particles pass through the vapour they leave behind a trail of ionised atoms around which liquid droplets form. The result is a vapour trail not unlike that left by high flying aircraft.

The nature of the tracks produced in a cloud chamber is unique to each type of radiation. Alpha-particle tracks are relatively thick as they are strongly ionising. Beta-particle tracks are thin and not straight like those of the alpha particles. Since beta particles are light they are easily pushed off course by nearby air molecules. Gamma radiation produces tracks in an indirect way. Electrons which absorb energy from the gamma rays escape from their atoms and leave behind a beta-like trail.

Scintillation counter: This is a particularly useful device for detecting and analysing γ radiation. Normally it is difficult to detect gamma radiation as it is very penetrating. Using a Geiger counter for example, a gamma ray can pass right through its gas filled Geiger-Müller tube without registering a count.

The scintillation counter consists of a solid NaI crystal with which the γ radiation interacts. Photons produced from this interaction produce electrons from a photo cathode which enter a photomultiplier tube. The electrical pulse produced can be analysed to determine both the number and energies of the γ rays.

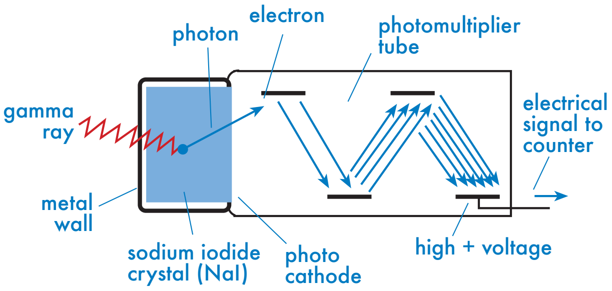


Figure 2.10 The scintillation detector. Gamma radiation causes photons to be emitted by the NaI crystal. The photomultiplier tube generates an electrical signal which can then be analysed.

Dosimeters: These are used to monitor personal exposure to radiation. This is particularly important for workers in areas that may be exposed to ionising radiation. Film badges or the thermoluminescent dosimeter (TLD) are commonly used.

The film badges contain photographic film in a light tight plastic holder. The degree of blackening of the film is an indication of the radiation dose received by the wearer. The more modern radiation badges contain thermoluminescent materials. When these are exposed to radiation they store a small fraction of the energy. When heated at a later date, the TLD will emit an amount of light which is in proportion to the radiation exposure.

Measuring radiation – activity

The activity of a radioactive sample is defined as the number of nuclei which decay each second. The unit of activity is the becquerel (Bq).

Activity 1 Bq = 1 decay per second

The activity of a radioactive sample cannot be affected by any physical or chemical means. However, the activity will diminish with time as it is dependent on the number of undecayed nuclei left in the sample.

Radioactive half-life

Radioactive decay is a spontaneous and random process. This means that we cannot predict which particular nuclei might decay at a given instant. However, when we consider even a small sample of a radioactive isotope, containing many billions of atoms, a very definite pattern of decay becomes evident (see Figure 2.11).

$$\frac{1}{2^n} = \frac{N}{N_0}$$

or

$$N = N_0 \left(\frac{1}{2}\right)^n$$

N = number of nuclei remaining
N_0 = original number of nuclei
n = number of half lives

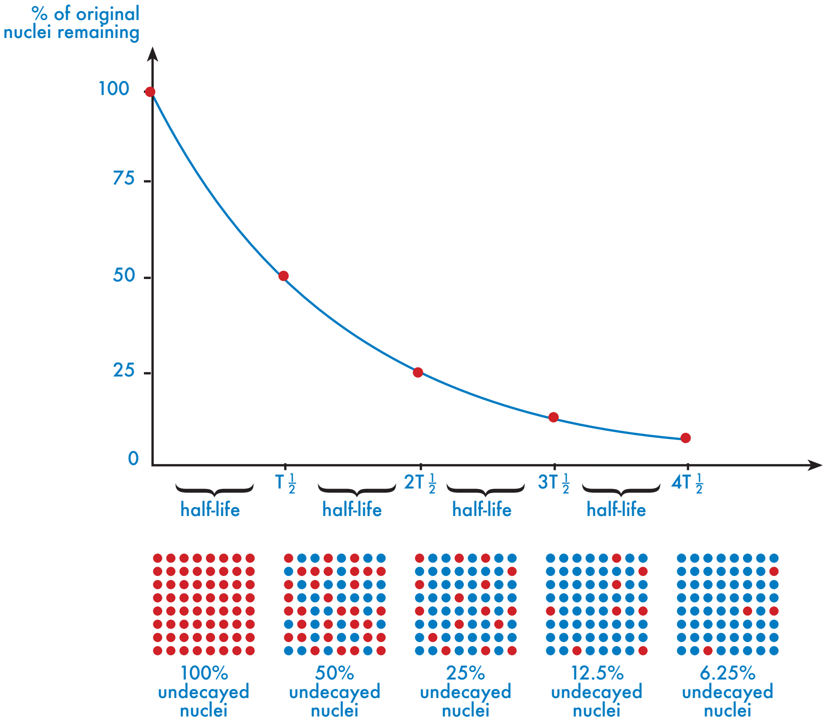


Figure 2.11 Characteristic decay curve. The time taken for half of the remaining sample to decay is the same from any point on the curve.

The actual rate of decay depends on the type of nucleus and upon the number of atoms present. This rate is unaffected by external conditions such as pressure, temperature or chemical agents.

The rate of decay of radioactive isotopes varies greatly. To compare decay rates it is best to consider the time taken for half (½) of a radioactive sample to decay. This is known as the half-life of the isotope.

Question 2.2

(a) A sample of Radon-222 has one quarter of its original nuclei left after 7.6 days. Calculate its half-life.

(b) Estimate the total number of days that would need to elapse so that less than 1% of the original Radon-222 nuclei are remaining?

(c) By checking the uranium decay series (Fig. 2.8, page 41) determine the parent element from which radon-222 is produced.

(d) Similarly determine the decay products of radon-222 and give an equation for the process.

Worked Example 2.1

The radioactive isotope gold-198 is a β^--emitter and is often used as a radioisotopic tracer. It can be used, for instance, by health engineers to trace the flow of sewage. It is found that its activity drops to ⅛ of its original value in just over 8 days.

(a) Write the β-decay equation for this isotope (${}^{198}_{79}\text{Au}$). You will need to refer to a periodic table.
(b) Calculate its approximate half-life.
(c) Estimate the fraction of gold-198 remaining after 2 weeks.
(d) Why do you think gold-198 may be chosen as a tracer to study the flow of sewage?

(a) ${}^{198}_{79}\text{Au} \rightarrow {}^{198}_{80}\text{Hg} + {}^{0}_{-1}\text{e}$

(b) Activity drops off as follows:

$$1 \xrightarrow{T\,\frac{1}{2}} \frac{1}{2} \xrightarrow{T\,\frac{1}{2}} \frac{1}{4} \xrightarrow{T\,\frac{1}{2}} \frac{1}{8} \xrightarrow{T\,\frac{1}{2}} \frac{1}{16}\ \text{etc}$$

Also we can use $N = N_0 \left(\frac{1}{2}\right)^n$

$\frac{1}{8} = 1\left(\frac{1}{2}\right)^n$

$n = 3$

Hence, to drop to ⅛ of its original value will take 3 half-lives.
Hence, half-life of gold-198 $\approx \frac{8\ days}{3} \approx$ 2.7 days

(c) After 2 weeks, 6 half-lives would have occurred for gold 198.
Hence fraction remaining = $(\frac{1}{2}) \times (\frac{1}{2}) \times (\frac{1}{2}) \times (\frac{1}{2}) \times (\frac{1}{2}) \times (\frac{1}{2}) = \frac{1}{64}$

(d) Since gold-198 is a β-emitter its presence can be detected through liquids or thin metal. The relatively short half-life of gold-198 means that:
(i) it is a fairly active isotope and more easily detectable;
(ii) it does not remain in the system for too long since its activity is effectively zero after a few weeks.

Worked Example 2.2

A 10.0 mg sample of strontium-90 is found to have an activity of 24 Bq. Its half-life is 28.5 years. Calculate:

(a) the fraction of undecayed atoms of Sr-90 remaining after 114 years

(b) the activity of the sample after this time.

Fraction of sample remaining

$$100\% \xrightarrow{28.5\text{ y}} 50\% \xrightarrow{28.5\text{y}} 25\% \xrightarrow{28.5\text{y}} 12.5\% \xrightarrow{28.5\text{y}} 6.25\%$$

Activity of sample

$$24\text{ Bq} \xrightarrow{28.5\text{ y}} 12\text{ Bq} \xrightarrow{28.5\text{y}} 6\text{ Bq} \xrightarrow{28.5\text{y}} 3\text{ Bq} \xrightarrow{28.5\text{y}} 1.5\text{ Bq}$$

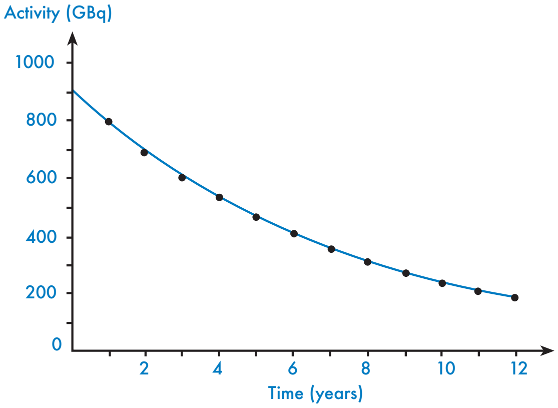
Hence, after 114 years, 6.25% of the Strontium-90 sample remains while its activity is reduced to 1.5 Bq.

Worked Example 2.3

The activity of a cobalt-60 source is monitored over several years and the results represented graphically as shown below.

(a) Use the graph to determine the half-life of cobalt-60.

(b) Use this result to estimate the time it would take the source to fall to an activity of only 1 GBq (1×10^9 Bq).



(a) Select any convenient point in the decay curve e.g. 1.0 years/800 GBq then look for another point which indicates only half that activity. In this case this second point is 6.3 years/400 GBq. Hence the half-life of cobalt 60 is 5.3 years.

(b) For the activity to drop to 1 GBq it will need to drop to about ($^1/_{1000}$) of its original activity.

Hence $(½) \times (½) \times (½) \times ...... \approx {}^1/_{1000}$ or $N = N_0\ (\frac{1}{2})^n$

$(½)^n \approx 1/1000$

$$\frac{1}{1000} = \frac{1}{2^n}$$

$n \approx 10$

$$2^n = 1000$$

Since $2^5 = 32$, $2^{10} = 1024$

$$n = 9.97$$

Hence it would take approximately 10 half-lives (53 years) for the cobalt-60 to drop to an activity of 1 GBq.

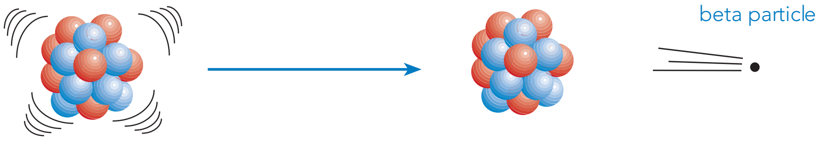
Carbon-14 dating

Carbon dating is possible due to the presence of minute quantities of radioactive carbon-14 in the atmosphere. This isotope has a half-life of approximately 5730 years. The amount of carbon-14 in the atmosphere however, is fairly constant, due to the effect of cosmic rays. Energetic neutrons are absorbed by nitrogen atoms and carbon-14 is created.

Formation of carbon-14

$$^{1}_{0}n + ^{14}_{7}N \longrightarrow ^{14}_{6}C + ^{1}_{1}p$$

Decay of carbon-14



$$^{14}_{6}C \longrightarrow ^{14}_{7}N + ^{0}_{-1}e$$

All living things contain some radioactive carbon-14. This is taken in by plants as carbon dioxide and by animals through their food. When a living thing dies it stops taking in carbon-14. From this point on the percentage of carbon-14 in the organism drops off at a known rate. Hence by comparing the carbon-14 to carbon-12 ratio of say living trees with that of an old specimen to be dated, it is possible to tell its age. This method of dating, called carbon dating, is useful for dating once living organisms up to about 50,000 years. This same method can be used to age older objects by making use of radioactive isotopes with longer half lives. Uranium-238 has a half life of 4.5×10^9 years and is useful for determining the age of rocks.

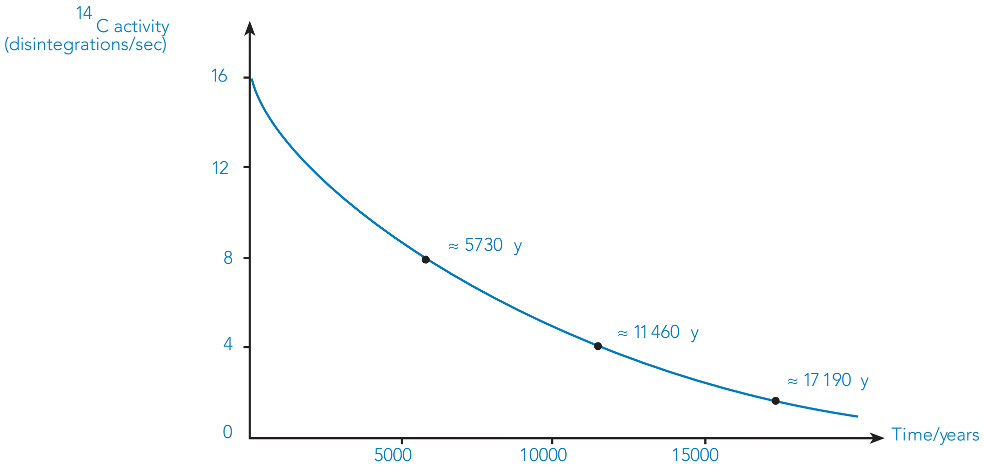


Figure 2.12 Carbon-14 decay curve. The age of once living organisms can be determined from measurement of the carbon-14 activity present in the specimen.

Question 2.3

(a) Carbon-14 dating is not useful for dating specimens that are very old (say more than 50,000 years) or relatively young (say 100 years old). Explain.

(b) What assumptions are made when using this technique of dating previously living organisms? List at least two.

Question 2.4

(a) A uranium bearing rock is being analysed to determine its age. It is assumed that the only radioactive isotope it originally contained was uranium-238. Use figure 2.8 to determine which other elements may now be present in the rock.

(b) Which element from the decay chain is likely to be found in most abundance? Why?

(c) Which element from the decay chain is likely to be in least abundance? Why?

(d) It is found that the rock contains about the same number of lead-206 atoms as uranium-238 atoms. Use this information to **estimate** the age of the rock.

2.2 RADIATION – EFFECTS AND USES

Radioactive isotopes

Most elements exist naturally in more than one isotopic form and in the majority of cases these isotopes are stable. At present the known number of naturally occurring stable isotopes is 264. As we have seen, however, many naturally occurring isotopes have unstable nuclei and hence are radioactive (see stability of nuclei). This is particularly so for the heavier elements. The breakdown of these elements provides us with a variety of many other radioactive isotopes. A sample of U-238 ore for example, will also contain traces of all its daughter products such as Th-234, Pa-234, U-234, Th-230, Ra-226, Fm-222, Po-218, Po-214, Pb-214, Bi-214, Pb-210 and others. All of these isotopes are radioactive, except of course the eventual stable isotope of lead, Pb-206.

Artificial radioisotopes

Artificial radioisotopes can be produced by bombarding the nuclei of certain elements with fast moving particles such as neutrons. In Australia, a large range of radioisotopes are produced in this way using the new OPAL research reactor located at Lucas Heights (NSW). Stable isotopes are placed in the U-235 reactor and subjected to an intense beam of neutrons. The neutrons are captured by the stable nuclei and this results in the formation of new radioactive isotopes.

Artificial radioisotopes can also be produced using a cyclotron. A cyclotron, such as the National Medical Cyclotron (see photo p. 180) is an electrically powered machine that accelerates charged particles, usually protons, to high speeds and beams them at a suitable target. This produces a nuclear reaction that creates an isotope.

The widely used radioisotope technetium-99m has a half-life of only 6 hours and so is generated from its parent radioisotope molybdenum-99 as required. Mo-99 is produced in the OPAL reactor and made available by ANSTO for hospitals and imaging practices in shielded generators like the one above.

Two of the most widely used artificial radioisotopes are cobalt-60 and technetium-99m. Cobalt-60 can be readily produced by the bombardment of normal cobalt-59 with neutrons.

$$^{59}_{27}\text{Co} + {}^{1}_{0}\text{n} \rightarrow {}^{60}_{27}\text{Co}$$

Technetium-99m, a gamma emitter, is produced in the excited state (hence the m for metastable) by the β-decay of molybdenum-99. The ^{99}Mo is itself produced in the OPAL reactor and has a half-life of several days.

$$^{99}_{42}\text{Mo} \rightarrow {}^{99m}_{43}\text{Tc} + {}^{0}_{-1}\text{e}$$

The half-life of ^{99m}Tc is fairly short (about 6 h) and hence hospitals that require it usually have their own 'generator'. This consists of an acidic solution of the radioactive isotope ^{99}Mo from which the technetium-99m can be obtained as required.

Uses of radioactive isotopes

Radioactive isotopes are widely used in the areas of industry, medicine and research. The usefulness of isotopes is related to their properties and to the effects of their radiation.

- *Radiation can alter the structure of materials.*

  A single alpha or beta particle can cause the ionisation of several atoms as it passes through a substance. This ionising effect makes possible the operation of such devices as smoke detectors and the destruction of cancerous cells using radiation therapy.
- *Radiation reveals information about the materials it interacts with.*

  The penetrating power of the different forms of radiation varies with the type of material. The amount of radiation passing through or reflected by a material can indicate its density or thickness. This can be used to discriminate between different materials or detect flaws within materials.
- *Radioactive materials can be easily traced as they move through a system.*

  Even very small quantities of radioactive material can be detected fairly readily. This allows for their use in tracer techniques. Hence radioisotopes can be used to trace the path of chemicals within the body, monitor biological processes or detect the occurrence of a leak from a gas pipeline.

Medical uses of radioisotopes

Some of the most valuable applications of the use of radioisotopes occur in the field of medicine. Radioisotopes are powerful tools for analysis, diagnosis and treatment. Two important applications are radiation therapy and tracer techniques.

- *Gamma radiation therapy* involves the use of a high activity cobalt-60 source for the treatment of inoperable tumours. The source provides a thin beam of radiation which is directed at the tumour. The source is continually rotated around the patient so that surrounding tissue will receive a relatively small exposure. The tumour, however, being the centre of this rotation, will receive a high dose of radiation and its cells will die.
- *Tracer techniques*. A radioactive isotope may be given to a patient by injection or swallowing and then its progress monitored as it moves through the body. Different substances are taken up by different organs of the body. Hence specific tracers are chosen to look at particular organs (see Table 2.3). Radioisotopes chosen as tracers usually have a fairly short half-life. Since only very small amounts of tracer are introduced into the body the short half-life ensures a high activity and easy detection. It also means that the isotope is not active in the body for too long.

The radioactive isotope technetium-99m is the most commonly used tracer. Its advantages include a short half-life (6 h), low production cost and chemical versatility. It can be introduced in various forms so as to be a tracer for checking such things as blood flow, thyroid function, bone disease, liver and heart function and detection of tumours.

Table 2.3 Some common isotopes and their medical applications.

ISOTOPE	RADIATION	HALF-LIFE	COMMENTS, USE
^{198}Au	β^-, γ	2.70 d	Diagnosis of liver function, general tracer.
^{45}Ca	β^-	163 d	Diagnosis of bone disease, metabolism studies.
^{60}Co	β^-, γ	5.27 y	Treatment of cancers. Sterilisation of medical instruments, etc.
^{137}Cs	β^-, γ	30.2 y	Treatment of cancers.
^{18}F	β^+	1.83 h	Positron-Emission Tomography – PET scans
^{131}I	β^-, γ	8.04 d	Diagnosis and treatment of thyroid disorder, detection of tumours.
^{24}Na	γ	15.0 h	Diagnosis of constriction of blood vessels, blood flow.
^{99m}Tc	γ	6.01 h	Most commonly used tracer, e.g. blood flow, thyroid, bone disease, lungs, liver, kidney.

Question 2.5

The ideal radioisotope for use in medical diagnosis should have the following properties: high activity, short physical half-life, short biological half-life. Explain what is meant by each of these terms and why they are important.

Other uses of radioactive isotopes

The use of radioisotopes in the areas of industry, agriculture and research are both interesting and varied. A brief description of some of these uses is listed below:

- *Industrial radiography*. Isotopes such as iridium-192 can be used to check flaws in steel welding. This is much like an X-ray. The γ radiation will discriminate between materials of different density; the steel being more dense than the weld. This technique of non-destructive quality control can also be used to inspect castings, ceramics and critical machinery such as aircraft engines.
- *Gauging*. The thickness of sheet materials, such as sheet plastic or sheet metal can be controlled without them being physically measured. The γ radiation from a source such as cobalt-60 has its intensity reduced as the thickness of the material it passes through increases. The reading by a radiation detector on the other side of the material can be used to monitor the correct thickness required during production (see Figure 2.13). In the packaging industry, the same technique can be used to ensure containers are correctly filled.

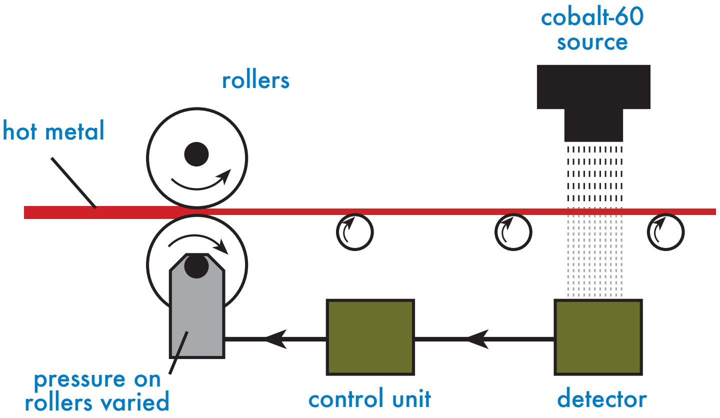


Figure 2.13 Monitoring and controlling the thickness of metal sheets. The reduced intensity of the gamma radiation reaching the detector is a measure of the thickness of the metal sheet. The control unit alters the applied pressure on the rollers when necessary.

- *Forensic analysis*. Neutron activation analysis (NAA) is a quick and sensitive method for determining the proportion of elements that exist in any given sample. This is achieved by placing the sample in a reactor and then analysing the radiation of the artificial isotopes produced. The original source of the sample perhaps from the scene of a crime can then be established.
- *Tracing applications*. These are many and varied. The flow rates of liquids and gases in pipelines and the flow rate of streams can be measured accurately using sodium-24 or cobalt-60 as a tracer. Importantly, leaks and blockages that occur in pipelines can also

be investigated. Gold-198, for example, can also be used to track treated sewage after its disposal. The flow of hot materials inside a blast furnace can also be analysed for efficiency using this same isotope. In agriculture, tracers are important in the study of such things as biological processes, soil erosion, use of fertilisers and insect biology.

- *Food irradiation*. Cobalt-60 can be used to irradiate packaged food and thereby help increase its shelf life. The gamma radiation passes through the food, destroying bacteria and microorganisms that could otherwise cause food spoilage and food poisoning. Many countries irradiate food for human consumption but at present this does not occur in Australia.

  Commercial cobalt-60 irradiation facilities are also used to sterilise medical supplies such as hypodermic syringes, surgical instruments, sterile dressings and pharmaceuticals. Such facilities incorporate 2 metre concrete shields for the protection of workers from the γ radiation. Automatic conveyers are used to transport the items to be irradiated.
- *Smoke detectors*. This important safety device is able to operate due to the ionising effect of americium-241 which emits α particles. An electronic alarm is prevented from sounding while a current is able to flow due to the presence of ionised air particles (see Figure 2.14). Smoke particles interfere with this current flow and hence trigger the alarm.

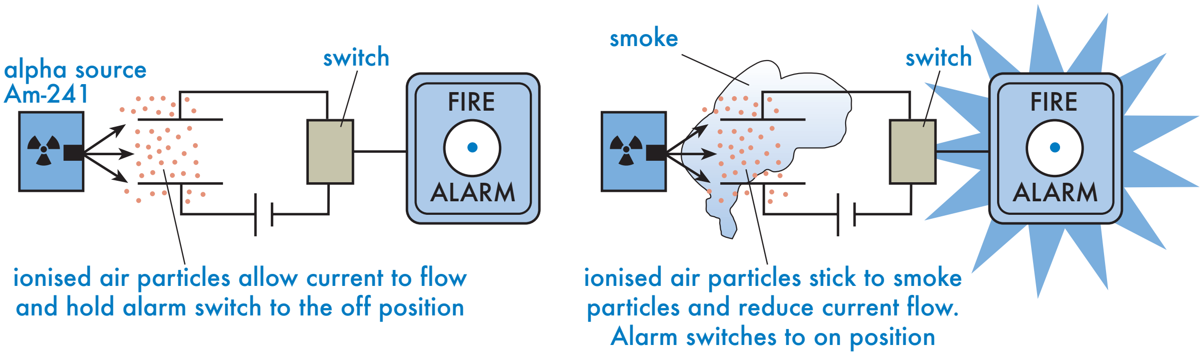


Figure 2.14 Operation of a smoke detector.

Biological effects of radiation

When ionising radiation interacts with living cells it transfers its energy to the individual atoms that make up the cell. This may cause damage to the cell by ionisation and the formation of extremely chemically reactive atoms or groups of atoms known as free radicals.

Where atoms or molecules are ionised, this can cause a change in the cell processes and cell chemistry. If DNA molecules are ionised for example, the effect may be the prevention of cell division, the premature death of the cell or a permanent genetic modification.

Radiation dose

The energy that our bodies receive from ionising radiation is referred to as the *absorbed dose*. Specifically, the absorbed dose is *the energy absorbed per kilogram of tissue*.

$$\text{Absorbed dose} = \frac{\text{energy absorbed}}{\text{mass of tissue}} = \frac{E}{m}$$

The SI unit is the gray (Gy). 1 Gy = 1 J kg^{-1}.

The quality factor

The effects of different types of radiation on living cells varies. Alpha particles, for example are far more ionising than gamma rays. Hence equal doses of these two types of radiation can have quite different biological effects. The quality factor for a particular radiation indicates the cell damage it causes in comparison to an equal dose of γ rays. The **dose equivalent** (in Sieverts) is a measurement which incorporates the quality factor. This means that 1 Sievert of any type of radiation will have the same biological effect.

$$\text{Dose equivalent} = \text{absorbed dose} \times \text{quality factor}$$

$$\text{SI units} = \text{sieverts (Sv)}$$

Table 2.4 Quality factors for different radiation.

RADIATION	APPROXIMATE QUALITY FACTOR (QF)
gamma rays	1
beta particles	1
slow neutrons	3
fast neutrons	10
alpha particles	10–20

Worked Example 2.4

A person of mass 70.0 kg accidentally absorbs 45.0 J of energy from a beta radiation source. Determine:

the absorbed dose;
the dose equivalent;
the dose equivalent if this energy had come from an alpha source.

(a) Absorbed dose $= \dfrac{\text{energy absorbed}}{\text{mass of tissue}}$

$$= \frac{45\text{ J}}{70\text{ kg}} = 0.643\text{ J kg}^{-1}$$

$$= 0.643\text{ Gy}$$

(b) (β source) dose equivalent $=$ absorbed dose × QF

$$= 0.643 \times 1\text{ J kg}^{-1}$$

$$= 0.643\text{ Sv}$$

(c) (α source) dose equivalent $= 0.643 \times 20$

$$= 12.9\text{ Sv}$$

Effects of ionising radiation on people

The effect of radiation on our bodies is due to the damage or changes that occur at the cellular level. The magnitude of this effect is proportional to the radiation dose equivalent received. The symptoms from a large radiation dose to the body become evident within a few days or weeks. These include nausea and vomiting and a general unwellness (radiation sickness).

The likely effects of large radiation doses are:

- < 10 mSv – No direct evidence of human health effects.
- ≈ 1 Sv – nausea, vomiting and diarrhoea (radiation sickness) will occur within days. Fatal cancers may form later in life.

- > 10 Sv – death likely to result within 2 weeks due to damage to white blood cells and the gastrointestine.
- > 50 mSv – death within hours or days due to severe damage to the vascular system and the central nervous system.

Some parts of the body are more sensitive to ionising radiation than others. The most sensitive are bone marrow, the reproductive organs, the eye and the digestive and circulatory systems. For example, doses of 2-3 Sv to the testes or ovaries will cause permanent sterility while similar doses to the eye will result in cataracts.

Lower doses of radiation may produce effects which only become apparent after several months or even years. These include a reduced life expectancy, the development of leukaemia or tumours and cataracts on the eye lens. Genetic damage, if it occurs, may not be apparent for several generations.

Radiation safety

The fact that we cannot see radiation makes it essential that appropriate protective safety measures are taken. Regulations exist which cover the safe handling, storage and waste disposal of radioactive materials. The preventative measures necessary depend on the type of radiation and the strength of the source. To minimise the dose from radioactive sources there are three important factors to consider. These are:

- *Distance* – The further you are from a source the safer you are. Not only is some of the radiation absorbed by the air or materials between you and the source but more importantly the intensity will drop off rapidly with distance (see Figure 2.15).
- *Shielding* – Shielding is particularly important if distance cannot be minimised. It can be chosen to absorb particular radiation. For example, perspex sheets will stop beta radiation, lead and concrete will absorb gamma rays, while boron and cadmium are good absorbers of neutrons.
- *Time* – The longer you are exposed to a source the greater the absorbed dose. Good planning can minimise this. For example, radioisotopes used in medicine are chosen so that they have a short biological half-life. This means that they are present in the body for a shorter time.

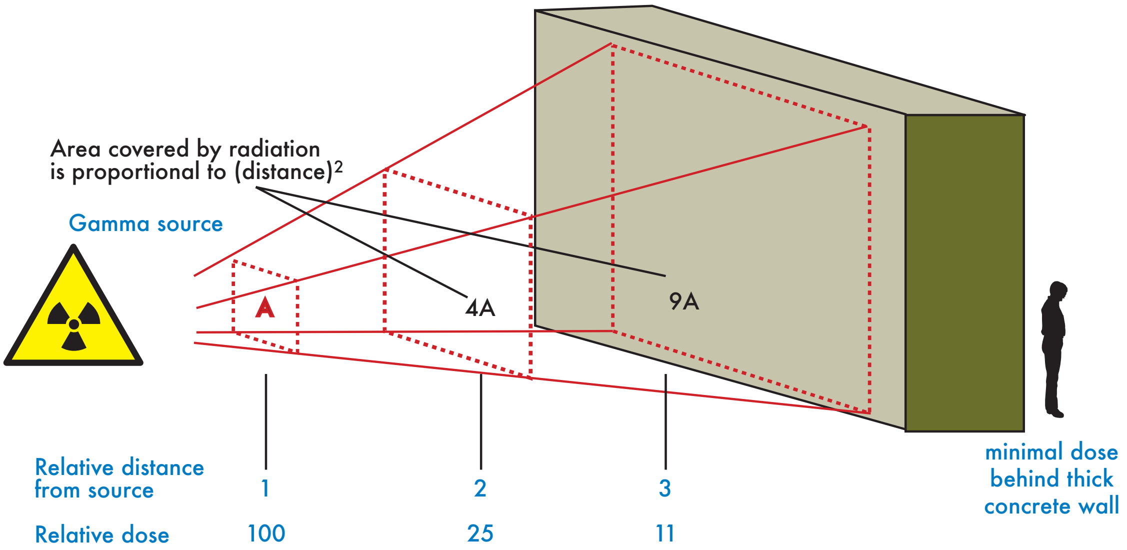


Figure 2.15 *The effect of distance on absorbed dose. The intensity of the radiation is proportional to ($1/d^2$).*

Question 2.6

(a) How are absorbed dose and dose equivalent different?

(b) Which is a better indicator of the effect of a radiation dose on your body?

Question 2.7

The amount of radiation which would kill 50% of exposed people within a particular time period is referred to as ‘LD50/number of days’ and is known as the lethal dose. It is estimated that the amount of gamma radiation for LD50/30 is 4 Sv.

(a) Explain what is meant by LD50/30 = 4 Sv.

(b) How much absorbed energy does this represent for an 85 kg person?

Question 2.8

The dose equivalent rate from cosmic radiation varies with altitude.

Approximate values are:

- sea level ≈ 0.03 μSv per hour
- 2 km (e.g. Mt Kosciusko) ≈ 0.08 μSv per hour
- 12 km (e.g. jet plane) ≈ 5 μSv per hour

(a) Why does the dose equivalent rate increase with altitude?

(b) Why is exposure to cosmic radiation of more concern to pilots and air crew than to their passengers? What precautions can they take?

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____

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(c) A pilot accumulates 200 flying hours in jet flights between Australian cities. Estimate his approximate total radiation dose during these flights. Compare this value with the total yearly dose for a person at sea level.

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2.3 NUCLEAR ENERGY

Two important nuclear reactions, fission and fusion, are the basis for the release of large amounts of energy. In each case this energy release is due to the rearrangement of the protons and neutrons within the nucleus of atoms.

Fission is simply the splitting of an atom and is the type of reaction that occurs in a nuclear reactor or an atom bomb.

Fusion on the other hand, involves the joining of two small nuclei to form a larger one. Solar energy, and the energy of all stars, is produced in this way.

Nuclear binding energy

Protons and neutrons are held together in the nucleus by the strong nuclear force. If we were to separate these particles from each other by totally breaking up the nucleus, a great deal of energy would be required. This energy is referred to as the binding energy of the nucleus.

Conversely, when individual particles come together to form a nucleus, energy is released. This release of energy is always accompanied by a loss of mass. This loss of mass, which can be calculated using Einstein's mass energy equation, is often referred to as the *mass defect*.

This means that the measured mass of a nucleus is always less than the sum of the individual masses of its nucleons. For example, when a neutron combines with a proton to form a deuteron nucleus, the masses involved are as follows.

neutron mass $^{1}_{0}\text{n}$ = 1.00866 u

proton mass $^{1}_{1}\text{p}$ = 1.00728 u

sum = 2.01594 u

deuterium nuclear mass = 2.01355 u

∴ mass difference (loss) = 0.00239 u

This loss of mass on formation of the deuteron nucleus is accompanied by a release of approximately 2.23 MeV of energy (0.00239 u × 931.5 – see Worked Example 2.5). This is referred to as the binding energy of the nucleus and is the energy that would be required to pull the nucleus apart.

Einstein's mass-energy equation

Albert Einstein's special theory of relativity shows that mass is a form of energy. The relationship between these two quantities is given by his famous equation as follows.

$$E = mc^2$$

E = energy (joules)

m = mass (kilograms)

c = speed of light

= 3.00×10^8 ms^{-1}

Table 2.5 Selected atomic masses. Note: 1 u = 1.6605×10^{-27} kg.

PARTICLE	MASS (u)	MASS (kg)
electron	0.000549	9.11×10^{-31}
proton	1.00728	1.6726×10^{-27}
neutron	1.00866	1.6750×10^{-27}
deuterium	2.01410	3.3445×10^{-27}
helium-4	4.00260	6.6466×10^{-27}
carbon-12	12.00000	1.99267×10^{-26}
thorium-234	234.04360	3.88643×10^{-25}
uranium-238	238.05079	3.95298×10^{-25}

Binding energy per nucleon

The binding energy per nucleon is a measure of the stability of a nucleus. If its value is high the nucleus is stable and difficult to pull apart. Atoms with mass numbers close to 60 have the highest binding energy per nucleon as shown on the graph in Figure 2.16.

Importantly, the graph shows that the BE/nucleon decreases for atomic masses greater than 60. This means that these atoms are less stable and it explains why energy can be released by both fission (the splitting of large nuclei) and fusion (the combining of light nuclei).

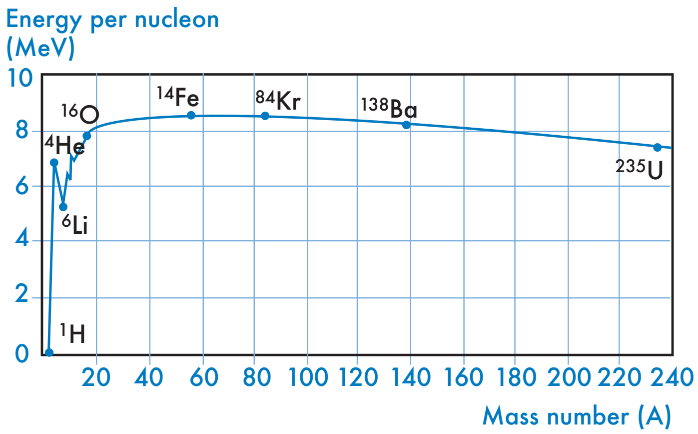


Figure 2.16 Binding energy per nucleon and mass number.

Worked Example 2.5

An atomic mass unit (u) is defined as 1⁄12 of the mass of a carbon-12 atom. Hence:

$$1\ \text{u} = 1.66 \times 10^{-27}\ \text{kg}$$

Determine the energy equivalence of this mass in joules (J) and electron volts (eV). For greater accuracy we will use $c = 2.9979 \times 10^{8}\ \text{ms}^{-1}$ and $1\ \text{eV} = 1.602 \times 10^{-19}\ \text{J}$

$$\begin{aligned}
E = m c^2 &= (1.6605 \times 10^{-27})\,(2.9979 \times 10^{8})^2 \\
\therefore 1\ \text{u} &= 1.4923 \times 10^{-10}\ \text{J} \\
\text{Also since } 1\ \text{eV} &= 1.602 \times 10^{-19}\ \text{J} \\
1\ \text{u} &= 1.4923 \times 10^{-10} / 1.602 \times 10^{-19} \\
&= 9.315 \times 10^{8}\ \text{eV} \\
\text{i.e.}\qquad 1\ \text{u} &= 931.5\ \text{MeV}
\end{aligned}$$

Worked Example 2.6

A helium atom consists of 2 protons 2 neutrons and 2 electrons. Use the mass data from Table 2.5 to determine:

(a) the binding energy for helium-4;
(b) the binding energy per nucleon for helium-4.

(a)

$$\begin{aligned}
\text{mass of 2 protons} &= 2 \times 1.00728 &&= 2.01456\ \text{u} \\
\text{mass of 2 neutrons} &= 2 \times 1.00866 &&= 2.01732\ \text{u} \\
\text{mass of 2 electrons} &= 2 \times 0.000549 &&= 0.00110\ \text{u} \\
&\text{Sum} &&= 4.03298\ \text{u}
\end{aligned}$$

$$\begin{aligned}
\text{mass of helium-4 atom} &= 4.00260\ \text{u} \\
\text{Hence mass difference} &= 0.03038\ \text{u} \\
\text{Hence binding energy} &= 0.03038 \times 931.5 \\
&= 28.3\ \text{MeV}
\end{aligned}$$

(b)

$$\begin{aligned}
\text{Binding energy per nucleon} &= \frac{28.3}{4} \\
&= 7.08\ \text{MeV / nucleon}
\end{aligned}$$

Nuclear fission

Nuclear fission is the splitting of the nucleus of an atom into two smaller nuclei. In this process large amounts of energy are released as well as gamma radiation and some neutrons. Fission can be spontaneous or induced by the absorption of neutrons.

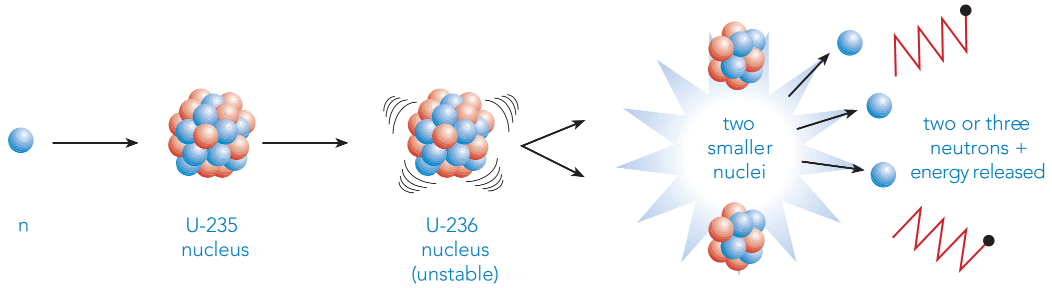


Figure 2.17 Nuclear fission. A slow neutron is absorbed by a nucleus and is temporarily formed. This nucleus is unstable since the nuclear strong forces are now less effective than the repulsive electrostatic forces. The nucleus breaks up into two smaller nuclei, some neutrons and large amounts of energy.

The fission process was first discovered in late 1938 by the German scientists Otto Hahn and Fritz Strassman. They positively identified barium and lanthanum among the products of the neutron bombardment of uranium. However, it was Otto's long time associate Lise Meitner who fully realised the implications of their results. She proposed the idea that the uranium nucleus could capture a neutron and then break up into two nuclei of about the same size. Nuclear fission was the name given to this process.

Two typical fission reactions are shown below. The uranium can break up into any of several different combinations of nuclides. Typically, however, the heavier particle has a mass number around 130 to 150 and the lighter fragment around 90 to 100.

$$ {}^{1}_{0}\text{n} + {}^{235}_{92}\text{U} \rightarrow {}^{236}_{92}\text{U} \rightarrow {}^{141}_{56}\text{Ba} + {}^{92}_{36}\text{Kr} + 3\ {}^{1}_{0}\text{n} \quad + \approx 200\ \text{MeV} $$

$$ {}^{1}_{0}\text{n} + {}^{235}_{92}\text{U} \rightarrow {}^{236}_{92}\text{U} \rightarrow {}^{140}_{54}\text{Xe} + {}^{94}_{38}\text{Sr} + 2\ {}^{1}_{0}\text{n} \quad + \approx 200\ \text{MeV} $$

Question 2.9

Both fission and fusion reactions can release energy. Use the graph in Figure 2.16 to explain why this can be so.

Question 2.10

Use the graph of BE/nucleon (Figure 2.16) to estimate the energy that would be released if a nuclide of mass number 200 was split into two equal parts.

Question 2.11

When uranium-235 undergoes a fission reaction which gives barium-141 and krypton-92, there is a loss of mass of 0.21534 u. Calculate the amount of energy released (in MeV).

Chain reactions

When a uranium-235 nucleus undergoes a fission reaction, some neutrons, usually two or three, are always released. If at least one of these neutrons is able to hit another uranium-235 nucleus, a self sustaining chain reaction results.

Fortunately, such a chain reaction does not easily occur due to a variety of factors.

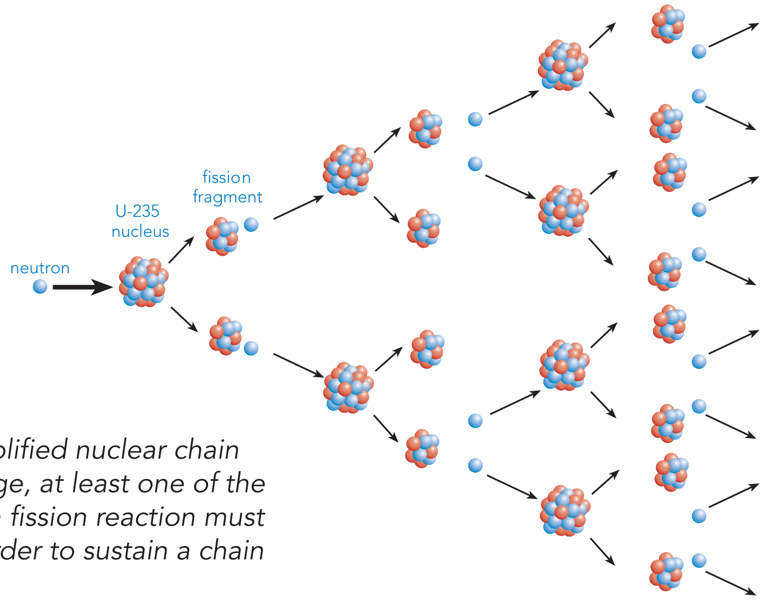


Figure 2.18 A simplified nuclear chain reaction. On average, at least one of the neutrons from each fission reaction must cause another in order to sustain a chain reaction.

- Neutrons may simply escape from the material without hitting any nuclei. Remember, nuclei are an extremely small part of an atom.
- Neutrons may be absorbed by uranium-238 nuclei which rarely undergo fission. Only 0.7% of naturally occurring uranium is the fissile uranium-235.
- Only the very slow neutrons, called thermal neutrons, are likely to cause uranium-235 to split. Fast neutrons emitted from a fission reaction are more easily captured by uranium-238.

Critical mass

Critical mass refers to the mass of fissile material required to sustain an *uncontrolled chain reaction* such as that which occurs in an atom bomb. If too little matter is present most of the neutrons produced in a fission reaction escape from the material without interaction. Critical mass depends on the % of uranium-235 in a sample since uranium-238 is not fissile. It also depends on the geometry (shape) of the mass.

For pure U-235 critical mass is only a few kilograms, while for 3% enriched uranium it is several tonnes. When an atom bomb is detonated, two separate masses of fissile material, each less than critical mass, are forced together by a chemical explosive. The two combined masses are then greater than critical mass and an explosion results.

Nuclear reactors

Nuclear reactors are able to produce large quantities of heat as a result of a controlled chain reaction. Enriched uranium-235 is used in thermal reactors while plutonium-239 is used in fast-breeder reactors. The heat produced in a reactor passes through a heat exchanger and eventually drives a turbine to produce electricity.

Australia does not have any nuclear power reactors. The nuclear reactor at Lucas Heights, OPAL, is a research reactor which mainly produces isotopes for use in industry and medicine. France produces the majority of its electricity using nuclear power. Other countries in Europe, the UK, USA and Japan are also significant users of nuclear power.

Reactor design can vary widely with the choice of fuel and moderator being of particular importance. In order that a controlled chain reaction can be sustained in a reactor an average of 1 neutron from each fission must cause another fission.

Hence enriched uranium is preferred since natural uranium only contains 0.7% of this fissile material. Also, since slow neutrons are more likely to cause the fission of uranium-235 a moderator is used to slow down the energetic neutrons produced during fission reactions.

The design features of thermal nuclear reactors include:

- *Nuclear fuel*. Modern reactors use enriched uranium (≈ 2% to 3% uranium-235) in the form of uranium dioxide.
- *Moderator*. Although fast neutrons can cause fission in uranium-238 (the more abundant isotope), the probability of fission of uranium-235 by slow neutrons is much higher. Hence a moderator, a material whose atoms are of a similar mass to the mass of neutrons, is used to deliberately slow down the neutrons to normal thermal energy. Hence the term thermal reactors. Graphite, water, heavy water and beryllium are commonly used as moderator materials.
- *Control rods*. The rate of the fission reaction is controlled by lowering or raising the boron-steel control rods. Neutrons are absorbed by the boron and inhibit the chain reaction.
- *Coolant*. This can be water, a gas, or liquid metal. The coolant removes heat from the reactor core and transfers it to the outside of the reactor for the generation of electricity.
- *Radiation shield*. This consists of very thick reinforced concrete. Its purpose is to protect workers and the nearby environment.

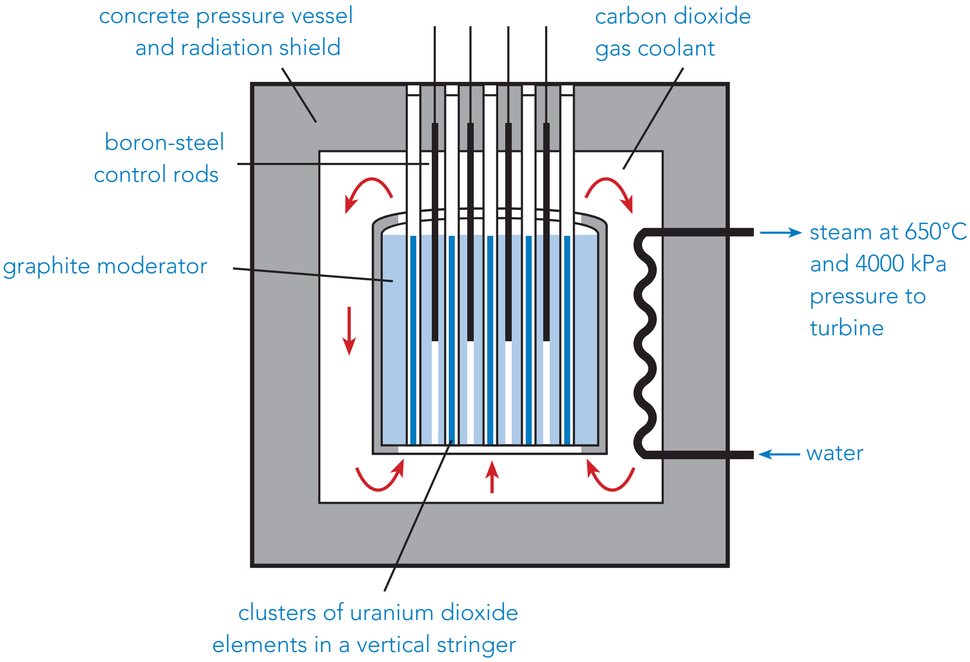


Figure 2.19 Simplified view of a modern thermal gas cooled reactor.

Fast-breeder reactors

These reactors use mixed plutonium uranium fuel which is initially produced as a by product of thermal reactors. Fast moving neutrons cause the fission of the plutonium-239 and hence the release of energy. These reactors also convert the normally wasted uranium-238 to plutonium-239, hence the name breeder reactors.

Plutonium however, is a highly hazardous material and also used in weapons manufacture. Hence the construction of these type of reactors is somewhat controversial. They also present some major design and cost problems.

Nuclear fusion

If two light nuclei can be brought close enough together they fuse and form a heavier nucleus. This fusion process, like fission, releases huge amounts of energy. This release of energy is possible since atoms such as helium have a much greater binding energy per nucleon than smaller atoms such as hydrogen and deuterium. This indicates that the helium nucleus is particularly stable.

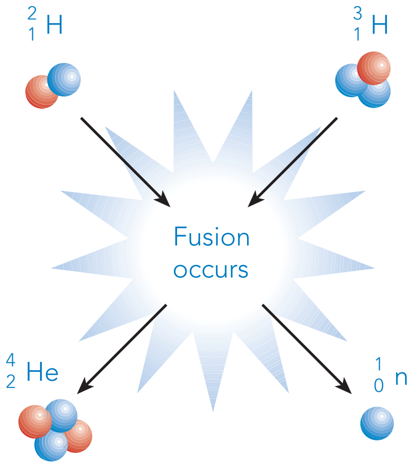


Figure 2.20 Typical fusion reaction. This particular reaction will most likely form the basis of fusion reactors in the future.

Fusion reactions however are difficult to sustain. Strong electrostatic forces prevent nuclei from coming close enough together for the strong nuclear forces to be effective. Temperatures in the order of 100 million K (10^8 K) are necessary to maintain such reactions. Nuclear fusion occurs on the sun and during the explosion of a hydrogen bomb.

Some typical fusion reactions are as follows:

$$^{2}_{1}H + ^{2}_{1}H \rightarrow ^{3}_{2}He + ^{1}_{0}n + 3.27\text{ MeV}$$

$$^{2}_{1}H + ^{3}_{1}H \rightarrow ^{4}_{2}He + ^{1}_{0}n + 17.6\text{ MeV}$$

$$^{2}_{1}H + ^{3}_{2}He \rightarrow ^{4}_{2}He + ^{1}_{1}p + 18.3\text{ MeV}$$

Fusion reactors

Several fusion reactions form the helium nucleus but that between deuterium and tritium occurs the most easily. This particular reaction holds the greatest promise for achieving a controlled fusion process in the future. The major attractions of fusion power produced from such a process are as follows:

- A ready supply of fuel that is almost limitless. Deuterium is available from sea water while tritium can be produced from beryllium.
- Waste products that are non-radioactive. This is a huge advantage over present fission reactors since it removes the problem of storing radioactive wastes safely for long periods.
- Safer reactors. Fusion reactors dealing with low density plasma would not be subject to melt down. Reactors could be sited more readily within communities.

The major difficulty in harnessing fusion power are the very high temperatures needed for the reaction. At these high temperatures plasma cannot be easily confined. Research is being undertaken using strong magnetic fields to trap the plasma (very hot ionised gas) that exists during a fusion reaction. At present the most encouraging design is a doughnut shaped device known as a *tokomak*. It uses large currents to create a toroidal magnetic field which can hold the plasma away from the container walls. Scientists are hopeful that this will lead to a practical fusion reactor in the future.

The hydrogen bomb

The temperature produced by a simple fission bomb (atom bomb) can be used to initiate a thermonuclear reaction. A hydrogen bomb essentially consists of a small atomic bomb surrounded by large amounts of lithium and deuterium. The initial fission reaction raises the temperature sufficiently for fusion to take place between deuterium and tritium. The tritium is formed when neutrons interact with lithium. Vast amounts of energy are released.

Nuclear waste management

Nuclear energy and nuclear technology provide many benefits but also some risks. One particular problem is the safe management of nuclear waste. Although the actual amount of waste, from say, a nuclear reactor is not large, it is radioactive and may remain so for a very long time. The way that nuclear waste is managed is dependent on its level. Long term it is hoped that all nuclear waste can stored safely underground in geologically stable areas.

Low level waste: Waste which contains low levels of radioactivity or short lived radioisotopes. This would include protective clothing used in nuclear facilities, gloves, cloths, filters and water from showers. This type of waste does not require special shielding during use. Solid items are usually shredded, compressed and stored in steel drums until safe to dispose as normal waste.

Medium level waste: Reactor parts and infrastructure that are contaminated during operations and used radioactive isotopes are examples of medium-level nuclear waste. Shielding is required when being used or stored. Waste is stored in bins placed in underground shielded concrete pits

High level waste: Mainly results from the spent fuel rods in nuclear power reactors and their reprocessing. This highly radioactive waste needs shielded storage as well as cooling. Australia does not produce any high level waste but has developed a technology whereby it can be trapped safely in an artificial glassy substance called Synroc.

In Australia, at Lucas Heights, a new Synroc nuclear waste treatment plant has recently become operational. It uses ANSTO Synroc technology, developed over many years, to immobilise waste from the production of molybdenum-99. Molybdenum-99, produced in the OPAL multipurpose reactor, is the precursor of technetium-99m, the most commonly used nuclear imaging radiopharmaceutical.

In the treatment plant (see images below) the waste is intimately mixed with the Synroc additive to form a granular powder. The powder cascades into a thermal processing unit before being dispensed safely to a stainless steel canister. The canister is then subjected to hot isostatic pressing, which consolidates the powder into a durable solid and reduces its volume.

Processing nuclear waste into Synroc. Images show 1) The initial can which is filled with the nuclear waste and Synroc additive, 2) The can after it has undergone hot isostatic pressing, 3) A cut section of a can after hot isostatic pressing, showing the solid Synroc inside.
Images courtesy of ANSTO.

REVIEW QUESTIONS

Chapter 2: Ionising Radiation and Nuclear Reactions

2.1 Radiation

1. Indicate whether each of the following is true or false. Alter any false statement so that they are true.
   - (a) Isotopes of the same element all have the same number of protons.
   - (b) In radioactive β^- decay the atomic mass number decreases by one.
   - (c) Alpha particles can only travel a few centimetres in air.
   - (d) Light rays and X-Rays are both forms of electromagnetic radiation.
   - (e) The activity of a radioactive sample is measured in sieverts (Sv).

2. Differentiate between each of the following terms:
   - (a) atomic number (b) mass number (c) isotope
   - (d) nuclide (e) atomic mass unit

3. How many (i) protons, (ii) neutrons does each of the following contain?
   - (a) $^{12}_{6}\text{C}$ (b) $^{1}_{1}\text{H}$ (c) $^{11}_{5}\text{B}$ (d) $^{235}_{92}\text{U}$

4. Write the nuclide symbol for an atom of
   - (a) sodium (Na) which has 11 protons and 12 neutrons.
   - (b) oxygen (O) which has 8 protons and 8 neutrons.
   - (c) potassium (K) which has 19 protons and 20 neutrons.
   - (d) strontium (Sr) which has 38 protons and 52 neutrons.

5. What is the characteristic feature that nuclei have when they are unstable and commence decaying?

6. Distinguish between the terms radioactive decay and radiation.

7. Describe the composition or nature of each of alpha, beta and gamma radiation.

8. Which (one or more), between alpha, beta and gamma radiation:
   - (a) has a velocity of just under 10% of the velocity of light.
   - (b) has a negative charge.
   - (c) produce the most ionisation.
   - (d) is a particle and has the least mass.
   - (e) travel at the speed of light.
   - (f) travel just under the speed of light.
   - (g) is not deflected by an electric field nor a magnetic field.
   - (h) is deflected towards the negative plate when in an electric field.
   - (i) produce the least ionisation.
   - (j) has the ability to affect a photographic plate.
   - (k) penetrate large air gaps but not 1 cm thickness sheets of aluminium?

9. In the physics laboratory Andrew uses a detector capable of detecting alpha, beta and gamma radiation to detect radiation emitted from a radioactive source. Explain each of the following observations noted by Andrew:

(a) (i) a thin piece of paper placed between the source and detector only slightly reduced the count rate on the detector
  (ii) a magnetic field placed between the detector and source but in a plane normal to the radiation noticeably reduced the count rate
  (iii) a 1 cm thick sheet of aluminium positioned where the magnetic field was (and instead of the magnetic field) resulted in a count rate similar to the magnetic field in (ii)

(b) What type(s) of radiation is emitted by the source Andrew is using in the experiment?

10. Write a general equation which represents the decay of a parent nuclide X to produce:
  (a) an alpha particle.
  (b) a beta particle.

11. Name the missing particle/radiation in each of the following:

  (a) $^{238}_{92}\text{U} \rightarrow {}^{234}_{90}\text{Th} + \_\_\_\_\_\_\_\_\_\_$

  (b) $^{90}_{38}\text{Sr} \rightarrow \_\_\_\_\_\_\_\_\_\_ + {}^{0}_{-1}\beta$

  (c) $\_\_\_\_\_\_\_\_\_\_ \rightarrow {}^{14}_{7}\text{N} + {}^{0}_{-1}\beta$

  (d) $^{226}_{88}\text{Ra} \rightarrow \_\_\_\_\_\_\_\_\_\_ + {}^{4}_{2}\text{He} + \gamma$

12. The diagnosis of blood disorders can be made using the radioactive nuclide $^{59}_{26}$Fe. A sample of this nuclide is found to have 50% of its atoms decayed by β emission after a period of 45 days. What fraction of the sample remains undecayed 6 months (ie. 180 days) after its initial use? Graphically represent the rate of decay of the sample over the 6 months.

13. Stephanie determines the activity of a radioactive sample to be 4.30×10^4 decays per second. If the sample has a half-life of 3.00 minutes, what can she expect the activity to be 30.0 minutes later?

14. Radionuclides can be used in hospitals for medical diagnosis and treatment. Suggest an advantage of having a facility such as the one at Lucas Heights to produce radionuclides for hospital use rather than import these from overseas.

15. Medical imaging of organs in the body can be performed using selected radionuclides. The choice of radionuclide depends on a number of factors including its half-life. Why is the half-life a critical factor in the selection of radionuclides?

2.2 Radiation – Effects & Uses

16. Indicate whether each of the following is true or false. Alter any false statement so that they are true.
    (a) Radioactive isotopes contain unstable nuclei.
    (b) Artificial radioisotopes can be produced by placing certain elements in a nuclear reactor.
    (c) Radioisotopes used in medical diagnosis typically have long half-lives.
    (d) Alpha particles are less ionising than gamma rays.
    (e) The energy that our bodies receive from ionising radiation is referred to as the absorbed dose.

17. Thyroid cancer can be treated by administering a large amount of a radioactive isotope of iodine. The thyroid, unlike other parts in the body, concentrates iodine in its cells. Suggest why the radioactive isotope of iodine can destroy the thyroid cancer cells but have little to no effect on other cells in the body.

18. Gamma radiation (e.g. from cobalt-60) has a number of applications or uses in industry. Name four of these.

19. (a) List three sources of radiation exposure which you may receive in daily life.
    (b) Are these exposures considered dangerous?

20. Supersonic jets travel at much higher altitudes than commercial subsonic airliners. Yet on a trans-Atlantic trip a crew member on a supersonic jet may receive 0.018 mSv of cosmic radiation compared to a subsonic airliner crew member who may receive 0.024 mSv of cosmic radiation. Although both doses are small, explain why the crew member on the subsonic airliner receives a greater dose of cosmic radiation.

21. Monazite, a product of the mineral sands industry, is radioactive. It contains thorium-232 which is an alpha emitter and has a half-life of 14.1 billion years.
    (a) Write an equation representing the alpha emission of thorium-232 to radium-228.
    (b) The control of airborne dust in the mineral sands industry is a major priority and the use of appropriate face masks is essential. Suggest why monazite dust is more dangerous if inhaled compared to contact with external skin such as on our arms.
    (c) Besides wearing face masks, what other precautions should workers take to avoid monazite dust entering their bodies?

22. List four sources of natural radiation.

23. Radon-222, a gas, has a decay series which includes the consecutive decays to polonium-218, lead-214 and bismuth-214. Name the particle emitted at each stage of the decay series.

24. Radon-222 is formed during the decay of radium-226 present in some building materials and certain soils which may be beneath and around the house.
    (a) Explain why the build up of radon-222 gas in a house is considered a health hazard for its inhabitants.
    (b) Suggest two ways inhabitants of houses which are subject to a build up of radon-222 gas can prevent such a build up reaching dangerous levels.

25. Briefly outline the effects of ionising radiation on a human body cell.

26. An alpha particle and a gamma ray of similar energy penetrate into soft body tissue. Which would you expect to have the greatest effect on a small section of this tissue? Why?

27. List two ways by which external radiation exposure to your body can be reduced.

2.3 Nuclear Energy

28. Indicate whether each of the following is true or false. Alter any false statement so that they are true.
    (a) Protons and neutrons are held together in a nucleus by the strong nuclear force.
    (b) Nuclear fusion of two small nuclei to form a larger one causes the release of energy due to an overall increase in mass.
    (c) The binding energy per nucleon is greatest for elements with a mass number close to 60 such as iron.
    (d) The fission process can be initiated by the absorption of slow neutrons by fissionable materials.
    (e) The purpose of graphite moderators in nuclear reactors is to absorb the neutrons.

29. (a) Compare the sum of the mass of the particles contained within the U atom with its atomic mass of 238.05080 u.
    (m_p = 1.00728 u, m_n = 1.00866 u, m_e = 0.00055 u)
    (b) Explain any discrepancy between the values of the masses determined in (a).
    (c) What name is give to this discrepancy in mass?

30. Calculate the binding energy per nucleon in (a) joules and (b) electron volts for the ${}^{238}_{92}$U atom in question 26. *(Note 1 u = 1.6605 × 10^{-27} kg).*

31. $${}^{232}_{92}\text{U} \rightarrow {}^{228}_{90}\text{Th} + {}^{4}_{2}\text{He}$$

For the above nuclear reaction calculate the energy (in MeV) released for the disintegration of the ${}^{232}_{92}$U atom.

(m_{He} = 4.002602 u, m_{Th} = 228.028741 u, m_U = 232.037156 u)

32. To sustain a chain reaction in a nuclear reactor, it is necessary for the high speed neutrons produced in the fission process to be captured by a nucleus. However it has been found that the probability of neutron capture by at such high speeds is low. What is used in the reactor to increase the probability of neutron capture?

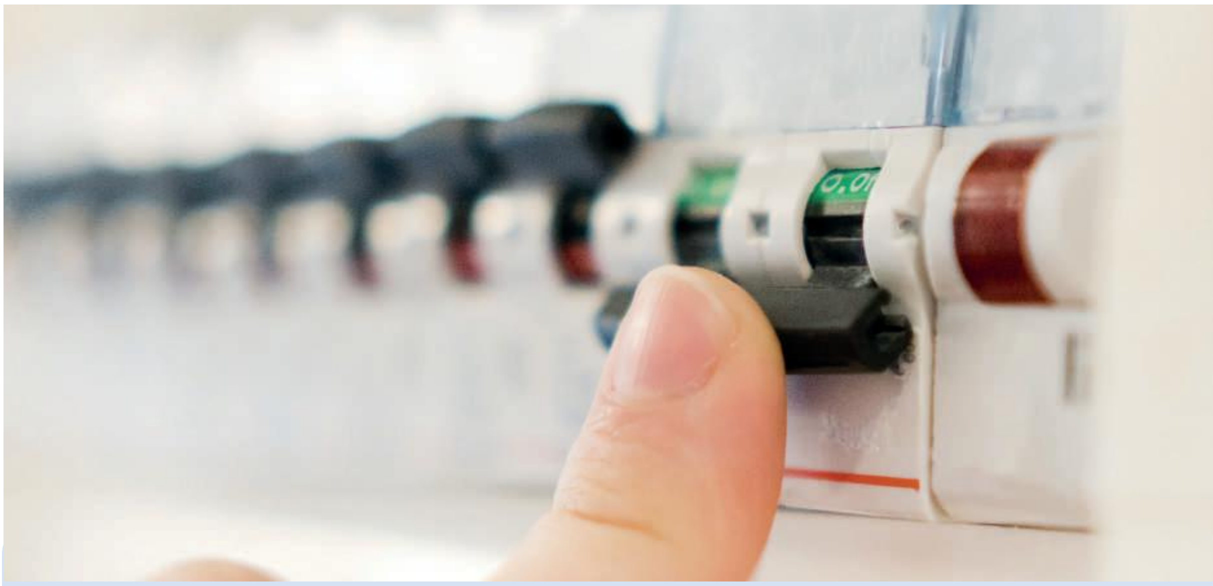
33. During a nuclear fission reaction, an atom of ${}^{235}_{92}$U captures a neutron to produce ${}^{141}_{56}$B, ${}^{92}_{36}$Kr and three neutrons as products in addition to energy.
    (a) Write a nuclear equation for the reaction.
    (b) Calculate the energy released by this reaction in MeV (ignore the initial energy of the captured atom).

(masses are: ${}^{235}_{92}$U = 235.04393 u, ${}^{141}_{56}$B = 140.91440 u, ${}^{92}_{36}$Kr = 91.92630 u, n = 1.00866 u)

34. For the reaction in Q.33, what mass of ${}^{235}_{92}$U is required to operate a 300 MW nuclear power station for a period of one year? (Assume 40.0% efficiency, 1 W = 1 Js^{-1}).

3

ELECTRICAL CIRCUITS



SYLLABUS CHECKLIST

SCIENCE UNDERSTANDING – ELECTRICAL CIRCUITS

☐ there are two types of charge that exert forces on each other

☐ electric current is carried by discrete charge carriers; charge is conserved at all points in an electrical circuit. This includes applying the relationship:

$$I = \frac{q}{t}$$

☐ energy is conserved in the energy transfers and transformations that occur in an electrical circuit

☐ the energy available to charges moving in an electrical circuit is measured using electric potential difference, which is defined as the change in potential energy per unit charge between two defined points in the circuit. This includes applying the relationship:

$$V = \frac{W}{q}$$

☐ energy is required to separate positive and negative charge carriers; charge separation produces an electrical potential difference that drives current in circuits

☐ power is the rate at which energy is transformed by a circuit component; power enables quantitative analysis of energy transformations in the circuit. This includes applying the relationship:

$$P = \frac{W}{t} = V\,I$$

☐ resistance depends upon the nature and dimensions of a conductor

☐ resistance for ohmic and non-ohmic components is defined as the ratio of potential difference across the component to the current in the component. This includes applying the relationship:

$$R = \frac{V}{I}$$

☐ circuit analysis and design involve calculation of the potential difference across the current in, and the power supplied to, components in series, parallel, and series/parallel circuits. This includes applying the relationships:

series components, I = constant $V_t = V_1 + V_2 + V_{3...}$

$R_t = R_1 + R_2 + R_{3...}$

parallel components, V = constant $I_t = I_1 + I_2 + I_{3...}$

$$\frac{1}{R_t} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}...$$

☐ there is an inherent danger involved with the use of electricity that can be reduced by using various safety devices, including fuses, residual current devices (RCD), circuit breakers, earth wires and double insulation

☐ electrical circuits enable electrical energy to be transferred and transformed into a range of other useful forms of energy, including thermal and kinetic energy, and light

3.1 ELECTRICITY

Electrostatics

If two objects of different materials are rubbed together, such as a plastic ruler and a woollen jumper, static electricity results. The friction between the objects causes a transfer of electrons from one of the materials to the other. This results in the bodies acquiring equal and opposite static charges.

Electrostatics is the study of the causes and effects of these static charges. Some common occurrences that can be explained by electrostatics are listed.

- You can sometimes get a small electrical shock after walking across new carpet.
- A plastic comb run through your hair will attract small pieces of paper.
- A balloon that is rubbed against some clothing will tend to stick to walls.
- You can sometimes feel a small electrical shock from a car after travelling for some time.

Electric charge

Electrostatic experiments with many different materials have established the following:

- Only two types of charges exist, positive and negative. Positively charged objects have a deficiency of electrons. Negatively charged objects have an excess of electrons.
- Like charges repel, unlike charges attract.
- Both positively and negatively charged objects attract neutral conductors.

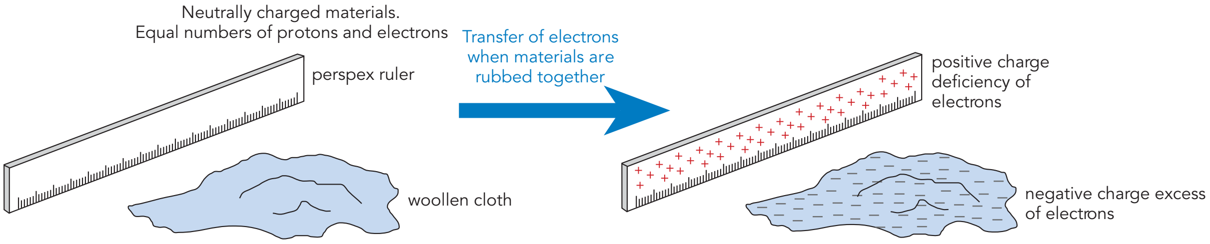


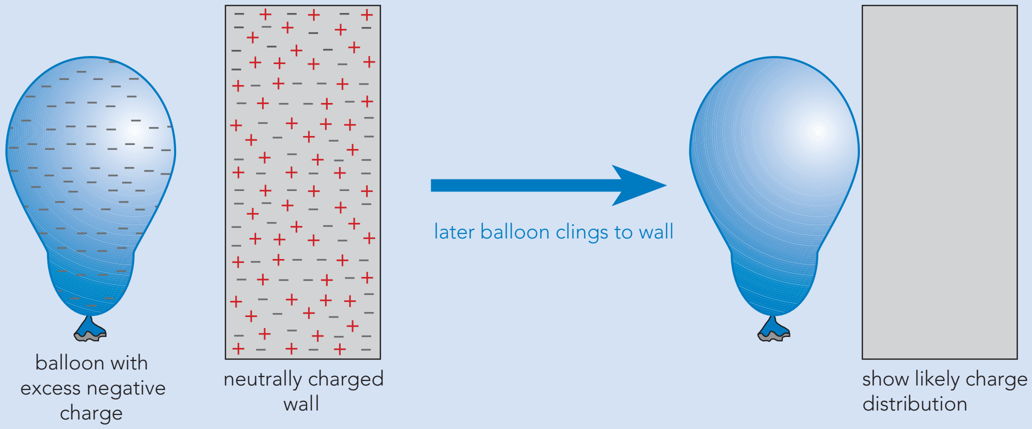
Figure 3.1 Acquiring static charge through friction. When the ruler is rubbed with the cloth the cloth pulls some electrons from atoms on the surface of the ruler. This leaves the ruler with less electrons than protons (positive) and the cloth with excess electrons (negative).

Question 3.1

Electrostatic charge due to friction is always the result of electrons transferring from one material, or surface, to another. In terms of the structure of atoms explain why a transfer of protons does not occur. Refer to previous sections (e.g. 2.1) on the structure of atoms if necessary.

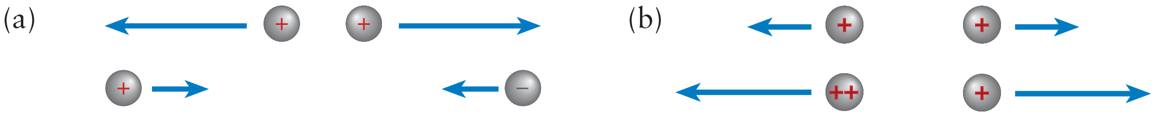
Question 3.2

A party balloon is charged by rubbing it on some clothing and then placed near (but not touching) a neutrally charged wall. It is found that the balloon drifts towards and clings to the wall. Explain how this is possible. (Hint: firstly complete the sketch below to show change in charge distribution.)



Force between charges

It has been shown by experiment that charged objects exert forces on each other. These forces, called **electrostatic forces** can act at a distance. Their nature and magnitude depends on the individual charges and their distance apart. In summary we can show that like charges repel and unlike charges attract and that the force between them increases greatly if they are closer together.



Like charges repel, unlike charges attract. Force is reduced as distance apart is increased

An increase in magnitude of either charge will result in a greater force

Figure 3.2 The nature of forces between charges.

Electric fields

Electrostatic forces can be detected in the space around a charged object. The region in which such forces can be found is called an electric field.*

- An electric field exists at a point if a charge placed at that point experiences a force.
- An electric field is a vector quantity.
- The direction of an electric field is taken as the direction that a positively (+) charged body would move if placed at that point.
- An electric field is represented by lines of force or flux lines.

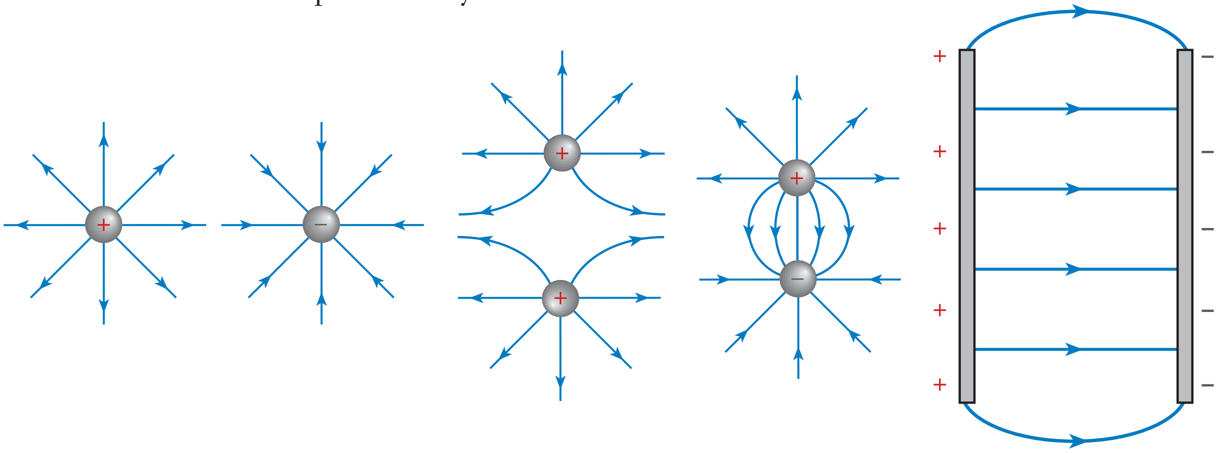


Figure 3.3 Typical electric field patterns. Arrows are always away from positive. Field is strongest where lines of force are closer together. Field is uniform when lines of force are parallel.*

Electric potential

Charged bodies can gain electrical potential energy when they are moved in an electrical field in a similar manner to which masses gain gravitational potential energy when they are lifted in a gravitational field. Consider a positively charged body that cannot move, such as the charged metal sphere in Figure 3.4. If a positive charge is to be brought near the sphere, say to point B, then work has to be done on the charge in order to overcome the force of repulsion.

- The work done in bringing a distant positive charge to point B is stored as electrical potential.
- If the charge is moved to A it will acquire a higher electrical potential energy.
- Points A and B are points at different electrical potential. Point A has a higher potential than point B.

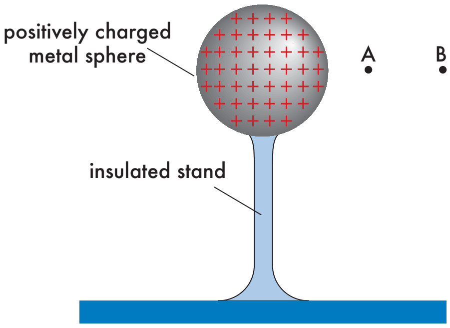


Figure 3.4 Points in an electrical field. Point A has a higher potential than B.

Electrical potential difference (Voltage)

Moving a charge in an electric field involves work (energy) and hence a change in electrical potential energy. A potential difference of 1 volt exists between two points if a charge of 1 coulomb moving between those points has its electrical potential energy changed by 1 joule.

The voltage, correctly termed EMF (electromotive force) of an electrical source such as a battery, is a measure of the energy supplied to each coulomb of charge passing through it. Hence a source such as a battery supplies electrical potential energy.

$$V = \frac{W}{q}$$

V = voltage (volts)
W = work (joules)
q = charge (coulombs)

---

* *Electrical fields may not be required for this course.*

Worked Example 3.1

Electrons in an old style TV tube are accelerated through a potential difference of 2.00 kV. Given that the mass of electrons is 9.11×10^{-31} kg and that their charge is 1.60×10^{-19} C determine

(a) The work done on the electrons.
(b) The kinetic energy of the electrons.
(c) The final velocity of the electrons, assuming they were initially at rest.

$V = 2.00 \times 10^{3}$ V
$q = 1.60 \times 10^{-19}$ C
$m = 9.11 \times 10^{-31}$ kg
$W = ?$
$E_K = ?$
$u = 0$
$v = ?$

(a) $W = qV$

$= (1.6 \times 10^{-19})(2000)$

$= 3.20 \times 10^{-16}$ J

(b) E_K = work done on electrons

$= 3.20 \times 10^{-16}$ J

(c) $E_K = ½mv^2$

$= 3.20 \times 10^{-16}$ J

$$\therefore v^2 = \frac{(2)(3.2 \times 10^{-16})}{9.11 \times 10^{-31}}$$

$v = 2.65 \times 10^{7} \text{ms}^{-1}$

Electric current

Any material which contains electric charges that are free to move is called a **conductor.** If such a material is connected between points of different electrical potential, then a flow of charge will occur. The rate of flow of electric charges, whether positive (+) or negative (–) is called an electric current. In a conducting solution both positive and negative ions are charge carriers while in a metallic conductor only electrons are charge carriers.

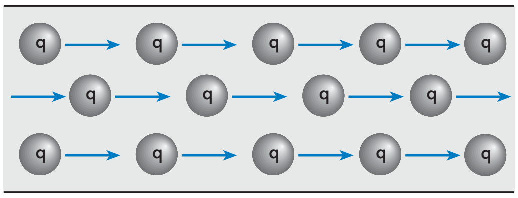


Figure 3.5 Current flow in a conductor. Current is defined as the net amount of charge passing a given point per second.

Conventional current is defined as being in the direction of positive charge flow. It may be considered as a current opposite in direction to a flow of electrons. When we refer to the direction of current in a circuit we are referring to conventional current.

Direct current (DC) refers to a current supply where the flow of charge is always in one direction (e.g. current from a battery).

Alternating current (AC) refers to a current supply where the flow of charge alternates back and forth (e.g. household supply). See also page 82.

An **electric current** (**I**) is defined as the net amount of charge passing a given point per second. In an electric circuit current is measured with an ammeter placed in series at that point in the circuit (page 73). The unit of current is the ampere (A).

$$\mathbf{I} = \frac{\mathbf{q}}{\mathbf{t}}$$

I = current in amperes (A)
q = charge in coulombs (C)
t = time in seconds (s)

Worked Example 3.2

A torch circuit carries a current of 2.50×10^2 mA for 3.50 minutes. Calculate the total charge that has left the battery in this time.

$q = ?$
$I = 0.250$ A
$t = 3.50$ min

$q = It$
$= (0.250)(3.50)(60)$
Total charge $= 52.5$ C

Question 3.3

The charge on a single electron (referred to as an elementary charge) is 1.60×10^{-19} C. Calculate the number of electrons that would constitute 1.00 coulomb of charge.

Electrical energy

Sources of electricity such as batteries provide energy to the charges flowing in a circuit. A battery, for example, contains stored chemical energy which is given to the electrons as electrical potential energy. This is converted to kinetic energy as the electrons are attracted to the positive terminal. Since the electrons collide with atoms as they move through the different parts of the circuit their energy is given up to the atoms as vibrational energy. Heat and sometimes light results. A 9 V battery, for example, will supply 9 J of energy to each coulomb of charge that passes through it. This exact energy is then lost to the external circuit by each coulomb of charge (see Figure 3.6).

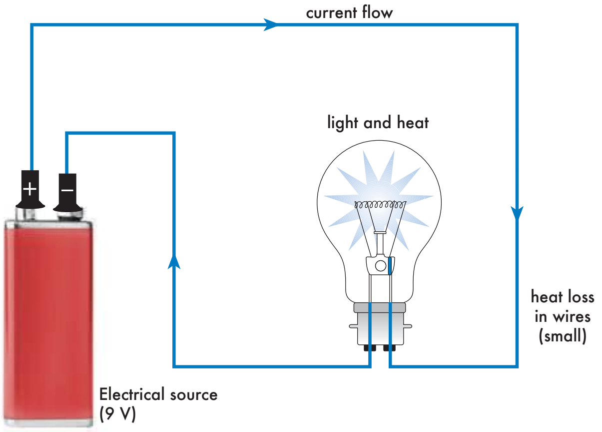


Figure 3.6 *Conversion of electrical energy to heat and light. Note: conventional current flow is taken from positive to negative.*

Electrical power

Power is defined as the rate of doing work or releasing energy. From our previous definitions of voltage and current we can see that power can be calculated as follows:

$$P = VI$$

$V =$ voltage (volts) *potential energy given to each coulomb of charge*
$I =$ current (amperes) *number of coulombs of charge flowing per second*
$P =$ power (watts) *rate of energy use*

Question 3.4

Show that the relationship $P = VI$ can be derived from the following:

$$\text{Power} = \frac{\text{work}}{\text{time}}, \; W = qV, \; I = \frac{q}{t}$$

Electrical energy used

The energy consumed by an electrical appliance depends upon the rate of energy use (power rating), and the time for which it is operating.

$$E = Pt$$
$$\text{or } E = VIt$$

E = Energy used (or work done), joules (J)
P = Power rating, Js^{-1} or watts (W)
V = Voltage supplied, volts (V)
I = Current, amperes (A)
t = Time, seconds (s)

The kWh – a handy unit*

Household electrical energy is measured in units called "kilowatt-hours" (kWh) since it is a more convenient unit. Your electricity bill from Synergy will refer to electricity units used. These are kWh units. The present charge is 28.5¢ a unit plus a service charge.

Since $1\text{ kW} = 1000\text{ Js}^{-1}$
and $1\text{ h} = 3600\text{ s}$
$1\text{ kWh} = 3600000\text{ J}$
$= 3.60\text{ MJ}$

**May not be required for this course.*

Worked Example 3.3

A motor car's two headlights are each rated at 50.0 W and operate on a 12.0 V power supply. Calculate:

(a) The current flowing in each headlight when they are in use.
(b) The charge passing through each globe every second.
(c) The total energy consumed by the two headlights during a 2.00 hour night journey.

P = 50.0 W each light
V = 12.0 V
I = ?
q = ?
t = 2.00 h

(a) $P = VI$

$$I = \frac{P}{V} = \frac{50.0}{12.0} = 4.17\text{ A (for each light)}$$

(b) $q = It$
$= (4.17)(1)$
$= 4.17\text{ C}$

(c) $E = Pt$
$= (50)(2)(2.0 \times 60 \times 60)$
$= 7.20 \times 10^5\text{ J}$

Worked Example 3.4

What is the current drawn by a 1500 W electric kettle if it operates on a 240 V supply? How much electrical energy (Joules) will it use if it is on for 4.50 minutes? Calculate the cost of the energy used if Synergy charge 28.5¢ per kWh.

P = 1500 W
V = 240 V
t = 4.5 min
= 270 s

I = ?
E = ?
Cost = ?

(a) $P = VI$

$$\therefore I = \frac{P}{V} = \frac{1500}{240} = 6.25\text{ A}$$

(b) $E = Pt$
$= (1500)(270)$
$= 4.05 \times 10^5\text{ J}$

(c) $1\text{ kWh} = 3.6 \times 10^6\text{ J}$

∴ No. of units of electricty used (kWh)

$$= \frac{4.05 \times 10^5}{3.6 \times 10^6} = 0.125\text{ kWh}$$

∴ Cost = (units) × (28.5¢)

= (0.1125) × (28.5¢) = 3.21¢

3.2 ELECTRICAL CIRCUITS

Electrical circuits allow the flow of charge from an electrical energy source to components connected within the circuit by conducting material. These circuits may be very simple or complex. However there are three recognisable types of circuits.

- **Series circuits**

These are often very simple circuits. There is only one possible path for the current and the same current flows through all parts of the circuit.

- **Parallel circuits**

The current has more than one possible path. The sum of the currents in the different parts of a parallel circuit is equal to the total current.

- **Complex circuits (Networks)**

These are a combination of series and parallel connections. Most electrical devices involve complex circuits.

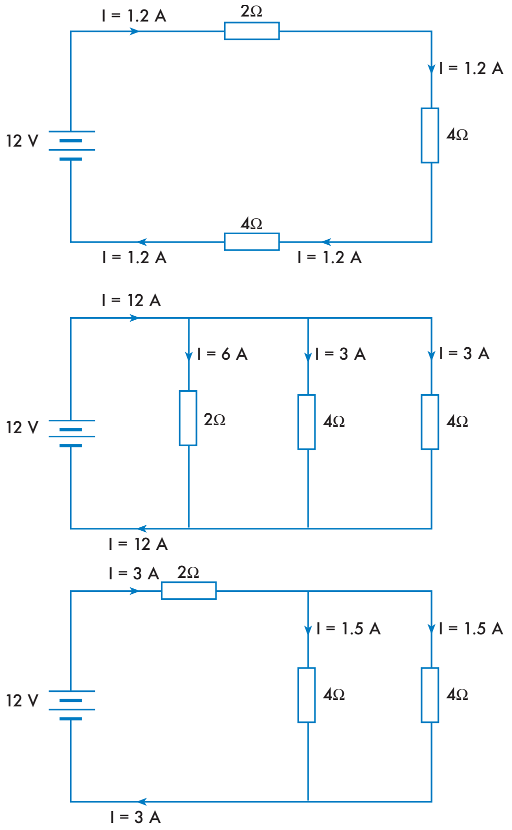


Figure 3.7 *Types of circuits.*

Circuit diagrams

Electrical circuits are best represented by diagrams which show each component of the circuit as a symbol. Conventional symbols used to represent components are shown below.

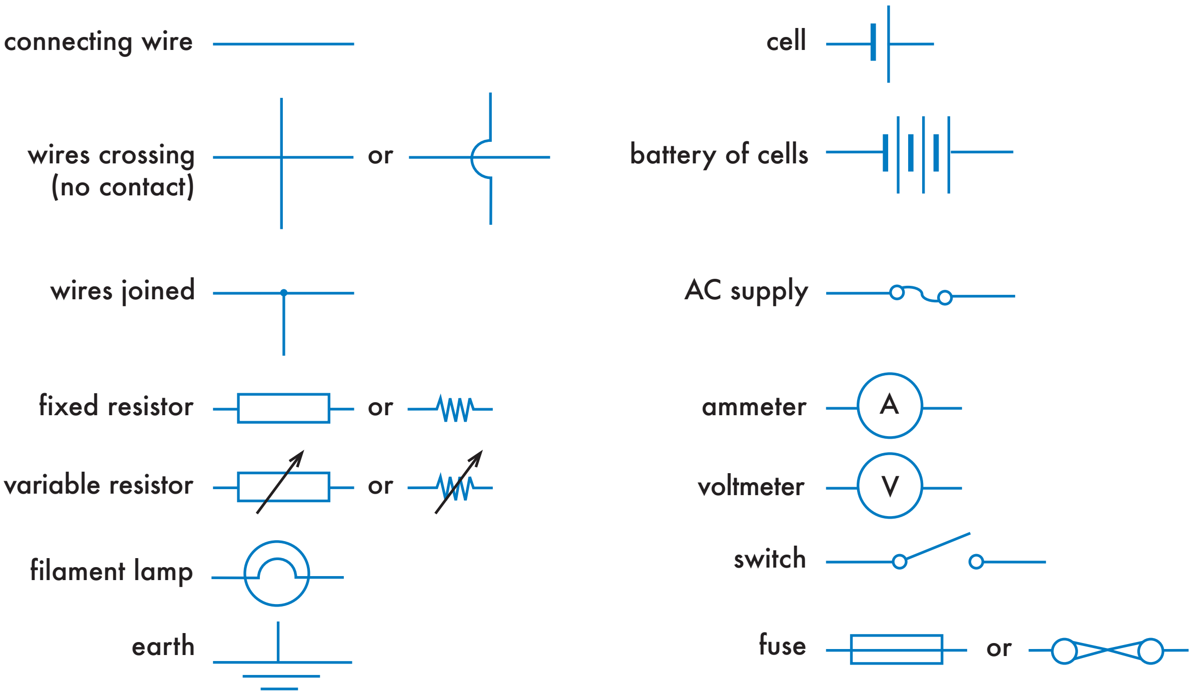


Figure 3.8 *Electrical circuit symbols.*

Resistance

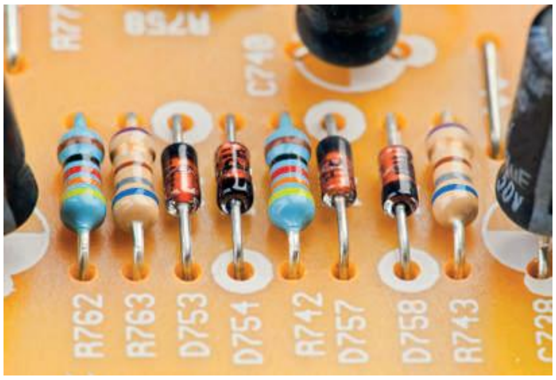
The electrical resistance of materials varies widely, from zero for superconductors, to extremely high values for insulators. The availability and number of 'free' electrons within a material greatly affects the ease with which a current will flow through it. The resistivities of different substances can be used to classify them as follows:

Superconductors
Some metals and ceramics have zero resistance when they are cooled to temperatures close to absolute zero. Applications include magnetic levitation.

Good conductors
Most metals have low resistivities – in the order of 10^{-8} Ωm, and are suitable for use in electrical wiring. Metals and alloys with relatively higher resistivities (≈ 10^{-6} Ωm), are useful for resistor and heater filaments.

Semi-conductors
Non metals such as germanium and silicon have relatively high resistance. However the resistance of these materials can be markedly and selectively reduced by introducing specific impurities. This special property allows the production of transistors and microchips, which are vital components for the electronics industry.

Insulators
Materials such as wood, glass and plastic have extremely high resistivities (≈ 10^{10} to 10^{15} Ωm), and are therefore very useful insulators. They are very necessary for the safe operation of electrical devices and the prevention of electrocution.



Various resistors and diodes on a motherboard.

Potential difference and current – Ohm's Law

The relationship between the current flowing through a resistor and the potential difference applied to it was first investigated by the German physicist Ohm. He found that:

> "*provided that the temperature remains constant, the current through a resistor is proportional to the potential difference applied across it*".

This is known as Ohm's Law. Note that this law only applies to metals and carbon at constant temperature. It is usually expressed as follows.

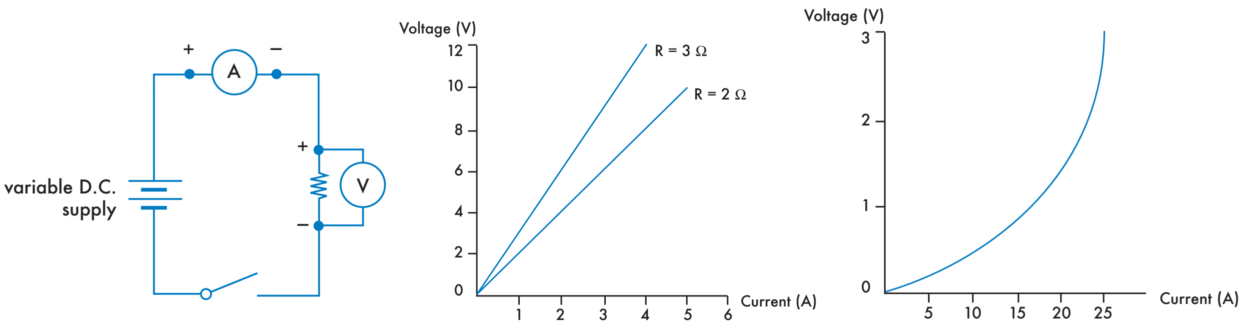
$$V = IR$$

R = resistance (ohms, Ω)
V = voltage (volts, V)
I = current (amps, A)

The constant of the relationship between V and I is called resistance. The unit of resistance is the ohm (Ω).

Ohmic conductors are those whose resistance remains constant as the current is varied. The slope of their V/I graph would be constant (see Figure 3.8(b)). Resistors and conducting wires used in circuits are ohmic conductors within specific limits.

Non Ohmic conductors do not show a constant relationship between voltage and current (see Figure 3.9(c)). Their resistance can increase with temperature, as does a globe filament, or decrease, as is the case with thermistors.



(a) Circuit for investigating Ohm's Law.

(b) Ohmic conductors. Gradient $\frac{V}{I}$ is constant.

(c) Non Ohmic conductors. Typical torch globe characteristics.

Figure 3.9 *Relationship between voltage and current.*

Factors affecting resistance

The electrical resistance of a particular conductor depends upon the type of material it is made from as well as its size and shape. Factors that affect the resistance are:

Length – the greater the length of a conductor the greater the resistance.

Cross-sectional area – the greater the cross-sectional area of a conductor, the smaller its resistance. This means for example that a thick copper wire will conduct electricity much more easily than a thin one since its resistance is lower.

Nature of the conducting material – An electrical property of materials is their resistivity. Copper for example has a lower resistivity than nichrome. This means that a nichrome wire will always have a greater resistance to electrical current to a copper wire of similar dimensions. Insulators such as wood and plastic are materials of high resistivity.

Temperature – An increase in temperature generally increases resistance although this is not always the case. In general the resistance of a metal increases with temperature whereas the resistance of some materials such as carbon are lower at higher temperatures.

Question 3.5

In general, the resistance of metals increases as their temperature rises, such as with a globe filament. What is the likely cause to this increase in resistance to current flow?

____

____

Question 3.6

(a) Use the graph in Figure 3.9(c) to estimate the resistance of the globe filament when:

(i) 1.5 V is applied, ____________

(ii) 3.0 V is applied. ____________

(b) If this globe is designed to operate at 3.0 V, what is its wattage rating?

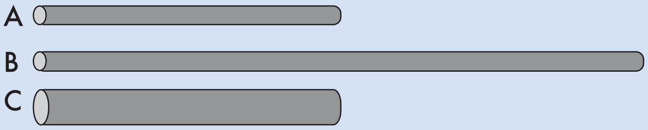
____

Question 3.7

Three wires, each made of copper are shown below. Wire B is twice as long as wire A while wire C is twice as thick as wire A. If a similar voltage is applied to each of the wires in turn which of them is most likely to:

(a) conduct the most current? ________________________________

(b) conduct the least current? ________________________________



Voltmeters and ammeters in circuits

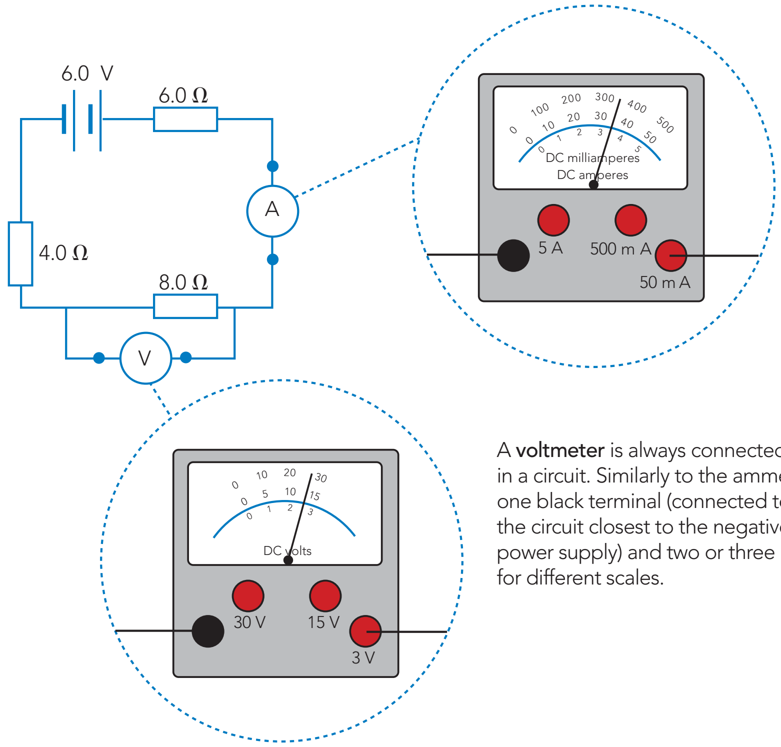
A voltmeter is used to measure the voltage (potential difference) between two points. It is therefore connected in **parallel** to the component it is measuring the voltage across (see Figure 3.9(a)).

Voltmeters are high resistance instruments. This is so that very little current is diverted from the circuit when a voltage measurement is made.

An ammeter is used to measure the current flowing through a particular point in a circuit. It is therefore connected in **series** at that point in the circuit (see Figure 3.10 below).

Ammeters are very low resistance instruments so that they will have little effect on the current flowing in a circuit.

Polarities of connections. The positive terminal of an ammeter or voltmeter is always connected to the part of the circuit coming from the positive terminal of the power supply.



An **ammeter** is always connected in series in a circuit. An ammeter has one black terminal and usually two or three red terminals. The black terminal is connected to the part of the circuit diagram closest to the negative power supply. One of the red terminals is selected depending on scale needed. Always choose 5 A scale first to avoid damage to the meter.

A **voltmeter** is always connected in parallel in a circuit. Similarly to the ammeter it has one black terminal (connected to the part of the circuit closest to the negative of the power supply) and two or three red terminals for different scales.

Figure 3.10 Voltmeters and ammeters in circuits.

Series circuits

When resistors are connected in series as shown at right.

The supply voltage (V) is shared among the resistors.

ie. $V = V_1 + V_2 + V_3$

The same current (I) goes through all the resistors.
The total resistance is the sum of the individual resistances.

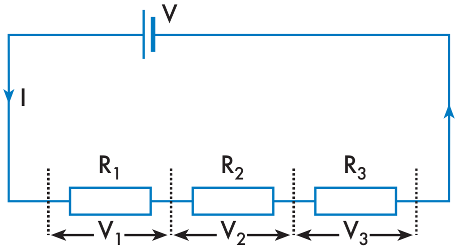


Figure 3.11 Resistors in series.

$$R_T = R_1 + R_2 + R_3$$

Parallel circuits

When resistors are connected in parallel as shown at right.
The current is shared among the resistors.

ie. $I = I_1 + I_2 + I_3$

The same voltage (V) exists across each resistance.
The total resistance is less than any of the resistances and is calculated as shown by the equation below.

$$\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$$

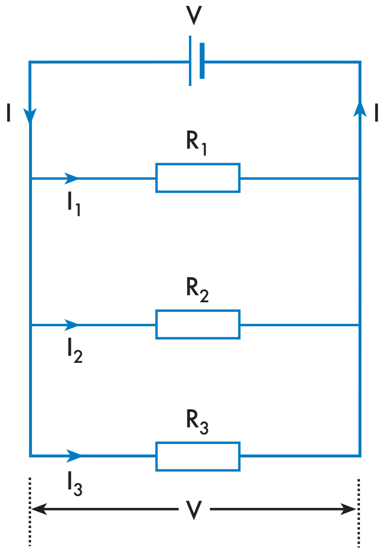


Figure 3.12 Resistors in parallel.

Worked Example 3.5

When a globe was connected to a 12 V battery it was found that the current flowing was 2.0 A. Calculate the globe's (a) resistance, (b) power rating.

$V = 12$ V
$I = 2.0$ A
$R = ?$
$P = ?$

(a) $R = \frac{V}{I} = \frac{12}{2.0} = 6.0\ \Omega$

(b) $P = V\,I = (12)(2.0) = 24$ W

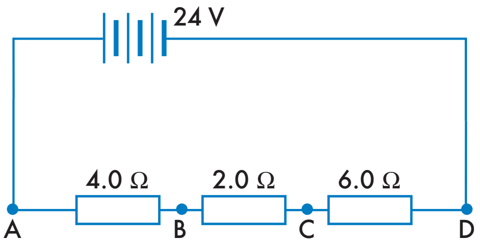
Worked Example 3.6

Three resistors, 4.0 Ω, 2.0 Ω, and 6.0 Ω are connected in series to a 24 V supply as shown. Determine: (a) total resistance, (b) the current flowing in each resistor, (c) the voltage across each resistor.

(a) $R_T = R_1 + R_2 + R_3$
$= 4.0 + 2.0 + 6.0$
$= 12\ \Omega$

(b) $V = 24$ V $\quad I_T = \frac{V}{R_T} = \frac{24}{12}$
$I = ?$
$R_T = 12\ \Omega \quad = 2.0$ A

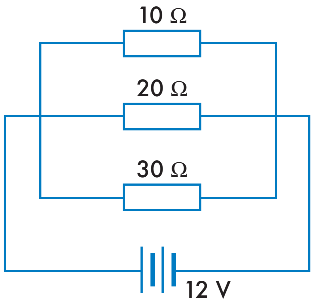
(c) $V_{AB} = I\,R = (2.0)(4.0) = 8.0$ V
$V_{BC} = I\,R = (2.0)(2.0) = 4.0$ V
$V_{CD} = I\,R = (2.0)(6.0) = 12.0$ V



Note that the voltages across the three resistors add up to the supply voltage, 24 V.
The same current goes through each resistor.

Worked Example 3.7

Three resistors, 10 Ω, 20 Ω, and 30 Ω are connected in parallel to a 12 V supply as shown. Determine: (a) total resistance, (b) the current in each resistor.



(a)

$$\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$$

$$= \frac{1}{10} + \frac{1}{20} + \frac{1}{30}$$

$$= \frac{6+3+2}{60} = \frac{11}{60}$$

$$\therefore R_T = \frac{60}{11} = 5.45\ \Omega$$

(b) Each resistor has a potential difference of 12 V across it.

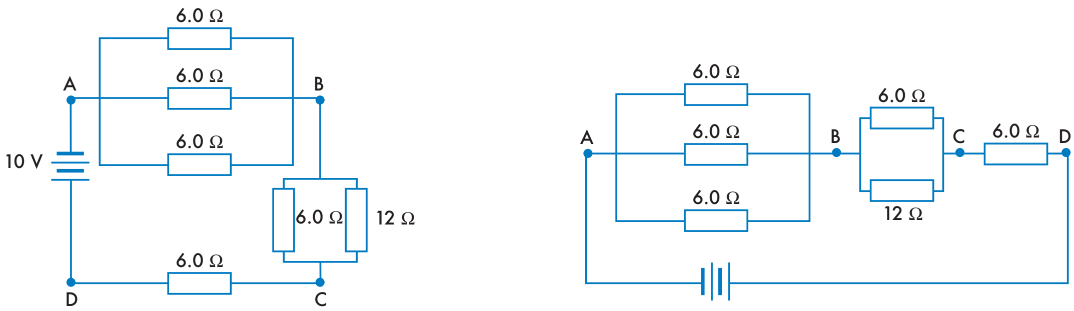
$\therefore$ for 10 Ω resistor $I_{10\,\Omega} = \frac{V}{R} = \frac{12}{10} = 1.2$ A

similarly $I_{20\,\Omega} = \frac{V}{R} = \frac{12}{20} = 0.60$ A, $I_{30\,\Omega} = \frac{V}{R} = \frac{12}{30} = 0.40$ A

Note that $I_T = 1.2 + 0.60 + 0.40 = 2.2$ A. Can you verify this?

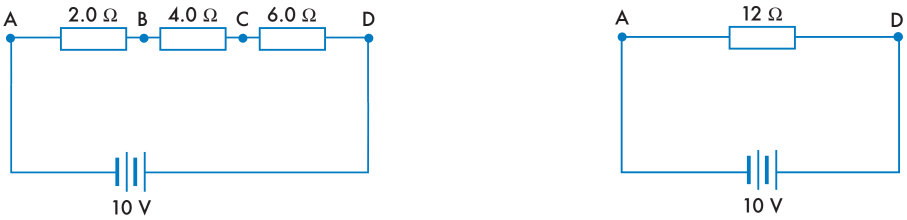
Complex circuits

Most electrical circuits are a combination of series and parallel circuits. To determine the equivalent resistance of the circuit, each part of the circuit is dealt with separately and simplified to a series circuit. Figure 3.13 shows how a network of resistors can be simplified to a single equivalent resistor.



(a) Complex network consisting of 2 parallel networks, A to B and B to C, in series with a 6 Ω resistor, C to D.

(b) The same circuit, redrawn for clarity.



(c) Using $\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2}$ ... etc a single resistor replaces the parallel networks.

(d) The equivalent resistance for the circuit.

Figure 3.13 Simplifying complex circuits.

Question 3.8

The total resistance of a parallel circuit is always less than any of the individual resistors. Why is this?

____

____

____

Question 3.9

You have a large supply of 2 Ω resistors but require a 5 Ω resistance. Using the least number of 2 Ω resistors, show how this can be done.

____

____

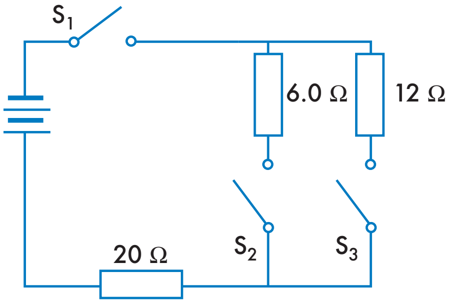
____

Worked Example 3.8

Three resistors are connected to a DC power supply as shown. When all switches are closed it is found that the current in the 20 Ω resistor is 500 mA.

(a) For these conditions determine:
  - (i) The total resistance of the circuit.
  - (ii) The potential difference across each resistor.
  - (iii) The current in the 6 Ω resistor.
  - (iv) The voltage of the DC supply.

(b) If S_3 is opened and S_1 and S_2 remain closed determine the current now flowing through the 20 Ω resistor.



(a) (i) The 6.0 Ω and 12 Ω resistors are in parallel

$$\frac{1}{R_p} = \frac{1}{6.0} + \frac{1}{12} \quad {}^*R_p = \text{resistance of parallel section}$$

$$= \frac{2.0 + 1.0}{12} = \frac{3.0}{12} \therefore R_p = \frac{12}{3.0} = 4.0\ \Omega$$

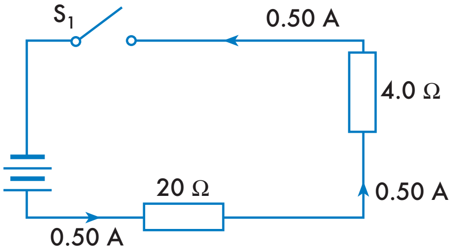
Hence $R_T = 20 + 4 = 24\ \Omega$

(ii) A simplified circuit shows the parallel section as 4.0 Ω.

Using $V = IR$

$$V_{20\Omega} = (0.50)(20) = 10\text{ V}$$

$$V_{4\Omega} = (0.50)(4) = 2.0\text{ V}$$



The voltage across the 6.0 Ω and 12 Ω resistor is 2.0 V. Across the 20 Ω resistor it is 10 V.

(iii) Since the 6 Ω resistor has 2.0 V across it

$$I_{6\,\Omega} = \frac{V}{R} = \frac{2.0}{6.0} = 0.33 \text{ A}$$

(iv) The voltage of the supply is equal to the total of the voltages across the resistors in series.

$$V = 10 + 2.0 = 12 \text{ V}$$

Note: Taking the 12 Ω resistor out of the parallel section actually increased the overall resistance of the circuit (Why?). This caused a drop in the current through the circuit.

(b) If S_3 is opened the total resistance for the circuit will be

$$R_T = 20 + 6.0 = 26\ \Omega$$

∴ Current flowing in this series circuit

$$I = \frac{V}{R} = \frac{12}{26} = 0.46 \text{ A}$$

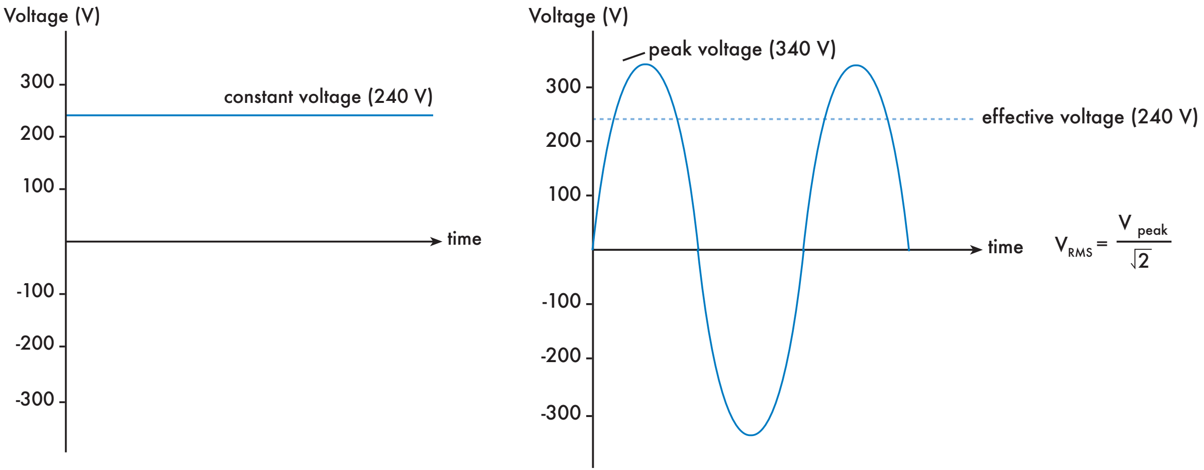
AC Power Supply

The power generated for both homes and industry is alternating current (AC). This form of power has many distinct advantages over a DC (direct current) supply.

AC power

- is more easily generated
- is generally safer and cheaper for most applications
- is easily transformed to higher or lower voltages for different uses
- is suitable for devices such as clocks and tape recorders since its frequency can be precisely controlled
- can be transmitted at high voltages to minimise energy losses

The nature of AC power means that both the voltage and current continually rise and fall and vary in direction with time. The effective voltage (or current) is a mathematical average called the root mean square voltage (V_{RMS}).



(a) DC voltage (b) AC voltage

Figure 3.14 Comparing AC and DC voltage.

Electricity in the home

Electricity supplied to our homes is usually single phase 240 V AC or if 3 phases are connected the effective voltage is 415 V. The single phase cable connected to your home fusebox (or switchboard) contains two insulated wires, one being the active and the other being the neutral. The active wire is connected through the meter, to a main switch and then to different circuit each with their own fuse. The neutral wire is earthed by connecting it to a metal water pipe or similar.

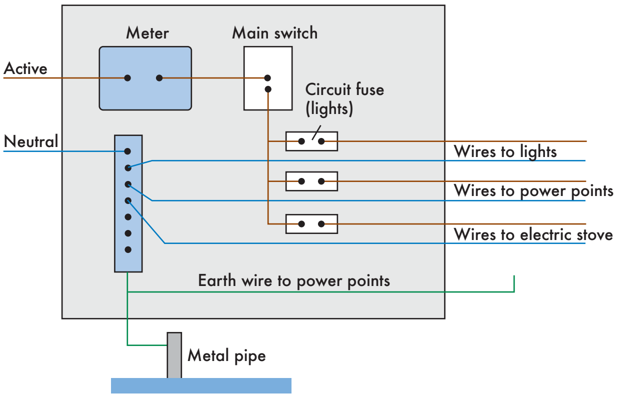
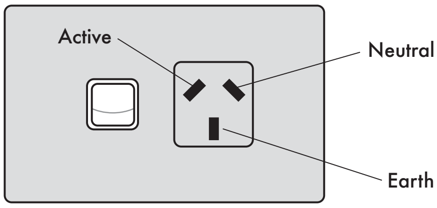
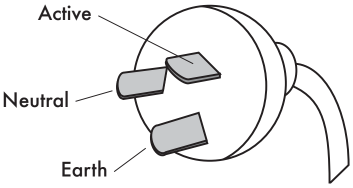


Figure 3.15 Typical household wiring circuit.

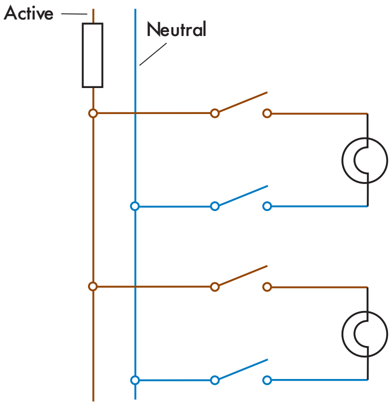




Electrical circuits in the home

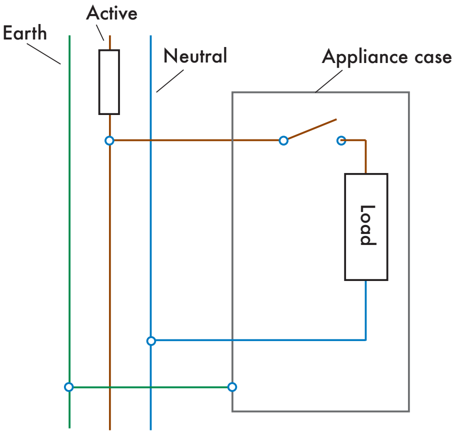
Home lighting circuit

In a household lighting circuit all the lights are wired in parallel so that they all receive the full mains voltage (240 V). Each light can be independently switched although sometimes two or more lights may have a common switch.



Power circuits

Power points are on a separate circuit of their own and are also wired in parallel. This allows full mains voltage (240 V) to each power point and independent switching. An earth wire is also used in power connections. This wire connects the case of an applicance to earth. It prevents electrocution in the event that the appliance became live.



The previous (old) and international (new) colour codes for wiring are listed below.

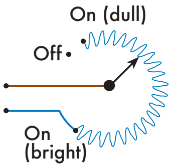
WIRE	PREVIOUS (OLD)	INTERNATIONAL (NEW)
Active	Red	Brown
Neutral	Black	Blue
Earth	Green	Green/Yellow

Two way switches

These handy devices allow a light (or other appliance) to be turned on or off from two different points. A common example is a hallway light which can be switched from either end.

Dimmer switches (Rheostat)

The brightness of lights can be varied by using a switch which incorporates electronic components such that it acts somewhat like a variable resistor.



Safety features in the home wiring system include

- **earth wire** – The earth wire is connected to the metallic case of an appliance so that should the appliance become live, the current will flow harmlessly to earth. A fuse will most likely blow.
- **fuses** – Fuses are made from low melting point wires which will melt (blow) if too large a current goes through a circuit.
- **circuit breakers** – Circuit breakers ensure that current flow in a circuit does not go over a breaker's particular level. If the current exceeds this level, an electromagnetic device breaks the circuit and prevents further current flow. Circuit breakers are preferred to fuses as they respond instantaneously and are easily reset.
- **earth leakage device** – A residual current device (RCD) is able to detect any difference between the currents in the active and neutral wires which could be caused by a fault or an accidental device grounding of a live wire. As little as a 30 mA difference will trip this circuit breaker within 50 milliseconds or so.
- **double insulation** – Some electrical appliances such as hair dryers and electrical drills have double insulation. The first layer of insulation is around the live components and wires while the second is a robust plastic outer case. There is no earthwire.
- **double pole switches** – These connect (and disconnect) both the active and neutral wires when the switches /switch is operated. This is preferable to the action of the single pole switches which could, through incorrect wiring, leave an appliance effectively connected to the mains even though the switch is off.

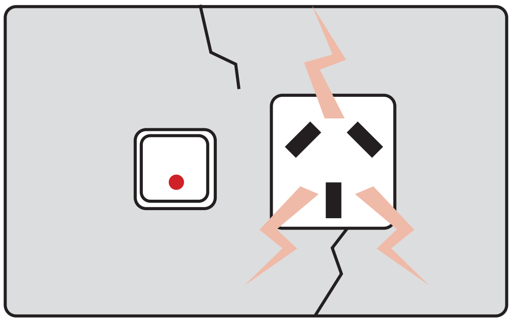
Electric shock – take care!

Although electricity is very useful, our mains supply presents a potential hazard to life as well as the possibility of fire. Quite small currents through the human body can cause severe shock or even death.

The severity of an electric shock depends on several factors but most importantly the amount of current passing through the body and the duration of the shock. A current of as little as 40 mA can cause severe shock over half a second.

The amount of current that flows is dependent on the voltage involved and the resistance of the human body. This resistance is mainly due to the skin as the internal part of the body conducts electricity fairly well due to the presence of ions. Dry skin and poor contact with the voltage source offer the greatest resistance. Moisture or water on the skin greatly reduces resistance.

- Appropriate care should be taken at all times when using electricity. This is particularly so in situations near water.
- Remember that only a licenced electrician may carry out wiring alterations and electrical repairs. This also applies to plugs and extension leads. A common cause of electrical accidents is due to incorrectly wired plugs and power leads.
- If a fuse blows the cause of the fault should be checked and rectified. Simply using a higher rated fuse may cause a more serious situation.



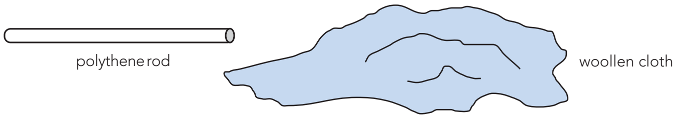
REVIEW QUESTIONS

Chapter 3: Electrical Circuits

3.1 Electricity

1. Indicate whether each of the following is true or false. Alter any false statement so that they are true.
   (a) Positive and negative charges attract each other.
   (b) The friction between two surfaces rubbing together, such as shoes on a carpet, can cause a static charge due to the transfer of protons.
   (c) The electric charge on a body can be measured in coulombs.
   (d) An electric field can exert a force on both positive and negative charges.
   (e) The rate of flow of an electric charge in a conductor is called the voltage.

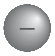
2. When rubbed with a woollen cloth, polythene acquires a negative charge. Is this negative charge simply created by the rubbing action? Explain your answer.



3. Explain why a hand-held insulator can be charged (e.g. by rubbing) but a hand-held metal rod cannot be charged.

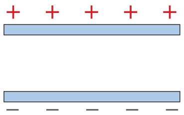
4. For each of the following re-draw the diagram and draw the electric field distribution associated with it.

(a) 

(b) 

(c) 

(d) 

(e) 

5. All conventional currents are electric currents but not all electric currents are conventional currents. Explain why this is so.

6. Chelsea used the battery from her car to supply 3.50 A to operate an electric motor for 30.0 minutes. Calculate the total amount of charge which flowed from the battery.

7. Maxwell set up a small circuit using a battery to supply an electric current to a lamp. If the battery can supply 200 C of electric charge in a 3.00 minute interval, how much electric current can Michael expect to have supplied to the lamp?

8. Hannah has a heating appliance rated at 2.40 kW when it has a current of 10.0 A flowing through it. If she wishes to operate the appliance for 1 hour, determine the:
   (a) potential difference required across the appliance,
   (b) amount of heat converted from electrical energy, and
   (c) total charge flowing through the appliance.

9. During a physics investigation, a student connected a circuit similar to a torch circuit. The student used three 1.50 V batteries to provide a total voltage of 4.50 V and also used a 2.50 W globe. When the switch was closed for 30.0 s the student observed a steady current on the ammeter. Calculate the:
   (a) current flowing through the circuit,
   (b) quantity of charge flowing through the circuit, and
   (c) the electrical energy converted by the globe.

3.2 Electrical Circuits

10. Indicate whether each of the following is true or false. Alter any false statement so that they are true.
    (a) In a parallel circuit there is more than one possible path for the current.
    (b) The electrical resistance of materials is measured in ohm.
    (c) The electrical resistance of a thick copper wire is greater than that of a thin copper wire of the same length.
    (d) A voltmeter is always connected to an electrical circuit in parallel and not in series.
    (e) It is not possible to combine 4.0 Ω resistors to give an overall resistance of 6.0 Ω.

11. Draw a circuit diagram for a torch which includes two batteries, a switch and a light globe.

12. When performing an investigation to verify Ohm's Law, what relationship between current and the potential difference are you likely to establish?

13. A driving lamp fitted to a car is specified as a 100 W, 12.0 V lamp. Calculate:
    (a) the current flowing through the lamp, and
    (b) the resistance of the lamp.

14. In a physics experiment to determine the resistance of an unknown resistor Michelle recorded the following data:

VOLTAGE (V)	0	2	4	6	8	10	12
CURRENT (I)	0	0.1	0.2	0.3	0.4	0.5	0.6

    (a) Draw a circuit diagram to represent a circuit and apparatus most likely used by Michelle.
    (b) Draw a graph of the data and use the graph to determine the resistance of the resistor.

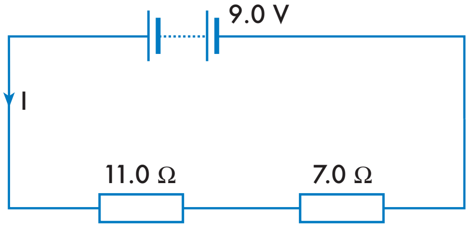
15. An electric motor found in a child's toy requires two 1.50 V dry cell batteries to be connected in series. If the motor draws a maximum current of 300 mA calculate:
    (a) the resistance of the motor, and
    (b) the maximum power consumption of the toy.

16. A Christmas tree is decorated by a string of 16 light globes which are connected in series to a low voltage outlet of 12.0 V. If the total power consumption is 24.0 W, calculate the
    (a) potential difference across each light globe, and
    (b) resistance of each light globe.

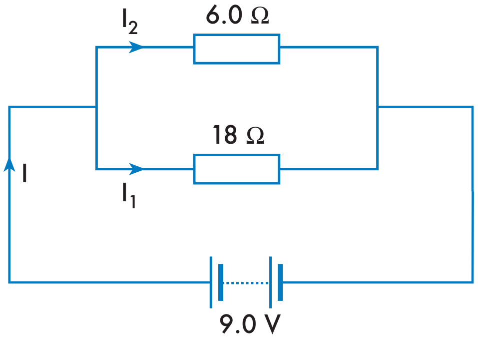
17. For the Christmas tree decoration in Q16, if a short circuit occurred in the socket of one of the globes so that it didn't light up but the other 15 globes did, what would be the total power consumption?

18. Charles wishes to connect a number of 75.0 W, 240 V coloured party light globes around his patio. How many globes can he use without blowing a 5.0 A fuse when he turns the light globes on?

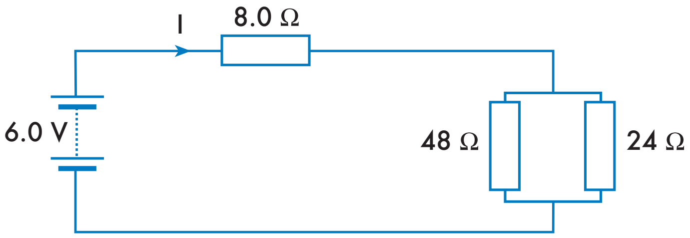
19. For the circuit shown below calculate the:
   (a) total resistance of the circuit, and
   (b) the current, I.



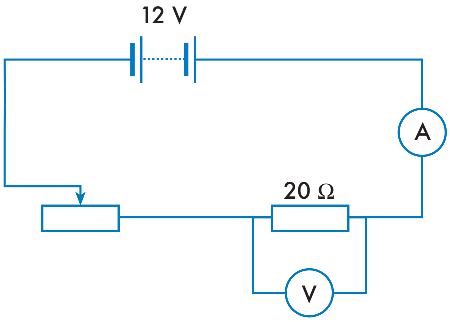
20. For the circuit shown below calculate the:
   (a) total resistance of the circuit,
   (b) I,
   (c) I_1, and
   (d) the potential difference across the 6.0 Ω resistor.



21. For the circuit shown below calculate the:
   (a) total resistance of the circuit,
   (b) I,
   (c) potential difference across the 24 Ω resistor, and
   (d) power dissipated through 8.0 Ω resistor.



22. Maxwell was conducting an experiment to confirm Ohm's Law on a resistor. He was able to vary the amount of current flowing through the resistor by using a rheostat (variable resistor). His circuit was set up as shown below. With a current reading of 0.50 A on the ammeter, calculate:
    (a) the value of V Max should observe on the voltmeter, and
    (b) the resistance of the rheostat on this setting.



23. An electric immersion heater is used to heat water in a jug. Briefly explain where the energy transformation(s) is occurring and why.

24. Kylie made a cup of coffee by boiling 300 mL of water in an electric kettle which had the following written on its base: 240 V, 2400 W. If the kettle took 50.0 seconds to boil the water:
    (a) how much electrical energy was used in this time, and
    (b) can Kylie expect all of the heat energy transformed from this electrical energy to be absorbed by the water in the kettle and heat it to boiling point?

25. Why is a 'fuse' used in an electric circuit? (also explain what a 'fuse' is and how it works).

26. A television set owned by Michael is rated at 180 W and is designed to operate on a 240 V supply. If standard values for fuses are 2.00 A, 5.00 A and 10.0 A:
    (a) suggest a value for a fuse to be placed in the circuit to which Michael's television is connected, and
    (b) if a 10.0 A fuse was inadvertently used instead of the recommended fuse, predict what may happen if a fault in the television caused a much larger current to flow in the television set.

27. List three advantages of using an earth leakage circuit breaker.

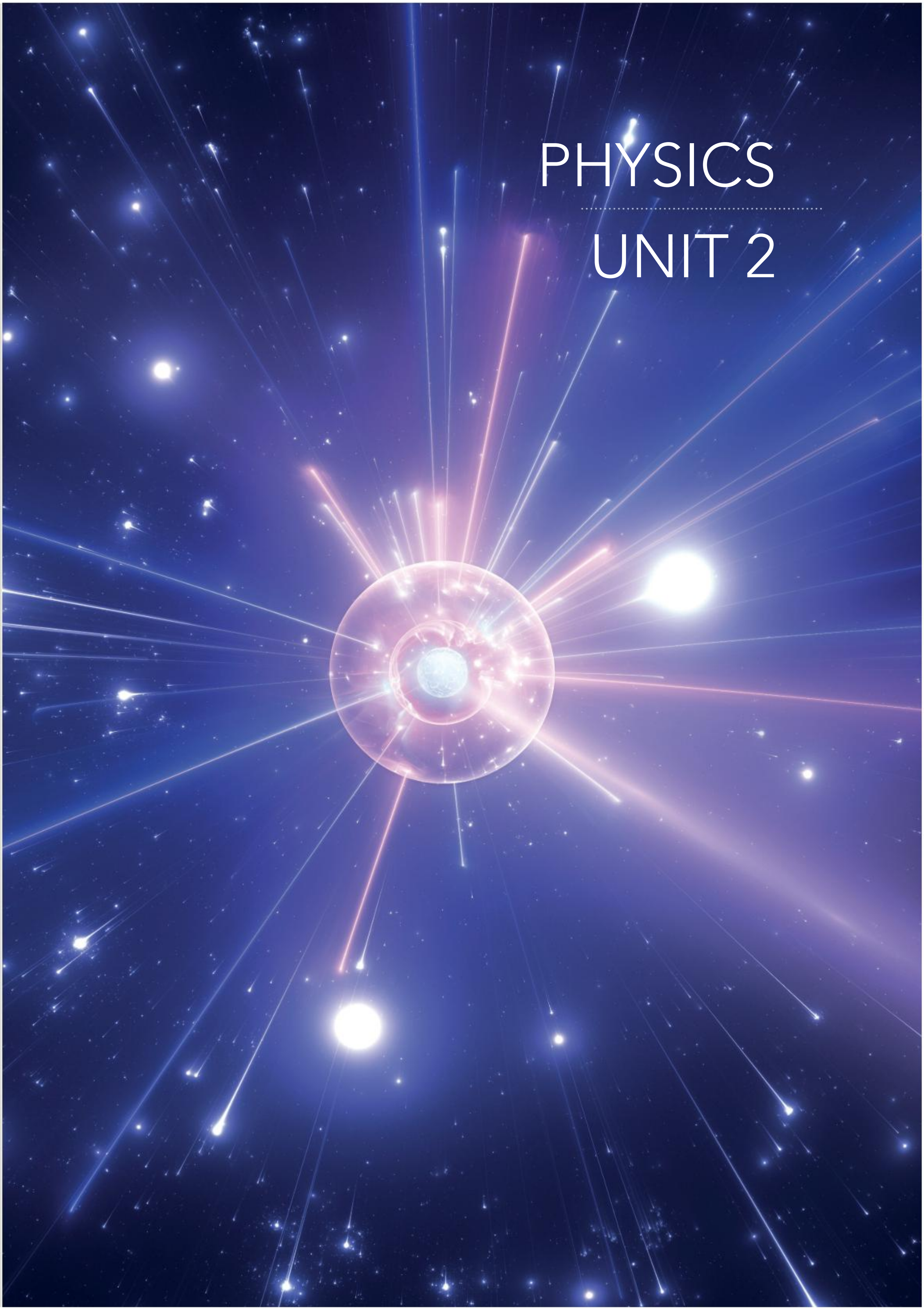
28. Suggest why it is advisable to turn off the ignition switch of a car that has been involved in an accident.

29. A car has both a battery and a generator. Would you expect them to be connected in series or in parallel? Why?

30. The 12.0 V battery in a car supplies a current of 3.50×10^2 A to provide the starter motor with maximum power.
    (a) Calculate the maximum power of the starter motor.
    (b) Determine the maximum resistance of the starter motor, the battery and the connective wires.
    (c) Compare the thickness of the wire connecting the battery to the starter motor with the thickness of the wire used in most other circuits in the car. Give a reason for your answer.

PHYSICS

UNIT 2



4

LINEAR MOTION AND FORCE

SYLLABUS CHECKLIST

SCIENCE UNDERSTANDING – LINEAR MOTION AND FORCE

☐ distinguish between vector and scalar quantities, and add and subtract vectors in two dimensions

☐ uniformly accelerated motion is described in terms of relationships between measurable scalar and vector quantities, including displacement, speed, velocity and acceleration. This includes applying the relationships:

$$v_{av} = \frac{s}{t}\ ,\ a = \frac{v - u}{t}\ ,\ v = u + at\ ,\ s = ut + \tfrac{1}{2}at^2\ ,\ v^2 = u^2 + 2as$$

☐ representations, including graphs, vectors, and equations of motion, can be used qualitatively and quantitatively to describe and predict linear motion

☐ vertical motion is analysed by assuming the acceleration due to gravity is constant near Earth's surface

☐ Newton's three Laws of Motion describe the relationship between the force or forces acting on an object, modelled as a point mass, and the motion of the object due to the application of the force or forces

☐ free body diagrams show the forces and net force acting on objects, from descriptions of real-life situations involving forces acting in one or two dimensions. This includes applying the relationships:

$$resultant\ F = ma\ ,\ F_{weight} = m\,g$$

☐ momentum is a property of moving objects; it is conserved in a closed system and may be transferred from one object to another when a force acts over a time interval. This includes applying the relationships:

$$p = m\,v\ ,\ \Sigma\, m\, v_{before} = \Sigma\, m\, v_{after}\ ,\ m\,v - m\,u = \Delta\, p = F\,\Delta\, t$$

☐ energy is conserved in isolated systems and is transferred from one object to another when a force is applied over a distance; this causes work to be done and changes the kinetic (E_k) and/or potential (E_p) energy of objects. This includes applying the relationships:

$$E_k = ½\, m\, v^2\,,\ E_p = m\, g\, \Delta h\,,\ W = F\, s\,,\ \ W = \Delta E$$

☐ collisions may be elastic and inelastic; kinetic energy is conserved in elastic collisions. This includes applying the relationship:

$$\Sigma\, ½\, m\, v^2{}_{before} = \Sigma\, ½\, m\, v^2{}_{after}$$

☐ power is the rate of doing work or transferring energy. This includes applying the relationship:

$$P = \frac{W}{t} = \frac{\Delta E}{t} = F\, v_{av}$$

4.1 MOTION IN A STRAIGHT LINE

The motion of bodies exists all around us. It may be as simple as a child pushing a trolley, as complex as moving down a roller coaster or as unapparent as the movement of the earth in space. In this book we will consider only straight line motion and use the earth as our frame of reference. The ideas we will use can also be applied to more complex motion.

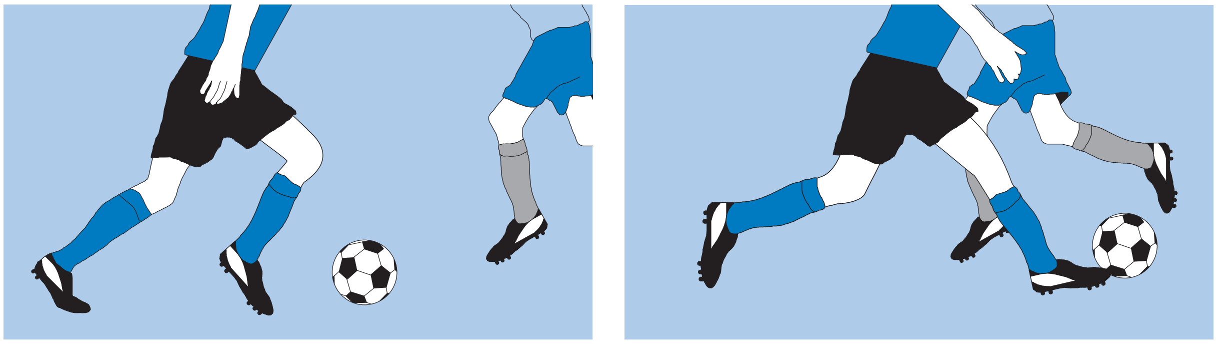


Figure 4.1 *Bodies in motion.*

Describing motion

Motion involves the change of position of a body with respect to time (and some given frame of reference). Important terms used in describing motion are:

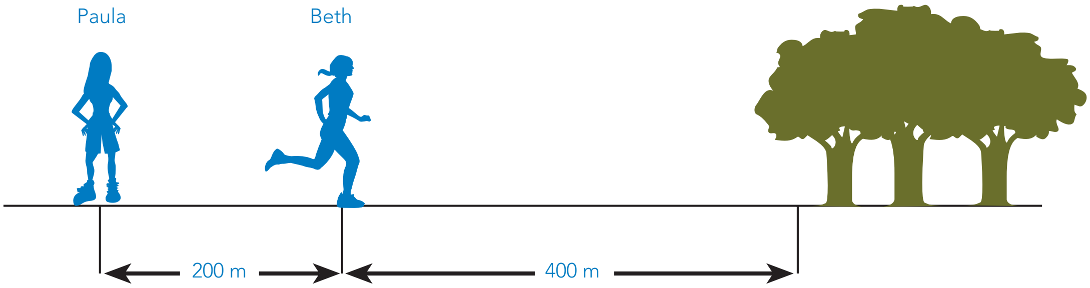
- **position:** The location of a body with respect to the origin, e.g. a yacht is 2.55 km due West of a jetty.
- **displacement:** The change in position of a body in a particular direction (as measured in a direct line from the origin), e.g. 10.2 m South East, 4.21 km due North.
- **distance:** How far a body has travelled, irrespective of direction, e.g. a runner completing a lap of the oval travels a distance of 400 m. The displacement in this case however is zero.
- **speed:** The rate at which distance is travelled, e.g. a car is travelling at 65 kmh^{-1}.
- **velocity:** The rate of change of position in a particular direction, e.g. a car is travelling at 65 kmh^{-1} South East.
- **acceleration:** The rate of change of velocity in a particular direction, e.g. a falling body accelerates at 9.80 ms^{-2} towards the earth.

Measuring motion

To quantify motion we need to measure both time and distance. The distance may be measured from some reference point at specific intervals of time. In the laboratory these measurements can be made using rulers and a watch, ticker timers, multiflash photography or with motion detectors. The data collected can then be represented graphically or analysed using equations of motion.

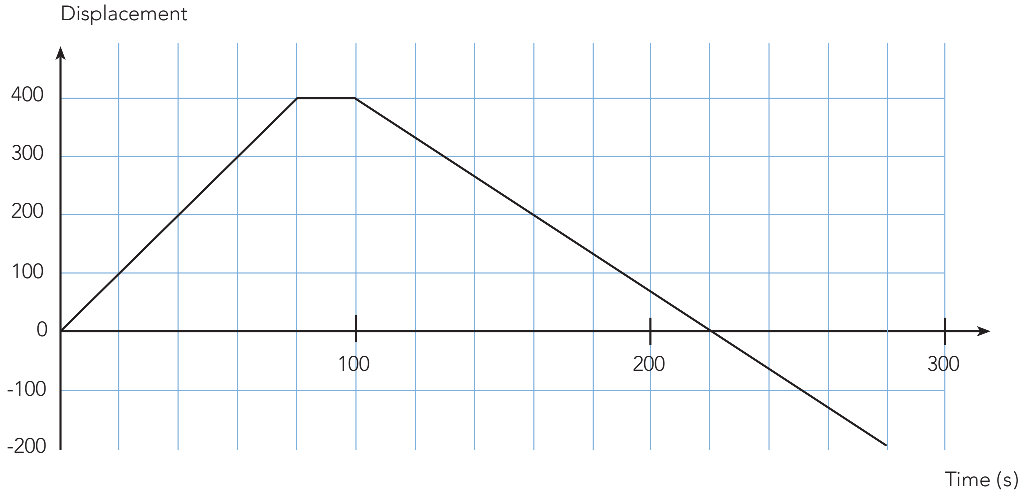
Worked Example 4.1

Beth decides to do some training for her athletics carnival by running to a nearby park and then back to her friend Paula. She is initially standing 200 m from Paula and runs 400 m towards the park as shown. Her steady run to the park took 80 seconds, she rested for 20 seconds and then jogged back to her friend Paula in 180 seconds (see diagram).



(a) Graph Beth's movements on a displacement/time graph.
(b) What distance has Beth travelled?
(c) What is Beth's displacement at the end of her run?
(d) What is the significance of the slopes of the graphs?
(e) At what time did Beth go past her original starting point?

(a) Distance towards the park is taken as a positive displacement. Beth's starting point is taken as zero.



(b) Beth has travelled a total of 1000 m (400 + 400 + 200).
(c) Beth's displacement is 200 m (i.e. 200 m from her starting point and in a direction opposite from the park).
(d) The slopes of the graph indicate velocity.
(e) At t = 220 s her displacement is zero. That is she is back at her starting point.

Calculating speed

Speed is easily calculated by dividing the distance travelled by the time taken. However there is an important difference between average speed and instantaneous speed.

Average speed provides an overall description of motion and does not indicate variations of speed that may have occurred during the time under consideration.

$$\text{Average speed} = \frac{\text{total distance travelled}}{\text{time taken}}$$

$$v_{av} = \frac{s}{t}$$

Instantaneous speed is the actual speed at any particular moment. A car's speedometer gives the approximate instantaneous speed of a moving car. To calculate instantaneous speed we consider a very small instant in time. The gradient of a distance/time graph at a given point in time will give instantaneous speed at that instant of time. Instantaneous velocity would be the gradient of a displacement/time graph at a given point in time.

$$\text{Instantaneous speed} = \frac{\text{distance moved}}{{}^{*}\text{time taken}}$$

$$v = \frac{\Delta s}{\Delta t} \quad {}^{*}\text{as } \Delta t \Rightarrow 0$$

**As the time interval tends to zero. See also p. 96 for graphical analysis.*

Worked Example 4.2

Use the data in Example 4.1 (Beth's run) to calculate:

(a) Beth's average speed for the total run.
(b) Beth's instantaneous speed at t = 20 s.

(a)

$s_{(total)}$ = 400 + 600 = 1000 m

$t_{(total)}$ = 80 + 20 + 180 = 280 s

$$v_{av} = \frac{s}{t} = \frac{1000}{280} = 3.6 \text{ ms}^{-1}$$

(b) If we assume a steady run by Beth then her instantaneous speed for the first 80 seconds is always the same. It is given by the gradient of the graph.

$\therefore$ at $t = 20$

$$v = \frac{s}{t} = \frac{400 \text{ m}}{80 \text{ s}} = 5.0 \text{ ms}^{-1}$$

Question 4.1

(a) How is speed different to velocity? ____________________

(b) Use the graph of Beth's run in Ex. 4.1 to determine (for t = 160 s)

(i) her displacement ____________________

(ii) her average speed ____________________

(iii) her instantaneous velocity ____________________

Speed and velocity

These terms are often used interchangeably but they do have different meanings. Speed is a scalar quantity and simply tells us how fast a body is moving. Velocity is a vector quantity and tells us how fast a body is moving as well as the direction of motion (for vector and scalar quantities see page 96).

In calculating velocity we consider displacement (which is a vector quantity) instead of distance (which is a scalar quantity). Hence:

$$\text{average speed} = \frac{\text{distance travelled}}{\text{time taken}} \qquad \text{average velocity} = \frac{\text{displacement}}{\text{time taken}}$$

Worked Example 4.3

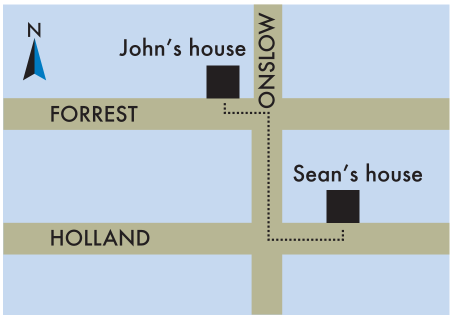
John rides his bicycle from his home in order to visit Sean. John has to travel 80 m due East, 150 m due South and then 120 m due East in order to reach Sean. He completes his ride in 65 seconds. Determine:

(a) The distance John travelled.
(b) His displacement.
(c) His average speed.
(d) His average velocity.

A vector diagram will allow us to determine John's displacement. This displacement is the direct distance from John's to Sean's house. Using a scaled diagram or trigonometry (see vectors page 98) we can show that the displacement from A to D is 250 m, 37° S of E.

(a) Distance John has travelled

$$= 80\text{ m} + 150\text{ m} + 120\text{ m}$$
$$= 350\text{ m}$$



(b) Displacement (see diagram)

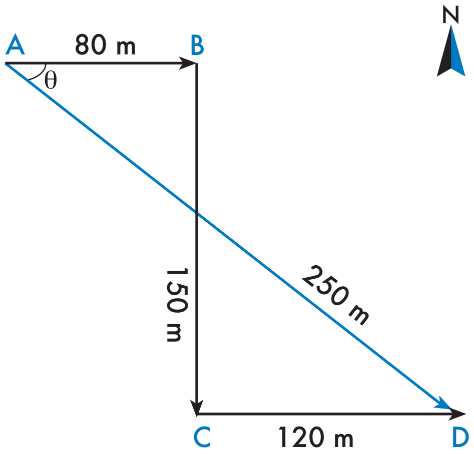
$$= 250\text{ m } 37° \text{ S of E}$$

(c) Average speed $= \dfrac{\text{total distance}}{\text{time taken}}$

$$= \frac{350\text{ m}}{65\text{ s}} = 5.4\text{ ms}^{-1}$$

(d) Average velocity $= \dfrac{\text{displacement}}{\text{time}}$

$$= \frac{250\text{ m}}{65\text{ s}} = 3.8\text{ ms}^{-1}\ \ 37^{\circ}\text{S of E}$$



$$\tan \theta = \frac{150}{200} \qquad \theta = 37^{\circ}$$

Question 4.2

John, (in Ex. 4.3), realised as soon as he reached Sean's house that he had forgotten his bag. He immediately turned his bike around and reached his home in 65 seconds, the same time as he had originally taken to reach Sean's house.

Calculate his average speed and average velocity for:

(i) the return journey ________________________________

____

(ii) the whole journey ________________________________

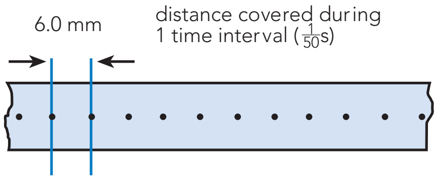
____

Ticker timers

A ticker timer is a handy device for measuring speeds in a laboratory situation. The hammer of the ticker timer vibrates at 50 Hz (A.C. current) and leaves carbon dots on a paper tape pulled through the timer. The data from the tapes can be used to calculate speed and acceleration.

Analysing ticker timer tapes

(a) tape showing constant velocity

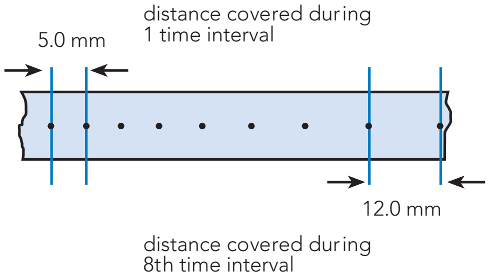


$$\text{speed} = \frac{\text{distance between dots}}{\text{time between dots}}$$

$$= \frac{6.0 \times 10^{-3}\ \text{m}}{0.020\ \text{s}}$$

$$= 0.30\ \text{ms}^{-1}$$

(b) tape showing constant acceleration



speed (during 1st time interval)

$$= \frac{5.0 \times 10^{-3}\ \text{m}}{0.020}$$

$$= 0.25\ \text{ms}^{-1}$$

speed (during 8th time interval)

$$= \frac{12.0 \times 10^{-3}\text{m}}{0.020}$$

$$= 0.60\ \text{ms}^{-1}$$

We can calculate the acceleration for the second tape as follows:

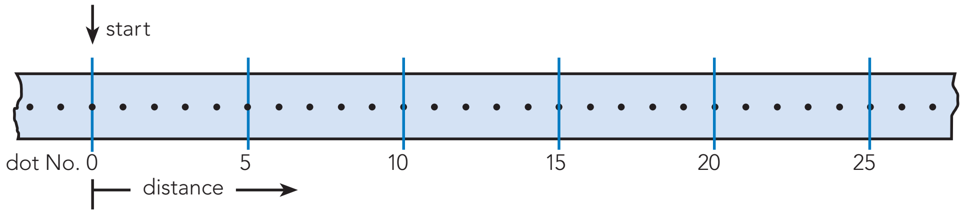
$$\text{Acceleration} = \frac{\text{change in velocity}}{\text{time taken for change}} \qquad \text{(See page 100)}$$

$$\text{ie.} \quad a = \frac{v - u}{t} = \frac{0.60 - 0.25}{(7)\ (0.02)} = \frac{0.35}{0.14} = 2.5\ \text{ms}^{-2}$$

Note that there were 7 time intervals between the beginning of u and the beginning of v.

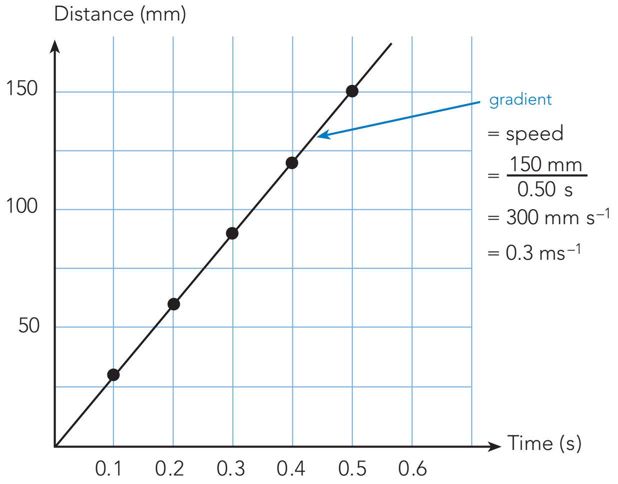
Graphing data from tapes

Careful measurements of the distances between dots on a tape can be used to create graphs. These graphs can be either distance/time or speed/time.



(a) Creating a distance/time graph

TIME (dots)	TIME (s)	DISTANCE (mm)
0	0	0
5	0.10	30
10	0.20	60
15	0.30	90
20	0.40	120
25	0.50	150



$= \text{speed}$

$= \frac{150 \text{ mm}}{0.50 \text{ s}}$

$= 300 \text{ mm s}^{-1}$

$= 0.3 \text{ ms}^{-1}$

(b) Creating a speed/time graph

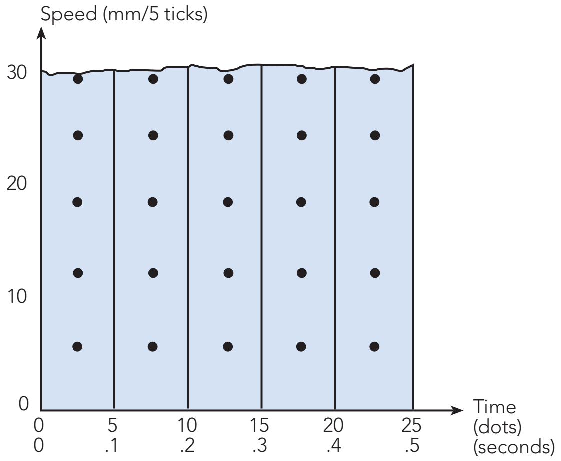
Equal time intervals of the paper tape (e.g. every 5 dots) can be cut up and pasted to produce a speed/time graph. Each strip represents the distance covered in a given time.

For the graph at right:

$$\text{speed} = \frac{30 \text{ mm}}{(5)\ (1/50 \text{ s})}$$

$$= \frac{0.03 \text{ m}}{0.10 \text{ s}}$$

$$= 0.30 \text{ ms}^{-1}$$



This graph shows constant speed

Vectors and Scalars

Physical quantities used to describe a situation; such as the motion of a cyclist, may be either vectors or scalars.

- A **scalar** quantity is fully described by magnitude only, e.g. the mass of the cyclist, the temperature of the day, the density of the air in the tyre.
- A **vector** quantity can only be fully described by giving both magnitude and direction, e.g. the velocity of the cyclist, the momentum of the cyclist, the force acting on the cyclist.

Question 4.3

Using the definitions given for scalars and vectors, list the following quantities in the appropriate group.

Velocity, speed, mass, momentum, density, volume, weight, acceleration, work done, impulse, distance, area, temperature.

SCALARS	VECTORS

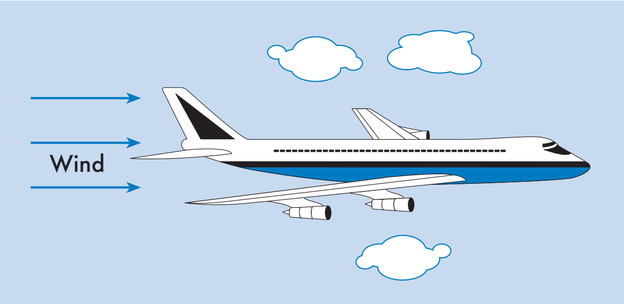
Vector addition

- Vectors are represented by arrows whose length represents magnitude and whose arrowhead indicates direction.
- Vectors are added geometrically by *placing the tail of one vector on the head of another*. The resultant is the vector which begins at the tail of the first vector and ends at the arrow head of the second (or last) vector.

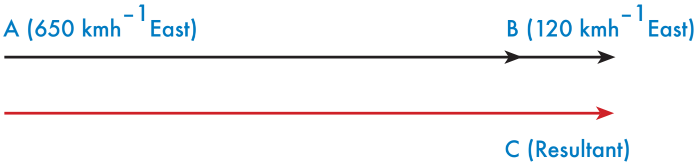
The resultant magnitude and direction of a vector can be determined by either using a scaled diagram or trigonometry.

Worked Example 4.4

The velocity of aircraft is often affected by the winds they encounter during flight. On a journey from Perth to Melbourne, a jetliner is travelling due East at 650 kmh^{-1} when it encounters a tail wind of 120 kmh^{-1} (i.e. wind is from West to East). Determine the resultant velocity of the jetliner.



Draw vectors (representing the plane's velocity) and (representing the wind velocity) and add them vectorially (place the tail of one vector on the head of the other). The resultant vector is as shown.



Hence C = A + B

= 770 kmh^{-1} East

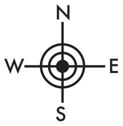
Worked Example 4.5

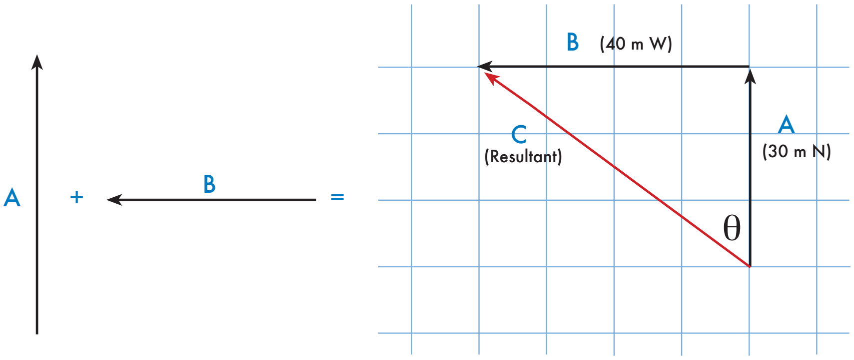
Vectors in two dimensions

Emily walks 30 m due North and then 40 m due West. Determine her final displacement (distance and direction from her starting point).

Consider the distances that Emily walked as vectors A, B and the resultant as vector C.

Hence $C = A + B$





If the vectors have been drawn to scale as shown we can measure the length and direction of the resultant vector. This will give us 50 m, 53.1° West of North.

Alternatively the problem can be done using trigonometry. Using Pythagoras' theorem we have:

$$C^2 = A^2 + B^2 = 30^2 + 40^2 = 2500$$

$$\therefore \quad C = 50 \text{ m}$$

Also $\tan\theta = \frac{40}{30} = 1.33 \therefore \theta = 53.1°$

$\therefore$ Resultant = 50 m, 53.1° West of North (or N 53.1° W)

Vector subtraction

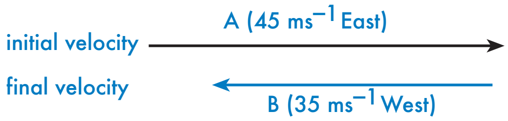
Sometimes we need to find the difference between two vectors. This is useful, for example, if we want to determine the change in velocity of a body. To do this we would subtract one vector (the initial velocity), from the other (the final velocity).

Because it is simpler to add vectors (tail of one onto the head of the other), we subtract vectors by adding the negative vector. For example, if vector A is the initial velocity and vector B the final velocity, then

$$\Delta v = \text{vector B} - \text{vector A}$$
$$= \text{vector B} + (-\text{vector A})$$

Worked Example 4.6

Greg bowls a cricket ball due East at 45.0 ms^{-1}. The ball is hit back due West by James at 35.0 ms^{-1}. Determine the change in velocity of the ball.



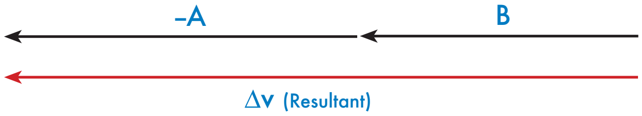
To find the change in velocity we will need to subtract vectors.

change in velocity = final velocity – initial velocity

$$\Delta v = B - A$$

$$= B + (-A)$$

=

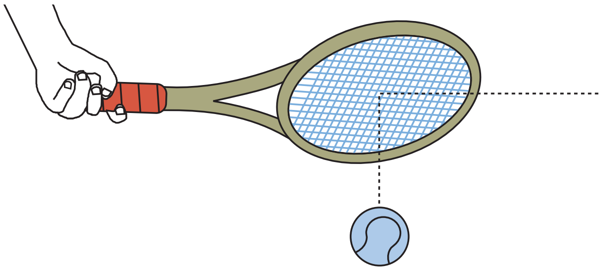


Hence Δv = 80 ms^{-1} due West

Worked Example 4.7

A tennis ball travelling due West at 24.0 ms^{-1} is hit with a racquet and moves off directly South at a speed of 20.0 ms^{-1}.

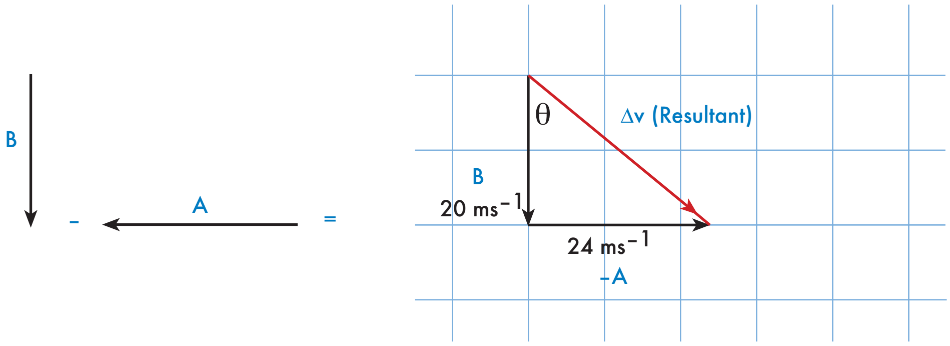
Determine the change in velocity of the tennis ball.



To find the change in velocity we will need to subtract vectors.

change in velocity = final velocity – initial velocity

$$\Delta v = B - A = B + (-A)$$

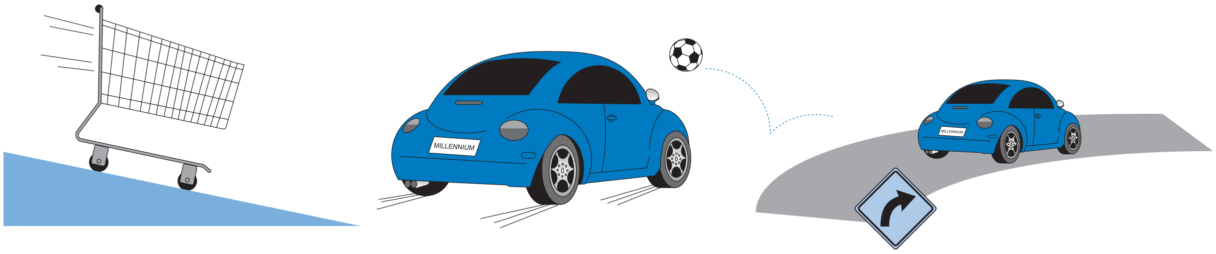


From the scaled diagram or using trigonometry:

Δv = 31.2 ms^{-1} at an angle of 50.2° East of South (S 50.2° E)

Accelerated Motion

Whenever there is a change in velocity we say acceleration has occurred. This may be due to the body going faster, slower or simply changing its direction of motion. Acceleration is defined as the rate of change of velocity.



Trolley accelerating down a plane *Car braking to a halt* *Car rounding a bend at constant speed*

Figure 4.2 Bodies undergoing acceleration.

$$\text{Average acceleration} = \frac{\text{change in velocity}}{\text{time taken}}$$

$$= \frac{\text{final vel} - \text{initial vel}}{\text{time}}$$

$$= \frac{v - u}{t}$$

$$a = \frac{v - u}{t}$$

$$\text{Instantaneous acceleration} = \frac{\Delta v}{\Delta t} \text{ as } t \to 0$$

This is the gradient of a velocity time graph at a particular instant of time (see page 103).

Worked Example 4.8

The trolley in Figure 4.2 accelerates from rest to a velocity of 2.60 ms^{-1} in 1.15 s. Determine its acceleration.

$a = ?$
$u = 0$
$v = 2.60 \text{ ms}^{-1}$
$t = 1.15 \text{ s}$

$$a = \frac{v - u}{t} = \frac{2.60 - 0.0}{1.15}$$

$$= 2.26 \text{ ms}^{-2}$$

Worked Example 4.9

The car in Figure 4.2 changes velocity from 85 kmh^{-1} to 20 kmh^{-1} in 4.5 s.

(a) Find the car's average acceleration.
(b) How much longer will it take this car to stop if it continues to brake at the same rate?

(a)
$u = 85 \text{ kmh}^{-1}$
$= 23.6 \text{ ms}^{-1}$
$v = 20 \text{ kmh}^{-1}$
$= 5.56 \text{ ms}^{-1}$

$$a = \frac{v - u}{t}$$

$$= \frac{5.56 - 23.6}{4.5}$$

$$= -4.0 \text{ ms}^{-2}$$

(Note that acceleration is negative.)

Speed conversion

$$\text{kmh}^{-1} \underset{\times 3.6}{\overset{\div 3.6}{\substack{\Rightarrow \\ \Leftarrow}}} \text{ms}^{-1}$$

$t = 4.5$ s
$a = ?$

(b) $u = 20$ kmh^{-1}
$= 5.56$ ms^{-1}
$v = 0$
$a = -4.0$ ms^{-2}
$t = ?$

$$a = \frac{v-u}{t} \quad \therefore \; t = \frac{v-u}{a}$$
$$= \frac{0-5.56}{-4.0} = 1.4 \text{ s}$$

The vehicle will take a further 1.4 seconds to come to a stop.

Question 4.4

The acceleration calculated for Ex. 4.9 has a negative value. Explain.

Question 4.5

A car rounding a bend at a constant speed (as in Figure 4.2) is actually accelerating. How can this be so?

Equations of motion

The following equations can be used in all situations that involve uniform acceleration.

$$v = u + at$$
$$s = ut + \tfrac{1}{2}at^2$$
$$v^2 = u^2 + 2as$$

u = initial velocity
v = final velocity
s = displacement
a = acceleration
t = time

Worked Example 4.10

A car accelerates uniformly from rest at 3.40 ms^{-2} for 6.0 seconds. Determine:
(a) its final velocity
(b) its displacement after 6.0 seconds
(c) its displacement during the fourth second.

(a/b) $u = 0$
$a = 3.40$ ms^{-2}
$t = 6.0$ s
$v = ?$
$s = ?$

$v = u + at$
$= 0 + (3.40)(6.0)$
$= 20.4$ ms^{-1}

$s = ut + \tfrac{1}{2}at^2$
$= 0 + (\tfrac{1}{2})(3.40)(6.0)^2$
$= 61.2$ m

(c) $u = 0$
$a = 3.40$ ms^{-2}
$t_3 = 3.0$
$t_4 = 4.0$
$\Delta s = ?$

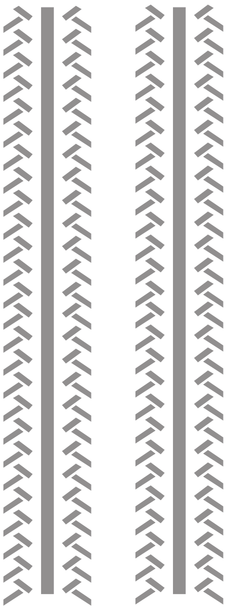
$s = ut + \tfrac{1}{2}at^2$
$s_{t = 3.0} = 0 + (\tfrac{1}{2})(3.40)(3.0)^2$
$= 15.3$ m
$s_{t = 4.0} = 0 + (\tfrac{1}{2})(3.40)(4.0)^2$
$= 27.2$ m

$\therefore$ displacement for the fourth second (Δs)
$\Delta s = s_4 - s_3$
$\Delta s = 27.2 - 15.3$
$= 11.9$ m

Worked Example 4.11

A car travelling at 80 kmh^{-1} was tested to see how quickly it could be brought to rest. The braking distance (the distance travelled by the car while the brakes were applied) was found to be 35.4 m. Determine:

(a) the car's acceleration (assumed uniform)
(b) the time taken for the car to stop.



$$\begin{aligned} u &= 80 \text{ kmh}^{-1} \\ &= 22.2 \text{ ms}^{-1} \\ v &= 0 \\ s &= 35.4 \text{ m} \\ a &= ? \\ t &= ? \end{aligned}$$

(a)

$$\begin{aligned} v^2 &= u^2 + 2as \\ a &= \frac{v^2 - u^2}{2s} \\ &= \frac{0 - (22.22)^2}{(2)(35.4)} \\ &= -6.97 \text{ ms}^{-2} \end{aligned}$$

(b)

$$\begin{aligned} v &= u + at \\ t &= \frac{v - u}{a} \\ &= \frac{0 - 22.2}{-6.97} \\ &= 3.19 \text{ s} \end{aligned}$$

Question 4.6

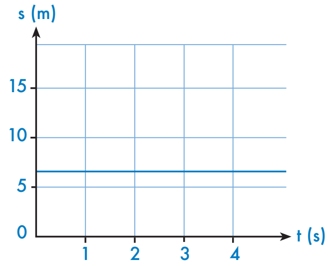
When a car is brought to rest in an emergency the stopping distance is greater than its braking distance. Explain.

Motion Graphs

Typical motion graphs are graphs of displacement/time and velocity/time are shown below:

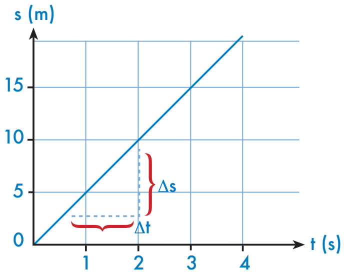
Displacement/time graphs

Slope of an s/t graph indicates velocity.



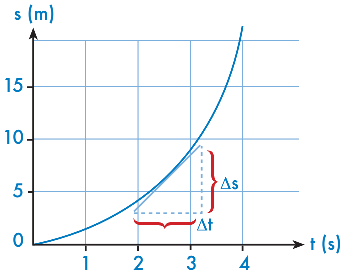
Zero velocity: This graph indicates that the body is not moving.

$$v = \frac{\Delta s}{\Delta t} = 0$$



Constant velocity: This graph has a constant slope, hence indicates constant velocity.

$$v = \frac{\Delta s}{\Delta t} = 5.0\ ms^{-1}$$



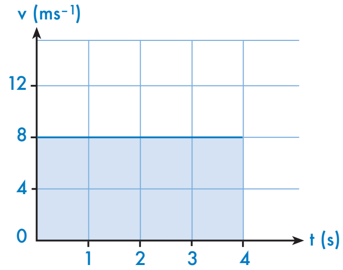
Acceleration: The slope of this graph is constantly changing. The instantaneous velocity at any point is given by the slope at that point.

at t = 2.5 s

$$v = \frac{\Delta s}{\Delta t} \approx 4.0\ ms^{-1}$$

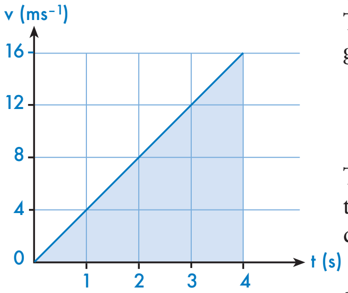
Velocity/time graphs

Slope of a v/t graph indicates acceleration.
Area under a v/t graph indicates displacement.



Constant velocity: This body is moving but not accelerating. The blue area under the graph gives the displacement.

$$s_{t=4} = (v)(t) = (8)(4) = 32\,m$$

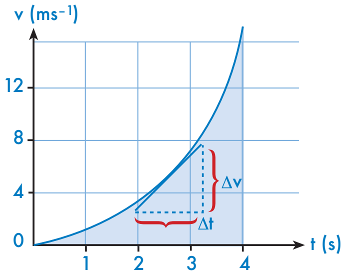


Constant acceleration: The slope of the graph gives acceleration.

$$a = \frac{\Delta v}{\Delta t} = 4.0\ ms^{-2}$$

The blue area under the graph gives displacement.

$s_{t=4}$ =Area = ½ (16)(4)
= 32 m



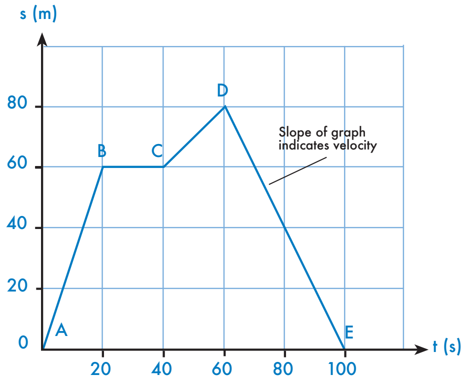
Increasing acceleration: the slope is constantly increasing. The instantaneous acceleration at any point is given by the slope at that point.

at t = 2.5 s

$$a = \frac{\Delta v}{\Delta t} \approx 4.0\ ms^{-2}$$

Analysing graphs – typical situations

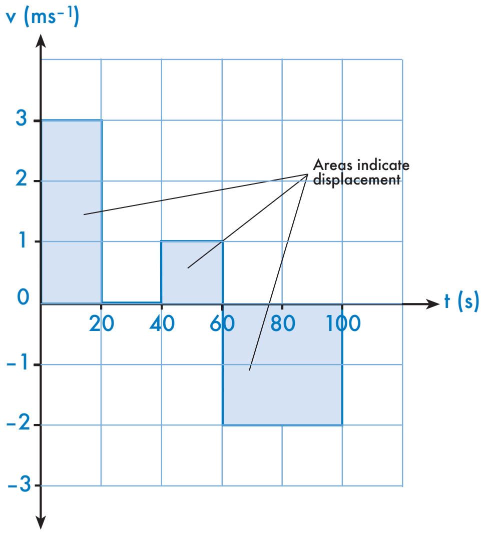
(a) Paula taking a walk (s/t graph)



A → B	walking at constant velocity
B → C	resting
C → D	constant velocity but slower than for A → B (slope is not as steep)
D → E	constant velocity in opposite direction (slope is negative)
E	Back at starting point.

(b) Paula's same walk (v/t graph). From the analysis of the s/t graph on the previous page we can draw a v/t graph of the same walk.

The velocity for each section is determined by the slope of the s/t graph.



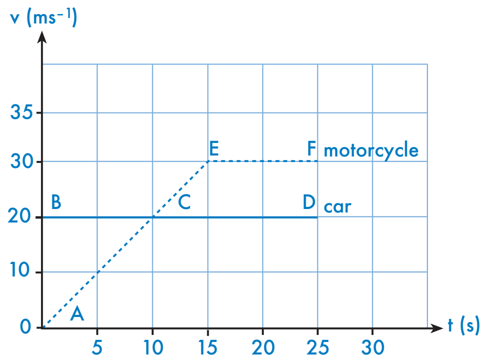
e.g. A → B $v = \frac{\Delta s}{\Delta t} = \frac{60}{20} = 3.0\ ms^{-1}$

B → C v = 0

C → D $v = \frac{20}{20} = 1.0\ ms^{-1}$

D → E $v = \frac{-80}{40} = -2.0\ ms^{-1}$

(c) Motorcycle overtaking a car. The v/t graph below illustrates the situation of a motorcycle (at rest) accelerating after a car (travelling at a constant speed) in order to catch up with it. The motorcycle will need to travel at a faster constant speed than the car in order to catch it.



B → D	constant velocity (car)
A → E	constant acceleration (motorcycle)
E → F	constant velocity (motorcycle)

At point C (t = 10 s) both the car and the motorcycle have the same speed but the motorcycle has not caught up with the car. The motorcycle will have caught up with the car when the area under the AE, EF graph is the same as the area under BD graph.

Question 4.7

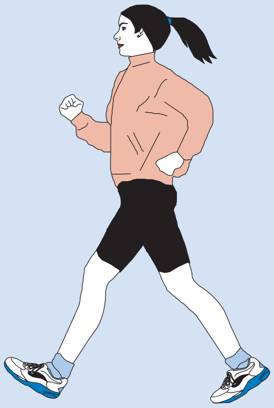
From the v/t graph of Paula’s walk determine (by using areas):

(a) Paula’s maximum displacement during her walk.

(b) Paula’s displacement from her original starting point at:

(i) t = 80 s

(ii) t = 100 s



Question 4.8

From graph (c) on the previous page answer the following.

(i) What is the significance of point C?

(ii) What is the acceleration of the motorcycle?

(iii) At what time does the motorcycle draw level with the car?
(Consider areas under each graph.)

Vertical motion

If a body is allowed to fall freely under the influence of gravity then it will accelerate at 9.80 ms^{-2} towards the earth. This means that its velocity will increase by 9.80 ms^{-1} every second (assuming no air resistance).

The equations of motion can be applied to falling bodies. If we use $v = u + at$ and $s = ut + ½at^2$ we arrive at the data shown below.

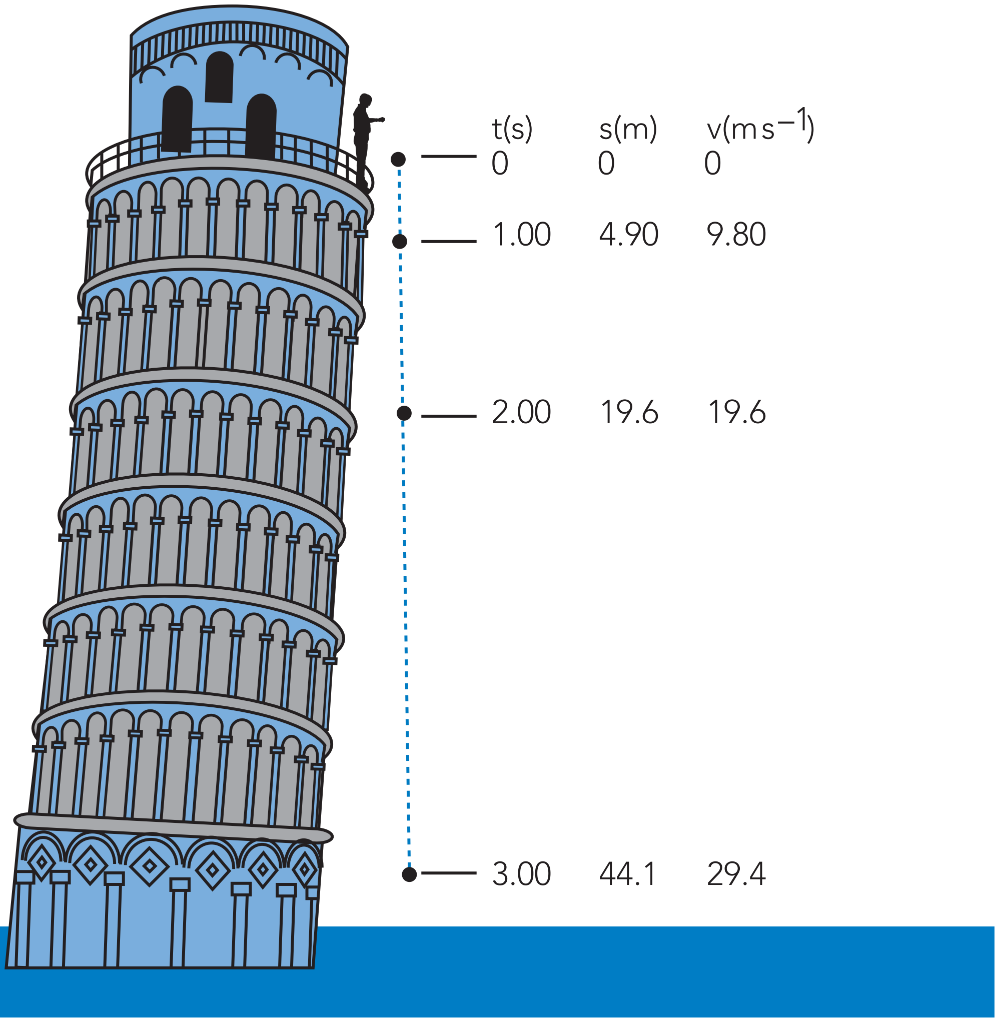


Figure 4.3 *Falling bodies.*

Falling bodies – motion graphs

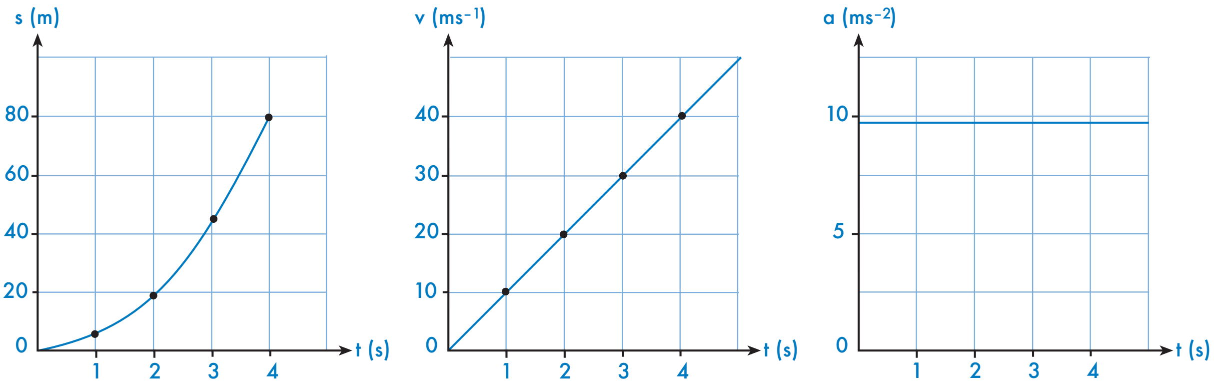
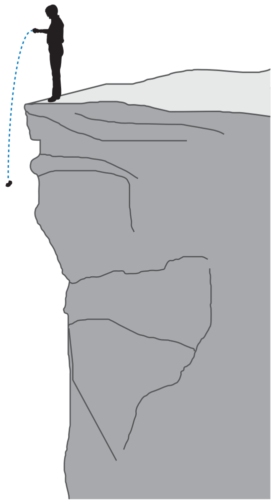


Figure 4.4 *Motion graphs for first four seconds of free fall. The s/t graph is parabolic and shows that* $s \alpha t^2$*. The v/t graph is linear, showing* $v \alpha t$ *while the a/t graph shows that a is constant while a body is in freefall.*

Worked Example 4.12

A rock is dropped from the edge of a cliff and it hits the river below 4.0 s later. Ignoring any effects from air resistance determine:



(a) its final velocity prior to hitting the water
(b) its average velocity during its fall
(c) the distance travelled by the rock.

$u = 0$
$v = ?$
$v_{av} = ?$
$s = ?$
$a = 9.8 \text{ ms}^{-2}$
$t = 4.0 \text{ s}$

(a) $v = u + at = 0 + (9.8)(4.0)$

$\therefore$ final velocity = 39.2 ms^{-1} downwards

(b) $v_{av} = \frac{u + v}{2} = \frac{0 + 39.2}{2}$

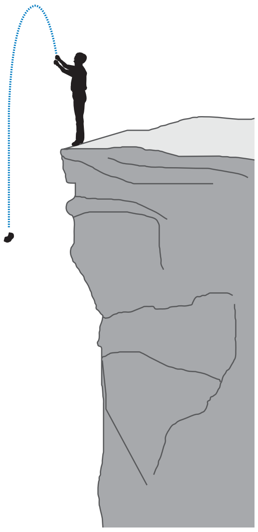
$\therefore$ average velocity = 19.6 ms^{-1} downwards

(c) $v_{av} = \frac{s}{t} \quad \therefore s = (v_{av})(t) = (19.6)(4) = 78.4 \text{ m}$

Note: We could have also found s using $s = ut + ½ at^2$
$= 0 + (½)(9.8)(4)^2 = 78.4 \text{ m}$

Worked Example 4.13

Suppose the rock in Ex. 4.12 had initially been thrown vertically upwards with a velocity of 12.0 ms^{-1}. Determine:



(a) the time it would take to reach its maximum height
(b) the average velocity of the rock while reaching its highest point
(c) the height reached above its point of release
(d) the rock's final velocity when it reaches the river below (78.4 m below release point).

For this problem consider upwards as being positive.

(a) $u = 12.0 \text{ ms}^{-1}$
$v = 0$
$a = -9.80 \text{ ms}^{-2}$
$t = ?$

$v = u + at$

$\therefore t = \frac{v - u}{a} = \frac{0 - 12}{-9.80} = 1.22 \text{ s}$

(b) $v = 0$
$u = 12.0 \text{ ms}^{-1}$
$v_{av} = ?$

$v_{av} = \frac{u + v}{2}$

$= \frac{12 + 0}{2} = 6.00 \text{ ms}^{-1}$

CAREFUL!
We are dealing with vector quantities so signs (+ or –) must be consistent for your variables. In this problem we have taken upwards as being positive.

(c) $v_{av} = 6.0\ ms^{-1}$

$s = ?$

$t = 1.2245$

(from previous calculation)

$$v_{av} = \frac{s}{t}$$

$$s = (v_{av})(t)$$

$$= (6.0)(1.2245)$$

$$= 7.35\ m$$

Alternate Methods:

$u = 12.0\ ms^{-1}$

$v = 0$

$a = -9.80\ ms^{-2}$

$s = ?$

$t = 1.22\ s$

(A) $v^2 = u^2 + 2as$

$$\therefore s = \frac{v^2 - u^2}{2a}$$

$$= \frac{0 - (12)^2}{(2)(-9.80)}$$

$$= 7.35\ m$$

or (B) $s = ut + \tfrac{1}{2}at^2$

$$= (12.0)(1.22) + (\tfrac{1}{2})(-9.80)(1.22)^2$$

$$= 7.35\ m$$

(d) Consider the fall from maximum height to the river below:

$u = 0$

$v = ?$

$a = -9.80\ ms^{-2}$

$s = -(7.35 + 78.4)$

$= -85.7\ m$

$v^2 = u^2 + 2as$

$= 0 + (2)(-9.80)(-85.75)$

$v = \pm 41.0\ ms^{-1}$

$= -41.0\ ms^{-1}$

(i.e. travelling downwards)

Alternate Method:

Consider the motion of the rock from the time it was released to when it just hits the water.

$u = 12.0\ ms^{-1}$

$v = ?$

$a = -9.80\ ms^{-2}$

$s = -78.4\ m$

$v^2 = u^2 + 2as$

$= (12)^2 + (2)(-9.80)(-78.4)$

$v = \pm 41.0\ ms^{-1}$

$= -41.0\ ms^{-1}$ (going down)

Question 4.9

Except at very low speeds, air resistance does affect the acceleration of falling bodies.

(a) What two main factors might affect the magnitude of this air resistance?

(i) ____

(ii) ____

(b) In what ways would the shapes of each of the graphs in Figure 4.4 be different if the effects of air resistance were considered?

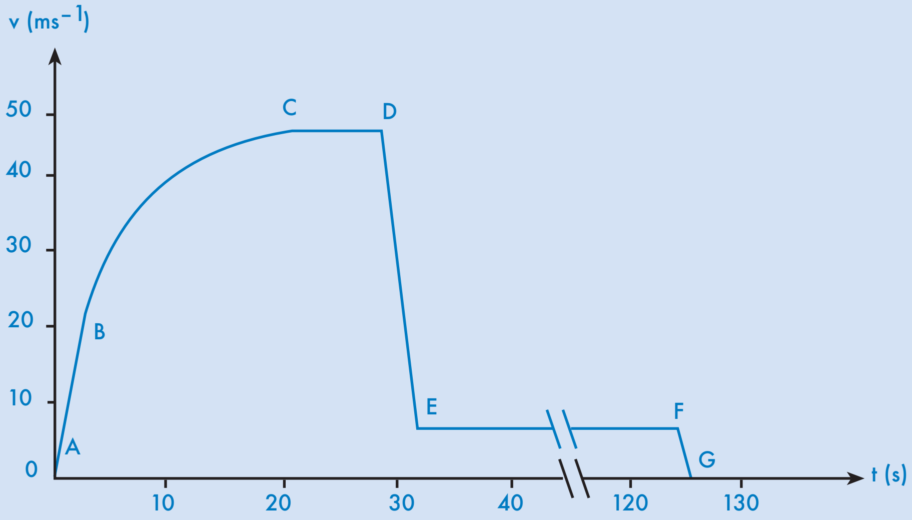
(i) s/t graph ______________________________

(ii) v/t graph ______________________________

(iii) a/t graph ______________________________

Question 4.10

The graph of the motion of a skydiver is represented below. The skydiver firstly goes into free fall without opening his parachute and achieves a maximum velocity (terminal velocity). The parachute is then opened and finally the ground is reached.



(a) Describe the motion for each section of the graph.

(i) A → B ______________________________

(ii) B → C ______________________________

(iii) C → D ______________________________

(iv) D → E ______________________________

(v) E → F ______________________________

(vi) F → G ______________________________

(b) Estimate from the graph:

(i) the height from which the skydiver fell

____

____

(ii) the skydiver's maximum acceleration prior to hitting the ground

____

____

(iii) how far the skydiver was from the ground when the parachute opened

____

____

(iv) the skydiver's terminal velocity with the parachute unopened.

____

____

4.2 FORCES AND THEIR EFFECTS

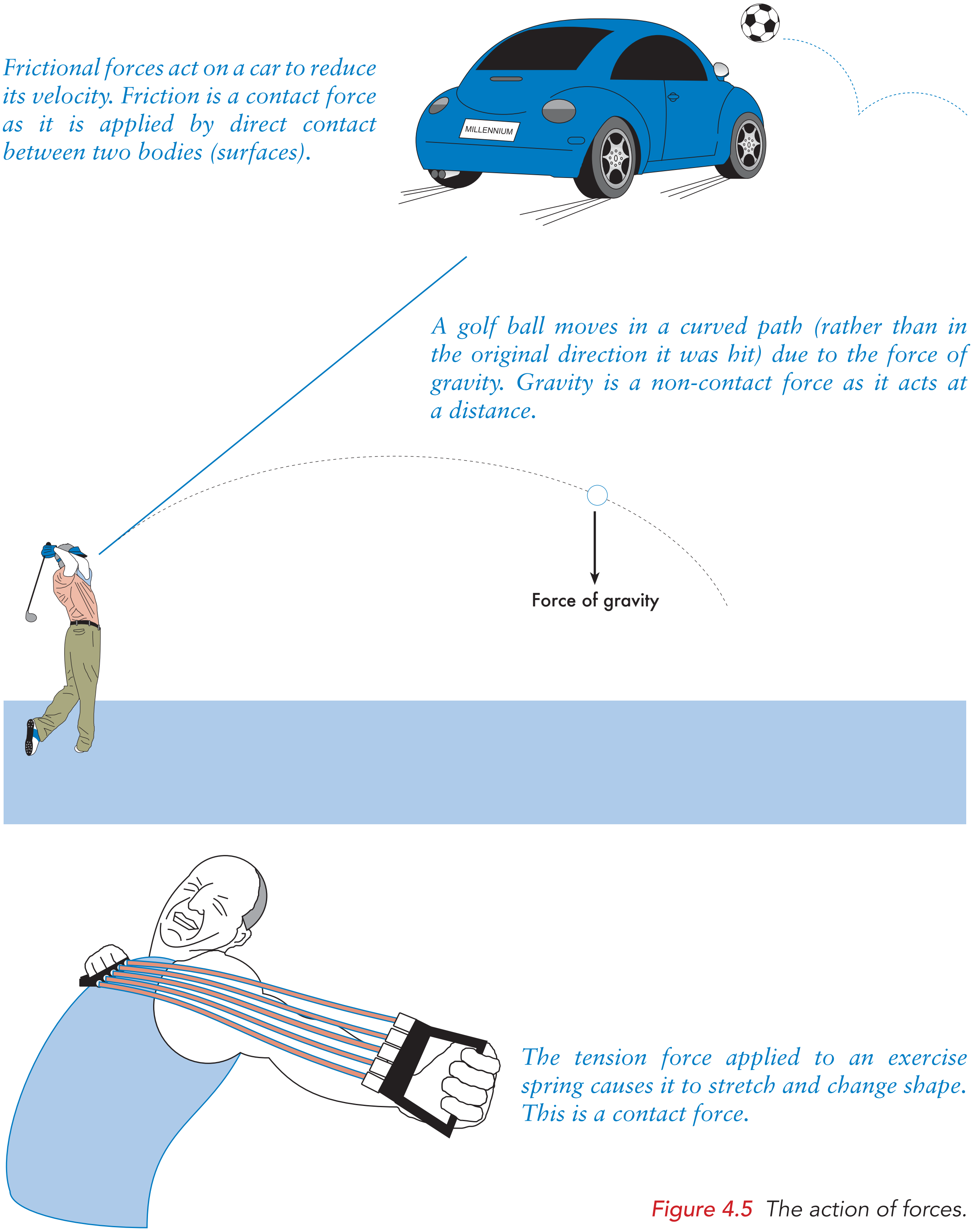
Force

A force can be simply described as a push or a pull acting on a body. There are many different types of forces that exist in every day situations such as the force of gravity, frictional forces, tension forces in a spring and electrical forces.

Some forces act on contact, such as the frictional force between your shoes and the ground as you walk; while others such as gravity act at a distance.

When a force is exerted on a body it will cause a change in its state of motion. A force acting on a body can cause any or all of the following:

- a change of speed, such as a car braking to a stop,
- a change of direction of motion, such as the parabolic flight of a golf ball under the influence of gravity,
- a change of shape, such as an exercise spring being pulled apart.



Frictional forces act on a car to reduce its velocity. Friction is a contact force as it is applied by direct contact between two bodies (surfaces).

A golf ball moves in a curved path (rather than in the original direction it was hit) due to the force of gravity. Gravity is a non-contact force as it acts at a distance.

The tension force applied to an exercise spring causes it to stretch and change shape. This is a contact force.

Figure 4.5 *The action of forces.*

Representing forces – vectors

Forces have direction as well as magnitude (size). Hence they are vector quantities and can be represented using arrows. Using vectors it is possible to determine the overall effect of two or more forces acting on a body (see also vector addition page 97).

Worked Example 4.14

Adding forces using vectors

In each of the following cases, forces of 200 N and 150 N are acting as shown by a free body diagram. The resultant force is determined using a vector diagram.

1)

Situation
(Free body diagram)

Vector diagram

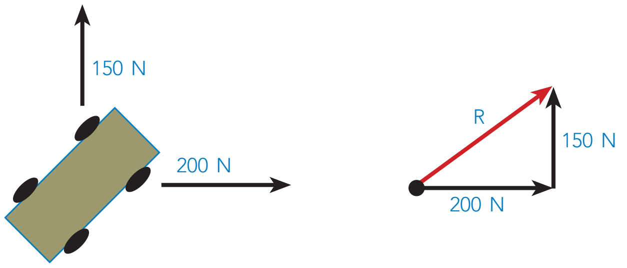
Resultant

R = 350 N East

2)

R = 120 N East

3)*



*R = 250 N 37°N of E (N37°E)

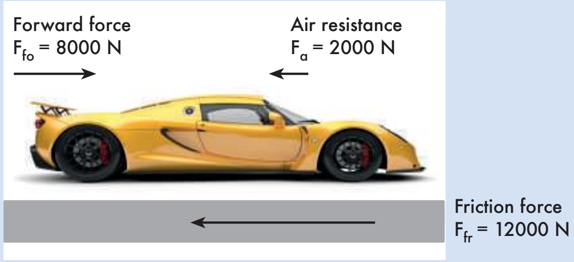
*This resultant is calculated using trigonometry
ie. $R^2 = (200)^2 + (150)^2$
and Tan $\theta = 150/200$

Note: (i) R always begins at the tail of first vector; always ends at the head of the last vector.
(ii) R indicates the magnitude and direction of the resultant (net) force.

Question 4.11

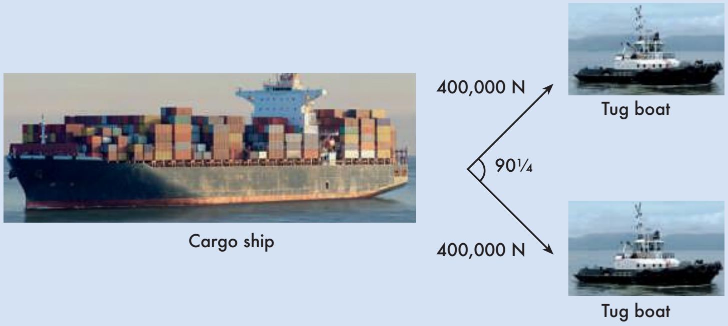
Draw vector diagrams to determine the resultant force in each of the situations below. Which way is the body accelerating?

(a)



(b)

(c)



Newton's First Law of Motion

The state of motion of bodies will only change if a net force (external) is applied to them. Newton's First Law of Motion deals with this idea and states:

> *"Every body continues in its state of rest, or of uniform motion in a straight line, unless acted upon by an external unbalanced force."*

This law is often referred to as the Law of Inertia. The larger the mass the larger the inertia. Inertia is the tendency of an object to remain at rest (or in uniform straight line motion) unless acted upon by an external unbalanced force.

Newton's First Law of Motion can be used to explain many everyday situations.

Situation 1

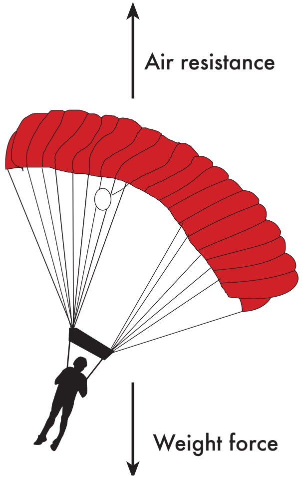
Passengers in a bus lurch forward as the bus brakes suddenly.

Explanation (using First Law)

Passengers are continuing their state of forward motion since there is no restraining force acting upon them. Seat belts can provide such a restraining force.

Situation 2

A parachutist falling to earth reaches a constant steady velocity.

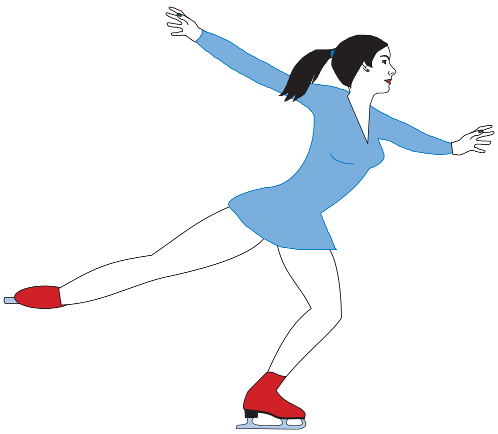


Explanation (using First Law)

The total of all the forces acting on the skydiver and his parachute is zero at terminal velocity. Therefore, there is no net external force acting and hence uniform motion results.

Situation 3

A skater gliding on ice.



Explanation (using First Law)

A skater on ice will continue to move easily over the ice unless an external force causes her to stop. This force could be generated by digging the skates into the ice or if the skater runs into another person or the skating ring.

Figure 4.6 *Newton's First Law of Motion.*

Question 4.12

Use the First Law of Motion to explain the following:

(a) You are a passenger in a car about to move off from a set of traffic lights. As the car accelerates forward you appear to move backwards.

____

(b) A moving car will come to a stop, even on a level road, if the engine is turned off.

____

Momentum – "the quantity of motion"

Any moving object has acquired momentum. This momentum is the product of mass times velocity and is a vector quantity having the same direction as the velocity.

$$p = m v$$

p = momentum (kg ms^{-1})
m = mass (kg)
v = velocity (ms^{-1})

Momentum can be thought of as the tendency of a body to keep on moving. It depends on both mass and velocity.

For example, it is more difficult to stop a heavy truck than a light car travelling at the same speed. A cricket ball travelling at high velocity is also harder to stop then one moving slowly.

Whenever an unbalanced external force is applied to a body its velocity will change and hence its momentum will also change. Newton's Second Law deals with this concept.

Newton's Second Law of Motion

Newton's First Law of Motion tells us that a body's state of motion will not change without a net external force being applied. The Second Law of Motion describes what effect such a force would have.

In its original form the second law states that "the rate of change of momentum of a body is proportional to the applied force and occurs in the direction of that force."

Mathematically, this can be stated as $F = \frac{\text{change of momentum}}{\text{time}} = \frac{mv - mu}{t} = \frac{m(v - u)}{t}$

Since $a = \frac{v - u}{t}$ this leads to:

$$F_{net} = m a$$

F = net force acting on mass m (N)
m = mass (kg)
a = acceleration (ms^{-2})

The relationship F = ma, which we have derived from the Second Law of Motion, is a very useful one and can be used to define the unit of force, the **newton**.

Since F = ma, a force of 1 newton is one which will accelerate a mass of 1 kilogram at 1 ms^{-2} in the direction of the force.

$$\mathbf{1\ newton = 1\ N = 1\ kg\ ms^{-2}}$$

The relationship F = ma also helps us to restate Newton's Second Law of Motion in a simpler way.

We can see that since:

$$a = \frac{F}{m} \quad \text{then} \quad \text{(i) } a\ \alpha\ F \ \text{ and } \ \text{(ii) } a\ \alpha\ \frac{1}{m}$$

Hence, in its more familiar form, Newton's Second Law of Motion states that:

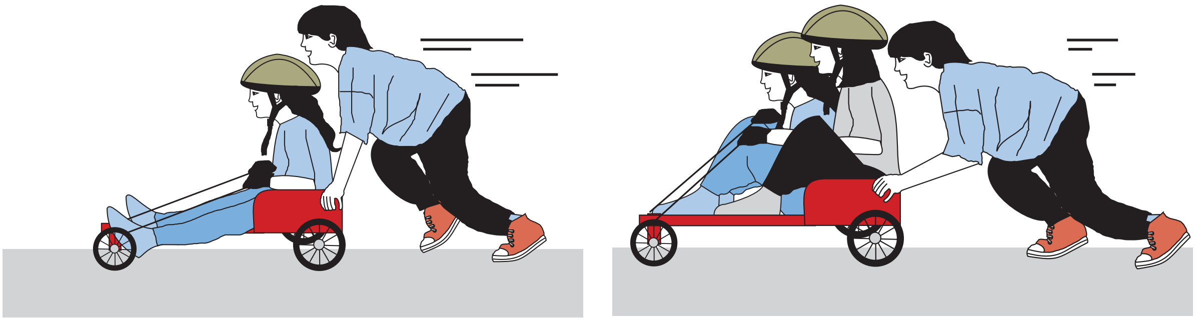
> *"The acceleration of a body is directly proportional to the net external force applied to it and inversely proportional to its mass."*

(i) $a\ \alpha\ F$

(a) (b)

The car in (b) will move off more quickly than the car in (a) since a greater force is applied.

(ii) $a\ \alpha\ \frac{1}{m}$



(c) (d)

The heavy cart (d) will move off much more slowly than cart (c) since its mass is greater.

Figure 4.7 Newton's Second Law of Motion.

Worked Example 4.15

A medium sized sedan with passengers and luggage has a mass of 1.15×10^3 kg. It accelerates from rest to 60 kmh^{-1} in 8.50 seconds. Determine:

(a) Its average acceleration.
(b) The average force applied.
(c) The momentum at its final speed.

$m = 1150$ kg
$u = 0$
$v = 60\ \text{kmh}^{-1}$
$= 16.7\ \text{ms}^{-1}$
$t = 8.50$ s
$a = ?$
$F = ?$
$p = ?$

(a) $a = \frac{v - u}{t} = \frac{16.7 - 0}{8.50} = 1.96\ \text{ms}^{-2}$

(b) $F = ma = (1150)(1.96) = 2.25 \times 10^3$ N

(c) $p = mv = (1150)(16.7) = 1.92 \times 10^4\ \text{kg ms}^{-1}$

Worked Example 4.16

The sedan in the previous example slows down from 60 kmh^{-1} to 20 kmh^{-1} in 3.50 seconds. Determine:

(a) The change in momentum.
(b) The rate of change of momentum.
(c) The average force acting while braking.

$u = 60\ \text{kmh}^{-1}$
$= 16.7\ \text{ms}^{-1}$
$v = 20\ \text{kmh}^{-1}$
$= 5.56\ \text{ms}^{-1}$
$m = 1150$ kg
$t = 3.50$ s
$\Delta p = ?$
$\Delta p/t = ?$
$F = ?$

(a)

$$\Delta p = mv - mu = 1150\,(5.56 - 16.7) = -1.28 \times 10^4\ \text{kg ms}^{-1}$$

(b) The rate of change of momentum

$$= \frac{-1.28 \times 10^4}{3.5}$$

$$\frac{\Delta p}{t} = -\,3.66 \times 10^3\ \text{kg ms}^{-2}$$

(c) From 2nd Law of Motion

$$F = \frac{\Delta p}{t}$$

$$= -\,3.66 \times 10^3\ \text{N}$$

Question 4.13

What is the significance of the negative (–) sign in the answers in Ex. 4.16 above?

Impulse – Change in momentum

As we have seen, an external force acting on a body can change its velocity and hence its momentum. The longer the force acts the greater the change in momentum.

The effect of a force on the momentum of a body is called the impulse of a force. Impulse is a vector quantity having the same direction as the change in momentum.

Impulse = Ft = mv – mu

Impulse, I = Force × time

= change in momentum

Units of Impulse = Ns or kg ms$^{-\circ 1}$

Worked Example 4.17

A resultant force of 35000 N acts vertically upwards on a 12 tonne rocket for 25 seconds. Find:

(a) Impulse.
(b) Change in momentum.
(c) Final velocity (if u = 0).

u = 0
F = 35000 N
m = 12 tonne
= 1.2×10^4 kg
t = 25 s
I = ?
Δ p = ?
v = ?

(a) Impulse = Ft
= (35000)(25)
= 8.75×10^5 Ns upwards

(b) Change in momentum
Δ p = Impulse
= 8.75×10^5 Ns upwards

(c) $\Delta p = mv - mu = m(v - u)$
$8.75 \times 10^5 = (1.2 \times 10^4)(v - 0)$
$\therefore v = 72.9$ ms^{-1} upwards

Worked Example 4.18

Suppose that in a car accident a passenger hits the padded dashboard at 70 kmh^{-1} and remains in contact with it for 0.55 s as he comes to a stop. Assume the passenger has a mass of 65 kg. Find:

(a) The impulse on the passenger.
(b) The magnitude of the average force exerted by the dashboard on the passenger.

u = 70 kmh^{-1}
= 19.4 ms^{-1}
v = 0
t = 0.55 s
I = ?
F = ?

(a) Impulse = Ft
= mv – mu
= 65(0 – 19.4)
= -1.26×10^3 Ns

(b) $Ft = -1.26 \times 10^3$

$$\therefore F = \frac{-1.26 \times 10^3}{0.55}$$

$= -2.29 \times 10^3$ N

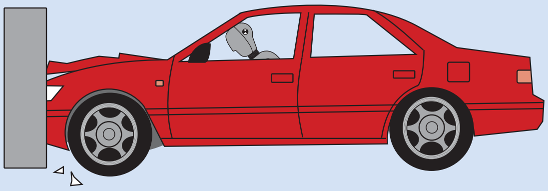
The magnitude of the average force between passenger and dashboard is 2.29×10^3 N.

Question 4.14

If the passenger (in Ex. 4.18) had hit the windscreen instead of the dashboard the contact time would have been much shorter (say 0.10 s). Under these conditions determine:

(a) Impulse.

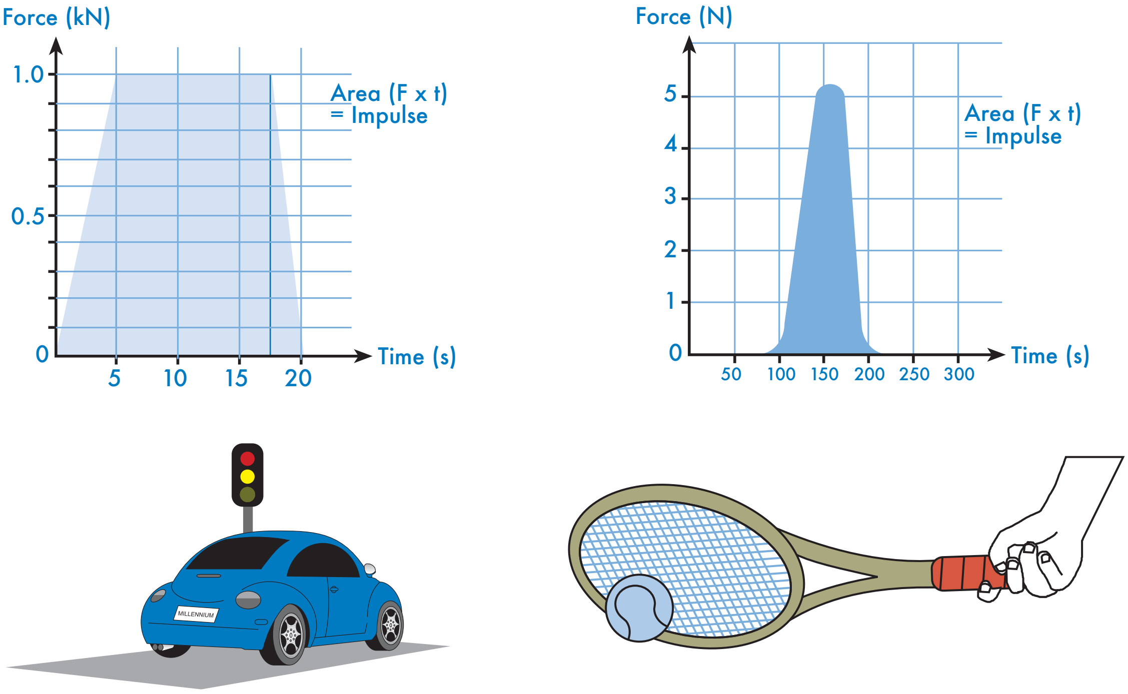
(b) Force of the windscreen exerted on the passengers.



Impulse – Force/Time graphs

Impulse can be given to a body over a very short time period, as in a collision, or over a much longer period, as in the steady acceleration of a car.

We can determine the change in momentum (impulse) from the area under a force versus time graph.



(a) A small car accelerating from a set of lights. *(b) A tennis ball being hit with a racquet.*

Figure 4.8 *Force – Time graphs.*

Worked Example 4.19

The small car represented in the graph Figure 4.8(a) has a mass of 960 kg. Use the graph to determine:

(a) Its change in momentum after 5.0 seconds.
(b) The total impulse received after 20 seconds.
(c) The car's velocity after 20 seconds.

(a) Change in momentum (or impulse) is given by area under the graph

At t = 5 $\Delta p = (½)(5 \times 1000) = 2500$ Ns

(b) At t = 20 total $\Delta p = 2500 + (12.5)(1000) + (½)(2.5)(1000)$

$= 2500 + 12500 + 1250$

$= 1.6 \times 10^4$ Ns (in direction of force)

(c) Since $\Delta p = mv - mu$

$16250 = 960\ (v - 0)$

$v = 17\ ms^{-1}$

Question 4.15

Use the graphs in Figure 4.8 to determine:

(a) At which time/s the car was undergoing its greatest acceleration.

(b) The maximum impulsive force exerted on the tennis ball by the racquet.

(c) The approximate change in velocity of the tennis ball if we assume its mass is (50 g).

Reducing Collision Force

Collisions can result in large impact forces which can cause damage to our bodies. Bones may break, ligaments can tear and vital organs affected.

To **reduce** the force caused by a collision we need to **increase** the impact time.

Since $\Delta p = I = Ft$

An increase in the time (t) taken to lose our momentum (Δp) causes a corresponding decrease in the average impact force (F).

There are many safety devices that make use of this idea including seatbelts, airbags, crash helmets and cushioned sports shoes. Modern cars are also designed to crumble at the front and rear in a way which increases the time taken to lose momentum.

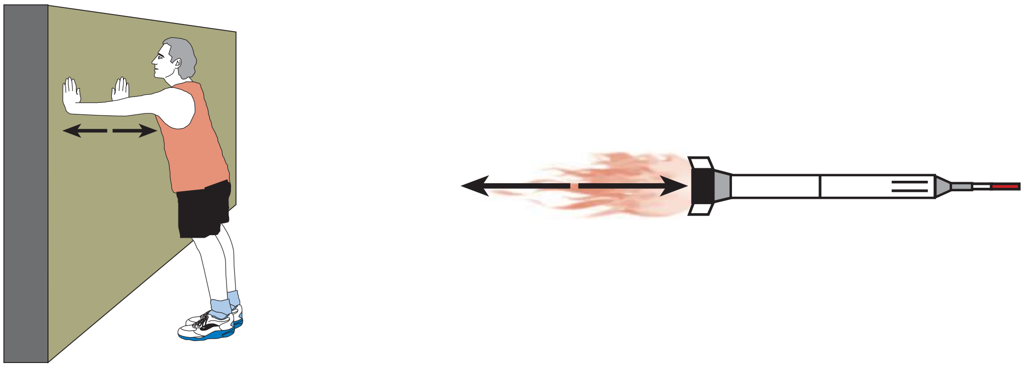
Newton's Third Law – Action and Reaction

Newton's Third Law of Motion simply states that:

> *"For every action there is an equal and opposite reaction".*

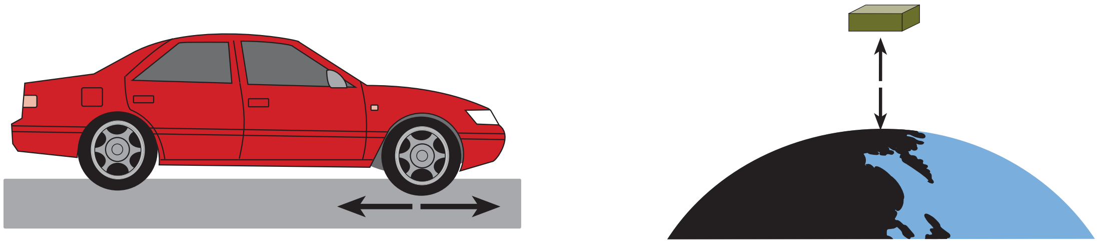
This means that whenever one body exerts a force (an action) on a second body, the second body exerts an equal and opposite force (a reaction) on the first. Consequently all forces act in pairs.

It may at first glance appear that since all forces act as equal and opposite pairs no motion could ever be possible. However, each force is acting on a different body and will affect each of these bodies differently depending upon their mass and the effect of any other forces that may be acting on them.



a) When a person pushes on a wall (action), the wall pushes back on the person with an equal and opposite force (reaction).

b) The rocket is pushing out gas particles (action) while the gas particles are pushing the rocket (reaction).



c) The car tyre is pushing the ground (action) and hence the ground is pushing the tyre (reaction).

d) The earth attracts the falling brick (action) and the brick attracts the earth with an equal and opposite force (reaction).

Figure 4.9 Newton's Third Law of Motion.

Question 4.16

Briefly describe the action and reaction forces involved in each of the following situations.

(a) Bowling a cricket ball.

(b) Diving into a pool (falling).

(c) Resting on a couch.

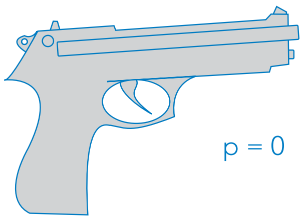
Question 4.17

When you kick a football, the force exerted by your foot on the ball is equal to that exerted by the ball on your foot. How then is it possible for the ball to move off with any speed?

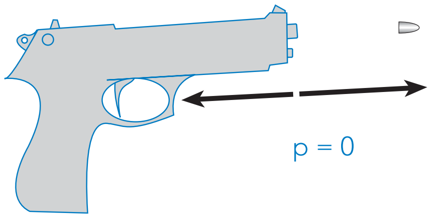
Conservation of Momentum

We have already seen that for a body to change its state of motion, and hence its momentum, an external force is necessary. If we consider any closed system the law of conservation of momentum states that "if no external force acts upon a system its total momentum remains unchanged". This law can be used to explain such occurrences as the following in Figure 4.10:

(a) When fired, a gun will recoil.

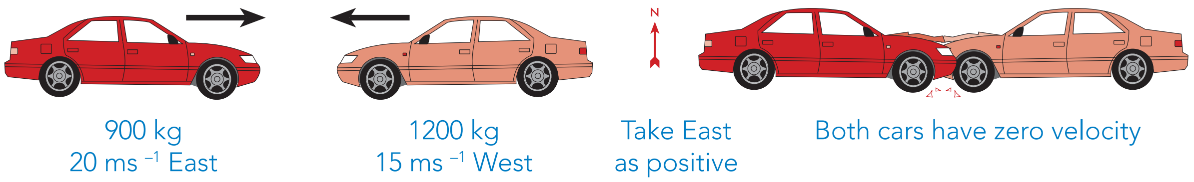


Before firing: *Total momentum of the system (gun + bullet) is zero.*



After firing: *Total momentum of the system (gun + bullet) is still zero. Note that momentum is a vector quality.*

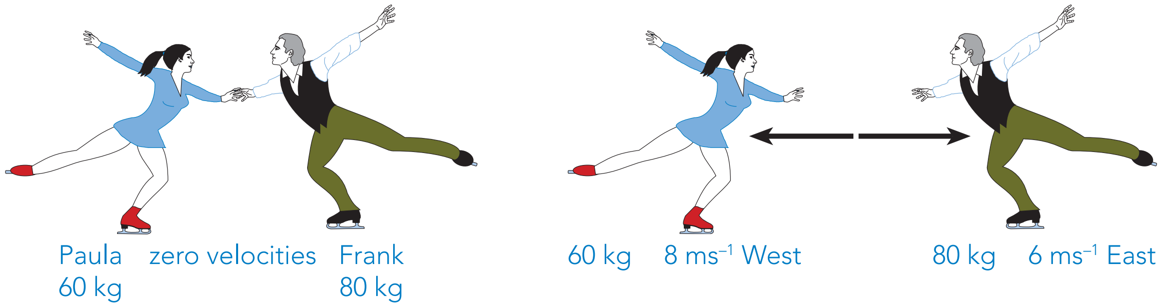
(b) When two cars of equal and opposite momentum collide their final velocity will be zero.



Before collision:
$p = (900)(20) + (1200)(–15)$
$= 0$

After collision:
$p = 0$

(c) When two skaters of different masses push each other apart, they move off with different velocities.



Before pushing:
Total momentum (Paula + Frank) is zero

After pushing:
$p = (60)(–8) + (80)(6)$
$= 0$

Figure 4.10 *Conservation of momentum.*

Conservation of momentum – calculations

For calculations involving the interaction of two bodies or collisions, the law of conservation of momentum can be best expressed as:

$$p_i = p_f$$

$$m_1 u_1 + m_2 u_2 = m_1 v_1 + m_2 v_2$$

p_i = initial momentum
p_f = final momentum
m_1 = mass 1
m_2 = mass 2
u_1 = initial velocity of mass 1
u_2 = initial velocity of mass 2
v_1 = final velocity of mass 1
v_2 = final velocity of mass 2

Worked Example 4.20

A model railway wagon of mass 150 g is moving at 4.00 ms^{-1} East towards a wagon of mass 200 g which is at rest. The two wagons lock together on collision and continue to move. Determine the velocity of the combined wagons assuming no effects from friction.

$m_1 =$ 0.150 kg
$m_2 =$ 0.200 kg
$u_1 =$ 4.00 ms^{-1} East
$u_2 =$ 0
$v_1 =$?
$v_2 =$?

$$v_1 = v_2$$

since wagons lock together

$$p_i = p_f$$

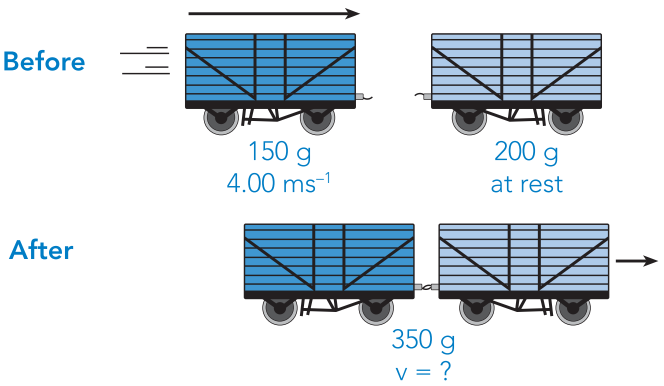
$$m_1u_2 + m_2u_2 = m_1v_1 + m_2v_2$$

$$(0.150)(4.00) + 0 = (0.350)(v)$$

$$v = 0.60/0.350$$

$$= 1.71\ \text{ms}^{-1}$$

It is always best to begin with a before and after sketch for these types of problems.



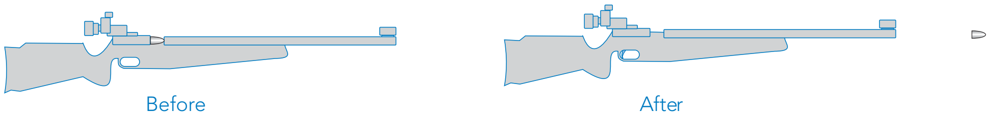
Worked Example 4.21

If a rifle of mass 4.40 kg fires a bullet of mass 50.0 g with a velocity of 550 ms^{-1} East. What will be its recoil velocity?

$$m_1 = 4.40\ \text{kg}$$
$$m_2 = 5.00 \times 10^{-2}\ \text{kg}$$
$$u_1 = 0$$
$$u_2 = 0$$
$$v_2 = 550\ \text{ms}^{-1}\ \text{East}$$
$$v_1 = ?$$

$$p_i = p_f$$
$$m_1u_1 + m_2u_2 = m_1v_1 + m_2v_2$$
$$0 = (4.40)(v_1) + (5.00 \times 10^{-2})(550)$$
$$-v_1 = \frac{27.5}{4.40} = 6.25\ \text{ms}^{-1}$$
$$v_1 = -6.25\ \text{ms}^{-1}$$

The recoil velocity of the gun is 6.25 ms^{-1} West.



Worked Example 4.22

A ball of mass 400 g hits the ground with a velocity of 8.4 ms^{-1} and bounces back upwards with a velocity of 6.0 ms^{-1}.

(a) Is momentum conserved? Explain.

(b) Calculate the ‘recoil’ velocity of the Earth. (Assume the Earth was initially at rest and that its mass is 6.0×10^{24} kg).

(a) The ball’s momentum changes. However, the Earth gains an equal and opposite momentum so that the total momentum of the Earth-ball system is conserved.

(b)

$$m_1 = 0.400\ \text{kg}$$
$$m_2 = 6.0 \times 10^{24}\ \text{kg}$$
$$u_1 = 8.4\ \text{ms}^{-1}$$
$$u_2 = -6.0\ \text{ms}^{-1}$$
$$v_1 = 0$$
$$v_2 = ?$$

$$p_i = p_f$$
$$m_1u_2 + m_2u_2 = m_1v_1 + m_2v_2$$
$$(0.400)(8.4)+0 = (0.400)(-6.0)+(6.0 \times 10^{24})(v_2)$$
$$\therefore v_2 = \frac{5.76}{6.0 \times 10^{24}} = 9.6 \times 10^{-25}\ \text{ms}^{-1}$$

Assume down is +ve.

The Earth’s recoil velocity would be extremely small (9.6×10^{-25} ms^{-1} downwards).

Question 4.18

When an inflated balloon is released so that the trapped air inside it can escape, it is noticed that the balloon rushes about wildly. Explain this motion in terms of the law of conservation of momentum.

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Mass and Weight

These two terms are often used synonymously but they have quite different meanings.

Mass is a scalar quantity. It is often simply defined as the quantity of matter in a body. It is measured in kilograms.

The mass of a body is also a measure of its inertia, or resistance to a change in its state of motion. The unit of mass can be defined using $F = m\,a$.

Weight is a vector quantity. It is the force of gravity exerted on a body and is measured in newtons (N).

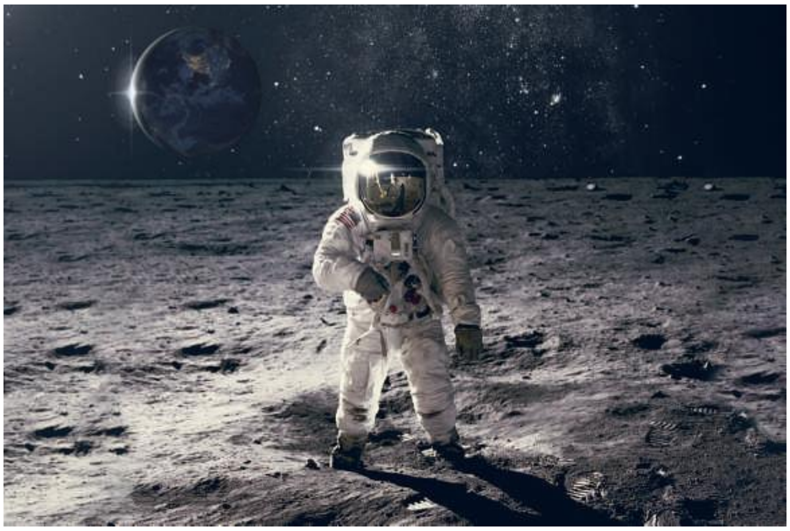
The weight of a body will vary with the strength of the gravitational field it finds itself in. For example a body will weigh much less on the Moon than on Earth. Mass, however, remains constant.

The weight of a body is given by:

$$W = mg$$

W = weight of body
m = mass of body
g = gravitational field strength, N kg^{-1}
(or acceleration due to gravity, ms^{-2})

g = 9.8 ms^{-2} on Earth's surface
= 1.6 ms^{-2} on Moon's surface
= 24.6 ms^{-2} on Jupiter's surface



Worked Example 4.23

The mass of a small four-wheel drive is 1150 kg. Determine:

(a) Its weight (i) on the Earth, (ii) on the Moon.

(b) Its horizontal acceleration (i) on earth, (ii) on the Moon when a constant horizontal force of 3.00×10^3 N is applied. Assume no friction.

(a) (i) $W = m\,g = (1150)(9.8) = 1.13 \times 10^4$ N (on Earth)

(ii) $W = m\,g = (1150)(1.6) = 1.84 \times 10^3$ N (on the Moon)

(b) Note: The mass of the body being accelerated will also be the same.

$$\therefore\ a = \frac{F}{m} = \frac{3000}{1150} = 2.61\ \text{ms}^{-2}$$

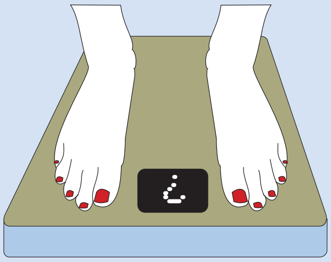
Question 4.19

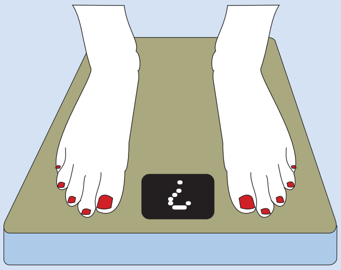
Michelle has a mass of 52.0 kg.

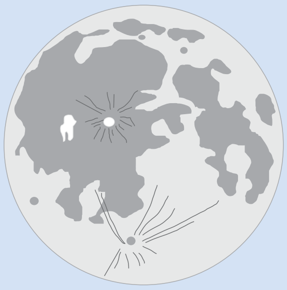
(a) What is her weight on Earth?

(b) What would be her weight on the Moon?

(c) What would her bathroom scales (which are calibrated in kg) read on the Moon?







4.3 WORK – ENERGY – POWER

Work

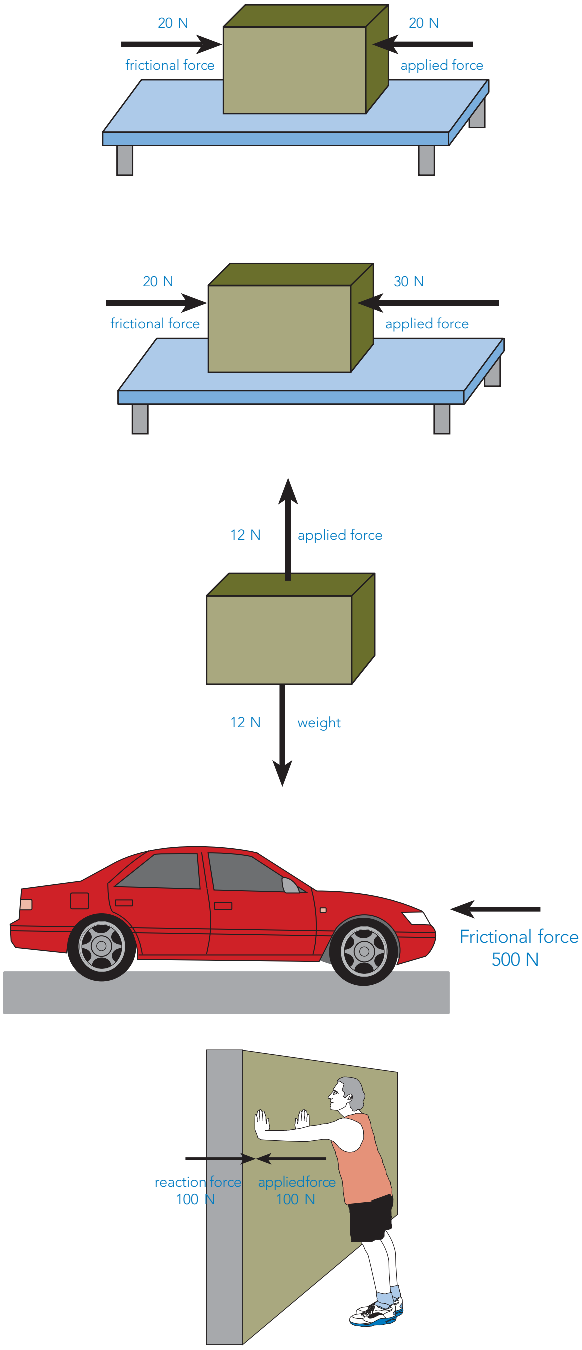
Work is said to be done when a force moves its point of application in the direction of the force. The work done on an object is the product of the applied net force multiplied by the displacement of the object in the direction of the force.

$$W = Fs$$

W = Work done, joules (J)
F = Force, newtons (N)
s = displacement, metres (m)

Work is a scalar quantity and measured in joules (J) or newton metres (Nm). In reality the work done is a measure of the energy used to carry out the work. This energy is transferred to the body that work is being done on.

Common examples:



A box is pushed across a bench at a constant velocity.
Work is being done by the applied force against friction. The energy used is transformed into heat, sound and deformation of surfaces. However no work is being done on the box as the net force acting on the box is zero and there is no change in its kinetic energy.

A box is accelerated across a bench.
As before, work is being done to overcome friction but in this case the applied force also in order to gives the box kinetic energy. The work done on the box will be equal to the increase in kinetic energy.

A box is lifted a height (h) at a constant velocity.
Work is being done against the force of gravity (F = mg). and hence the energy used becomes potential energy (mgh). There is no increase in the kinetic energy of the body as the net force acting is zero.

A moving car is brought to a standstill.
The work done is equal to the loss of kinetic energy of the car (½mv^2). This energy is transformed into heat, sound and deformation of surfaces.

A wall is pushed but does not move.
No work is being done on the wall although you may get tired. Unless a body moves in the direction of the applied force work is not being done on that body. Your energy is mostly doing work internally on your body which results in heat and some sound. Deformation of contact surfaces (shoes, floor etc.) may also occur.

Figure 4.11 The concept of work.

Energy

Energy is an abstract concept and can be best defined as the ability to do work. Like work, energy is a scalar quantity and is measured in joules (J). Whenever work is done there is a transfer of energy.

There are many forms of energy such as nuclear energy, heat energy, light energy, chemical energy and electrical energy. However for this topic we will consider only mechanical energy, that is, energy due to a body's position or motion.

Kinetic Energy (E_K) is the energy possessed by a body due to its motion. If a force is applied to a body its velocity will change and there is an increase in E_K. The work done on the body ($W = F\ s$) is equal to the change in energy possessed by the body ($W = \Delta E$).

Potential Energy (E_P) is the energy possessed by a body due to its position. This can be due, for example, to forces being exerted on it by a gravitational field, an electrical field or a magnetic field. Potential energy can be thought of as stored energy. Due to its position, the body has the ability to do work. A coiled spring, for example, has elastic potential energy and can do work if released.

In this topic we will only consider gravitational potential energy.

In summary we have:

$$W = \Delta E$$

$$E_K = \tfrac{1}{2} mv^2$$

$$E_P = m\,g\,h$$

W = Work done
ΔE = change in energy
E_K = kinetic energy (J)
E_P = potential energy (J)
m = mass (kg)
v = velocity (ms^{-1})
g = acceleration due to gravity ($9.80\ ms^{-2}$)
h = vertical height (m)

A tennis ball has potential energy due to its position in a gravitational field. If released, the force of gravity will do work on it. This work (W) is equal to the loss in potential energy (mgh). It is also equal to the gain in kinetic energy (½ m v²).

$W = \Delta E$ *(work done by gravitational field)*
$mgh = \tfrac{1}{2} m v^2$

An arrow released from a bow has kinetic energy (E_k) due to its motion. This energy was gained by the release of the elastic potential energy initially possessed by the drawn bow. The tension force on the bow acted on the arrow and transferred energy to it.

$W = \Delta E = \tfrac{1}{2} m v^2$ *(work done by bow)*

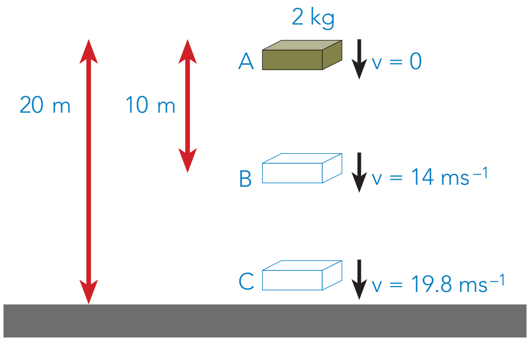
Figure 4.12 *The relationship between work and energy.*

Conservation of Energy

Energy is never lost in the real sense as it is only converted from one form to another.

A good example is the conversion of potential energy to kinetic energy as a body is allowed to fall freely from some given height.

Consider the energy of a 2.00 kg mass falling from a height of 20.0 m. (Assume air resistance is negligible.)



At position A: $E_P = 392$ J, $E_K = 0$, $E_T = 392$ J

At position B: $E_P = 196$ J, $E_K = 196$ J, $E_T = 392$ J

At position C: $E_P = 0$, $E_K = 392$ J, $E_T = 392$ J

Note: C is the point just prior to the body hitting the ground

Figure 4.13 *Conversion of potential energy to kinetic energy.*

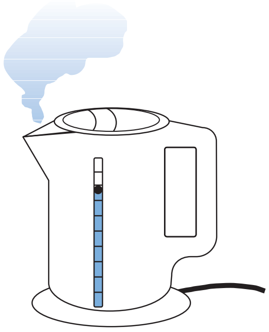
Power

Power is defined as the rate of doing work. Alternatively power is the rate at which energy is consumed.

$$P = \frac{W}{t} = \frac{\Delta E}{t}$$

$$\text{also } P = \frac{F.s}{t} = Fv_{av}$$

P = power (Js^{-1} or Watts)
W = work (J)
ΔE = change in energy
t = time (s)
F = force (N)
v_{av} = average velocity



Some common power ratings:

A 60 W globe	60 W
A car engine	30 kW
A kettle	1.25 kW
A 2 bar heater	2.4 kW
1 HP engine	746 W
A power station	500 MW

Force-displacement graphs

If force applied is graphed against displacement then the area under the graph represents the work done.

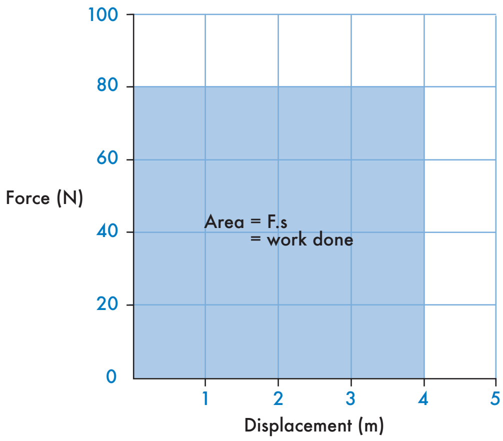


Figure 4.14 *Graphing F versus s.*

The area under the graph is equal to the work done. In this case W = Fs = 80 × 4 = 320 J. This also represents the ΔE of the body, that is, the gain in kinetic energy.

Worked Example 4.24

A 20 kg block initially at rest has a force of 30 N applied to it for 5.0 seconds. Assume that the force of friction is constant and is 20 N. Find:

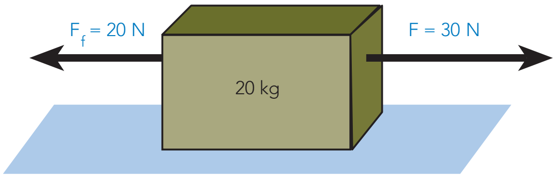
(a) The velocity after 5 seconds.
(b) The kinetic energy after 5 seconds.
(c) Work done by the 30 N force in this time.
(d) Why are (b) and (c) not equal?

(a)

$$\begin{array}{rcl@{\qquad}rcl} F(\text{nett}) & = & 10\text{ N} & F & = & ma \\ m & = & 20\text{ kg} & \therefore a & = & F/m = 10/20 \\ u & = & 0 & & = & 0.50\text{ ms}^{-2} \\ a & = & ? & \text{also } v & = & u + at \\ t & = & 5.0\text{ s} & & = & 0 + (0.5)(5) \\ v & = & ? & & = & 2.5\text{ ms}^{-1} \end{array}$$

(b)

$$\begin{aligned} E_K &= \tfrac{1}{2}mv^2 \\ &= (\tfrac{1}{2})(20)(2.5)^2 \\ &= 62.5\text{ J} \end{aligned}$$



(c)

$$\begin{aligned} s &= ut + \tfrac{1}{2}at^2 \\ &= 0 + (\tfrac{1}{2})(0.50)(5)^2 \\ &= 6.25\text{ m} \end{aligned}$$

hence

$$\begin{aligned} W &= Fs \\ &= (30)(6.25) \\ &= 187.5\text{ J} \end{aligned}$$

(d) Much of the work has been done to overcome friction and has been converted to heat (etc.) rather than kinetic energy.

Worked Example 4.25

Ben is practising his weightlifting by lifting a 160 kg barbell a distance of 1.90 m from the floor. He completes the lift in 1.25 s, holds the barbell for about 3 seconds and then allows it to drop to the floor.

(a) How much work has Ben done in lifting the barbell?
(b) What is Ben's power rating during his lift?
(c) How much potential energy does the barbell have while being held up?
(d) When the barbell is dropped what maximum velocity will it gain?

(a)

$$\begin{aligned} W = F.s = m\,g\,h &= (160)(9.8)(1.90) \\ &= 2.98 \times 10^3\text{ J} \end{aligned}$$

(b)

$$P = \frac{W}{t} = \frac{2.98 \times 10^3}{1.25} = 2.38 \times 10^3\text{ W}$$

(c) Work done = Potential energy gained

$$\therefore \quad E_P = 2.98 \times 10^3\text{ J}$$

As barbell falls

$$\begin{aligned} E_K\text{ gained} &= E_P\text{ lost} \\ \tfrac{1}{2}\,m\,v^2 &= m\,g\,h \\ v^2 &= 2\,g\,h = (2)(9.8)(1.90) \\ v &= 6.10\text{ ms}^{-1} \end{aligned}$$

Worked Example 4.26

A car of mass 1120 kg is travelling at 80.0 kmh^{-1} and slows down to 30.0 kmh^{-1} as it approaches a road works site. The car's reduced speed is achieved by applying the brakes over a distance of 100.0 m. Determine:

(a) The car's initial kinetic energy.
(b) The work done by the brakes in slowing the car down.
(c) The average force applied by the brakes.

(a) E_K = ?
m = 1120 kg
v = 80 kmh^{-1}
= 22.2 ms^{-1}

$E_K = \frac{1}{2}mv^2$
$= (\frac{1}{2})(1120)(22.2)^2$
$= 2.76 \times 10^5$ J

(b) $W = \Delta E_K$
u = 80 kmh^{-1}
= 22.2 ms^{-1}
v = 30 kmh^{-1}
= 8.33 ms^{-1}

Work done = Change in kinetic energy
$= E_{K\ (initial)} - E_{K\ (final)}$
$= (\frac{1}{2})(1120)(22.22)^2 - (\frac{1}{2})(1120)(8.33)^2$
$W = 2.76 \times 10^5 - 3.89 \times 10^4$
$= 2.38 \times 10^5$ J

(c) $W = 2.37 \times 10^5$ J
F = ?
s = 100 m

$W = Fs$
$F = \dfrac{W}{s} = \dfrac{2.38 \times 10^5}{100}$
$= 2.38 \times 10^3$ N

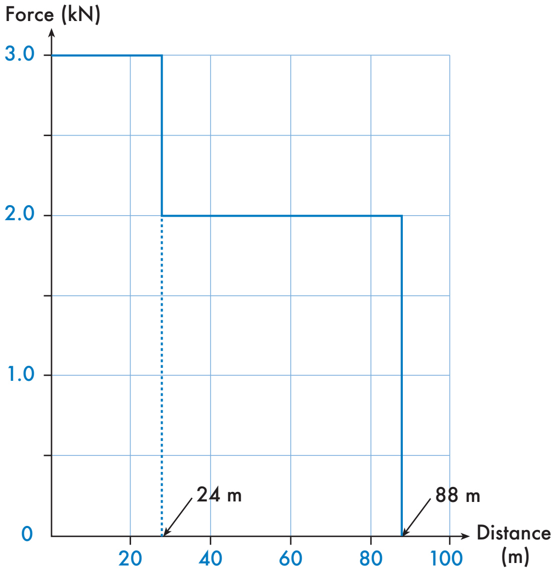
Worked Example 4.27

The idealised graph below shows the driving force acting on a small hatchback as it moves off from a set of lights. The 1000 kg car is accelerated by a constant force of 3000 N for the first 24 m and then by a constant force of 2000 N for the next 64 m as shown on the graph.

(a) How much work is done on the car during its first 24 m of travel?
(b) Assuming no effects from friction what is the car's velocity when it has travelled 88 m?
(c) If the car has taken 8.0 seconds to cover 88 m what is its average effective power output?

(a) E_K = ?
Work = Force × distance
(Area under graph)
= (3000)(24)
$= 7.2 \times 10^4$ J

(b) s = 88 m
m = 1000 kg
v = ?
E_K = Work done
= Area under graph
Total work done
= Area under graph
= (3000)(24) + (2000)(64)
= 72000 + 128000
$= 2.0 \times 10^5$ J
$\therefore \frac{1}{2}mv^2 = 2.0 \times 10^5$
$v^2 = \dfrac{(2.0 \times 10^5)(2)}{1000}$
v = 20 ms^{-1}



(c)

$$P = ?$$
$$W = 2.0 \times 10^5 \text{ J}$$
$$t = 8.0 \text{ s}$$

$$P = \frac{W}{t} = \frac{2.0 \times 10^5}{8.0}$$

$$= 2.5 \times 10^4 \text{ W}$$

or $= 25$ kW

Question 4.20

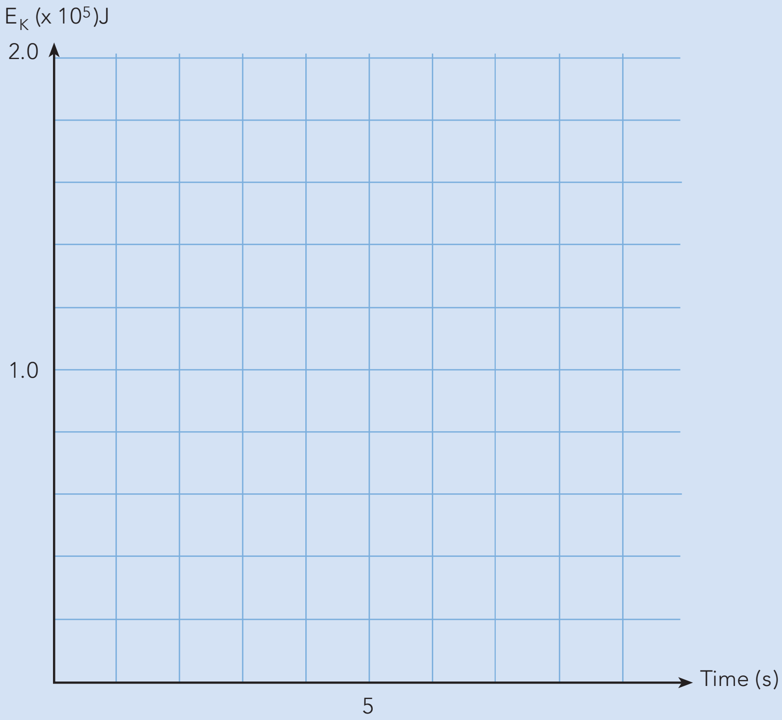
(a) Use the information from the previous problem to draw an E_K versus time graph for the small hatchback given that it accelerated uniformly:

- at 3.0 ms^{-2} for the first 4.0 seconds
- at 2.0 ms^{-2} for the next 4.0 seconds

(b) Use your completed graph to determine the power output of the car at

(i) t = 2.0 s

(ii) t = 6.0 s



REVIEW QUESTIONS

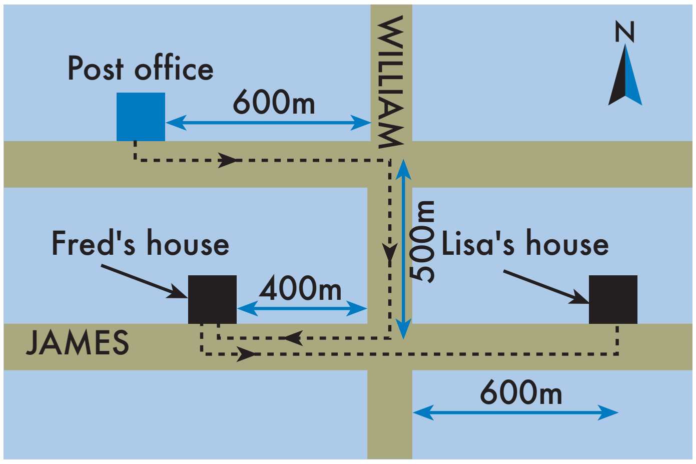
Chapter 4: Linear Motion and Force

4.1 Motion in a straight line

1. Indicate whether each of the following is true or false. Alter any false statement so that they are true.
   - (a) Velocity is the rate at which distance is travelled.
   - (b) A vector quantity has both magnitude and direction.
   - (c) The gradient or slope of a v/t graph indicates the displacement of a body at that point.
   - (d) The velocity of a falling body increases 9.8 ms^{-1} every second ignoring air resistance.
   - (e) A ball thrown vertically upwards in the air will experience zero acceleration at the top of its flight.

2. Differentiate between:
   - (a) distance and displacement;
   - (b) speed and velocity.

3. Lisa collects a parcel from the Post Office, walks 600 m East then turns South into William Street. On reaching James Street she walks 400 m West where she delivers the parcel at Fred's house. Lisa then walks East along James Street towards her house as shown.



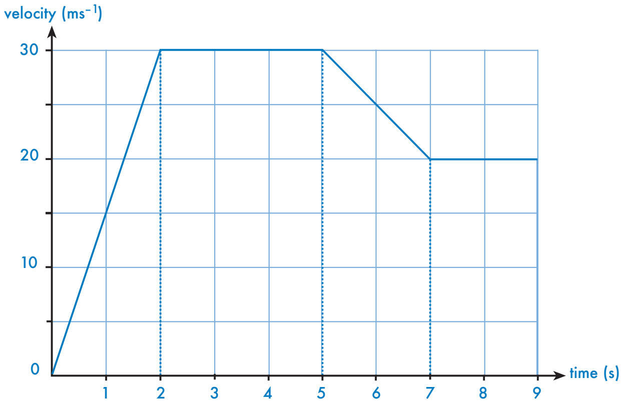
   - (a) Calculate the total distance that Lisa walked from the Post Office to her house.
   - (b) Calculate her total displacement (magnitude only) from the Post Office to her house.

4. During a physics experiment to determine the average velocity of a dynamics trolley, Sally obtained the following data:

TIME (s)	0	1	2	3	4	5
DISPLACEMENT (cm)	0	0.8	1.6	2.4	3.2	4.0

   - (a) Draw a displacement-time graph using this data.
   - (b) Use the graph to determine the average velocity of the trolley.

5. A vehicle started from rest at t = 0 and continued moving in a straight line for 9 s. An analysis of its motion is represented in the graph below:



(a) Briefly describe the vehicle's motion throughout the 9 s time interval.
(b) Calculate the vehicle's displacement after 9 s.
(c) Compare the vehicle's acceleration for the first 2 s with that for the interval between the 5th and 7th second.

6. When Ivan drove his car around a tight bend on a narrow mountain road a 5 kg piece of luggage was dislodged from the car's roof rack. The piece of luggage just rolled beneath the road's safety barrier and fell vertically down a ravine. On returning to the point where the piece of luggage fell into the ravine Ivan noticed that a 1 kg stone took 5 s from rest to reach the bottom of the ravine. Calculate the depth of the ravine.

7. Amelia, standing near the edge of a bridge walkway which is 10 m above a river, throws a small stone 20 m vertically into the air. Calculate the:
(a) initial velocity with which the stone left her hand, and
(b) the time taken for the stone to reach the water (ignore any effects due to friction).

8. Explain the difference between a scalar quantity and a vector quantity.

9. Classify the following quantities as either a scalar quantity or a vector quantity.

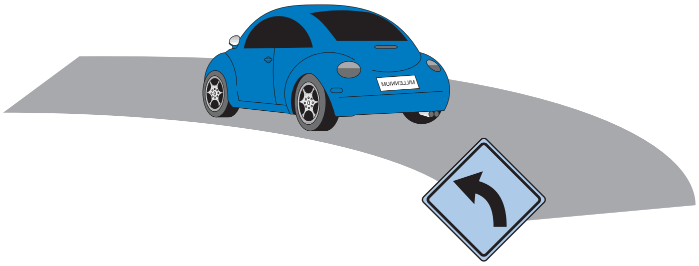
distance, force, mass, displacement, acceleration, velocity, volume, time

4.2 Forces and their effects

10. Indicate whether each of the following is true or false. Alter any false statement so that they are true.
(a) Forces can act in contact and at a distance.
(b) When an external unbalanced force is applied to a body its velocity will change.
(c) When a bus brakes suddenly passengers tend to lurch forward due to forward forces.
(d) Safety air bags in a car reduce impact forces on passengers by decreasing the impact time for them to stop during a collision.
(e) When two ice-skaters of different mass push each other apart with their hands the forces they exert on each other are equal.

11. A young child is restrained in a shopping trolley at a supermarket when the child's older brother pushes the trolley from rest with a force of 15 N. If the child's older sister simultaneously applies a force of 10 N on the trolley in the same direction, calculate the total force received by the trolley and child.

12. If the trolley and young child in question 11 received a retarding force of 3 N when the child's older brother pushes the trolley from rest with a force of 15 N, calculate the total force received by the trolley and child.

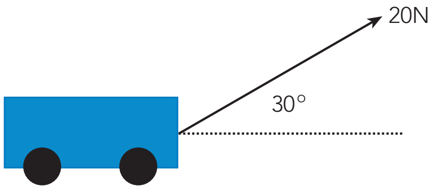


13. A car being driven North at 12 ms^{-1} rounds a corner so that it is now being driven West at 16 ms^{-1}. Calculate the change in velocity of the car.

14. John is a passenger on a train which has a velocity of 60 kmh^{-1}. Calculate John's velocity, relative to the ground if he walks towards the
    (a) front of the train at 2 kmh^{-1}.
    (b) back of the train at 2 kmh^{-1}.

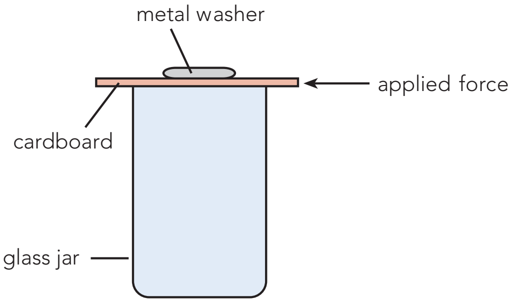
15. An athlete was running due East at 5 ms^{-1} when a southwesterly wind blowing at 2 ms^{-1} changes both his speed and the direction in which he was running. Calculate the magnitude of his new velocity.

16. A force of 20 N is applied to a small cart at an angle of 30° above the horizontal. Calculate the horizontal and vertical components of the force.



17. List four effects produced by forces.

18. Jayesh places a metal washer on a piece of cardboard which rests on top of a glass jar as shown in the diagram.
    (a) Predict what will happen to the washer when Jayesh quickly flicks the cardboard with his finger.
    (b) Explain your prediction.



19. State Newton's First Law of Motion.

20. When driving her car at a constant velocity of 60 kmh^{-1} on a flat road Mary found it necessary to keep her foot on the car's accelerator. Is Newton's First Law of Motion being broken? Why?

21. Chris was sitting in the dining car of the Indian Pacific train pouring himself a cool drink from a bottle into a glass standing on the table. As he was doing this the train braked quickly. Chris was quite proud that he was still able to hold the mouth of the bottle above the glass (which he prevented from moving) as the train braked.
   (a) Why was Chris proud of this achievement?
   (b) Would you expect all of the cool drink to pour into the glass during the braking?

22. State Newton's Second Law of Motion.

23. When observing the world land speed record for a vehicle a journalist was heard to say "the rapid increase in acceleration could cause the driver's internal stomach organs to receive enough force to produce severe stomach pains". Is the physics in this statement strictly correct? Explain your answer.

24. Kim was driving his car home after doing some shopping when he missed the turn-off to his street. Without thinking he braked hard causing his car to stop quickly. He looked into the back of the car to find that an egg carton, full of eggs, that he just bought at the shop had dislodged itself from the back seat onto the floor. On inspecting the carton he was surprised to find that not one egg was broken.

   Explain why:
   (a) the egg carton fell to the floor during braking, and
   (b) the material used in the egg carton prevented the eggs from breaking.

25. State Newton's Third Law of Motion.

26. Jacky and Susan were keen to enter the running races in the school sports. Neither had used starting blocks before and both decided to try them during a practice session. Susan attached her starting blocks to the ground with a peg while Jacky did not attach her starting blocks to the ground. Which runner is most likely to have the best start from their starting blocks? Explain your answer.

27. Li played squash in hard, flat soled shoes and after most games he suffered from sore feet and legs. When he switched to wearing soft, thick rubber soled shoes while playing squash, he no longer got sore feet and legs. Use Newton's Second Law of Motion to explain why the soft, thick rubber soled shoes did not cause sore feet and legs.

28. A journalist writing about the safety features of a recently released car wrote "the purpose of the air bag is to reduce injury to the driver if the car is involved in a collision". Briefly explain how the air bag can reduce injury to the driver.

29. A 80 kg ice skater moving at 3 ms^{-1} on wet ice collides with an ice skater of mass 60 kg moving in the opposite direction at 5 ms^{-1}. If the skaters hold hands and continue moving in the same straight line after the collision, calculate their common velocity.

30. Peta, a keen softball player, was having difficulty hitting the ball hard and therefore past nearby fielders. She was advised that her problem was related to her failure to 'follow through' when striking the ball. Explain why to 'follow through' is important in Peta's case.

31. Calculate the force on Vic's hand if he catches a 0.1 kg ball moving at 10 ms^{-1}. It is estimated that the ball came to rest 0.1 s after hitting Vic's hand.

32. In question 12 a shopping trolley with a young child in it is being pushed from rest with a force of 15 N against a retarding force of 3 N. This force is applied for 4 s. If the trolley and the young child have a combined mass of 60 kg, calculate
    (a) the acceleration of the trolley and child,
    (b) the change in momentum of the trolley and child, and
    (c) the distance travelled by the trolley and child during the time the force was applied.

33. Define the terms (a) mass, and (b) inertia.

4.3 Work, Energy, Power

34. Indicate whether each of the following is true or false. Alter any false statement so that they are true.
    (a) Work is being done when a box is pushed across a bench at a constant velocity.
    (b) Potential energy is possessed by a body due to its motion.
    (c) A car travelling at 40 kmh^{-1} has twice as much kinetic energy as when it travels at 20 kmh^{-1}.

(d) Work can be determined from the area under a force/time graph.
(e) Power is the rate at which work is being done.

35. A crane lifts a 1500 kg car 3.0 m vertically to place it onto the tray of a transport carrier truck. Calculate the:
(a) force exerted, and
(b) work done by the crane.

36. Theresa was driving her car of total mass 1500 kg at 60 kmh^{-1} on a level road when she released her foot from the accelerator, put the gear into neutral and 'free-wheeled' along the road until the car stopped (Not a wise thing to do!). Calculate the:
(a) initial kinetic energy of the car,
(b) stopping force (assume to be constant) if the car travelled 120 m before stopping,
(c) time taken to stop, and
(d) work done in stopping the car.

37. A small truck of mass 8000 kg is being passed on the freeway by a car of mass 1600 kg. If at the point of passing the car is travelling at 100 kmh^{-1} and has the same kinetic energy as the truck, what is the truck's velocity?

38. A toy car of mass 100 g is powered by a spring mechanism. If the energy transfer is 100% efficient and the potential energy of the spring at the moment the car is released is 2.0 J, calculate the speed with which the car can travel.

39. Jane threw a dart of mass 50 g into a block of soft wood. The block of mass 1.0 kg, was suspended freely by a length of fishing line before being hit by the dart. Andrew observed that the block with the dart in it swung to one side and rose a vertical distance of 40 cm. Calculate the speed of the dart when it hit the block.

40. Alan had difficulty pushing a peg of mass 200 g which was used to hold a rope to his tent into the ground so he decided to jump onto the peg. He jumped to a height of 30 cm and landed vertically on top of the peg which was 15 cm above the ground. To his dismay the peg only moved 9.0 cm into the ground.

If Alan has a mass of 45 kg, find:
(a) his energy just before impact with the peg.
(b) his velocity just before impact with the peg.

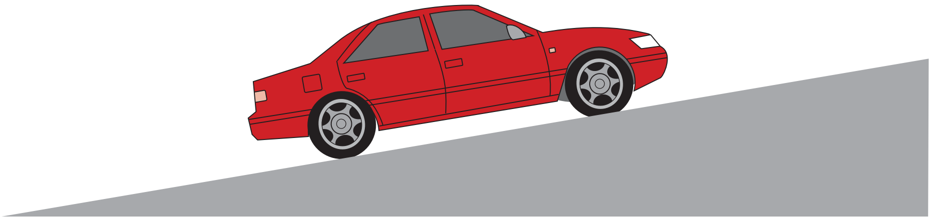
(c) the velocity of the peg after impact if Alan's velocity after the impact is the same as that of the peg.
(d) the energy loss due to the impact.
(e) the average force of friction due to the ground which acted on the peg.

41. During a physics experiment to measure the power necessary to run up a flight of stairs, Maree recorded a time of 10 s for Shirley to run up the stairs. The two girls also recorded the following data:

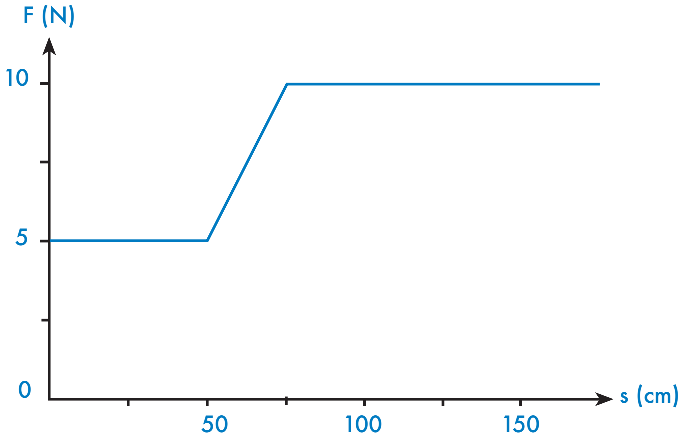
Shirley's mass = 50 kg
number of steps climbed = 30
height of each step = 25 cm

Calculate:
(a) the work done by Shirley, and
(b) her power output on reaching the top of the stairs.

42. Sam drives his car of mass 1500 kg up a 10° hill. The force due to gravity along such an incline is given by $m \times g \times \sin 10°$. Given that the total resistance due to friction is 200 N and that he is driving the car at a constant speed of 15 ms^{-1}, calculate the power developed by his car's engine.



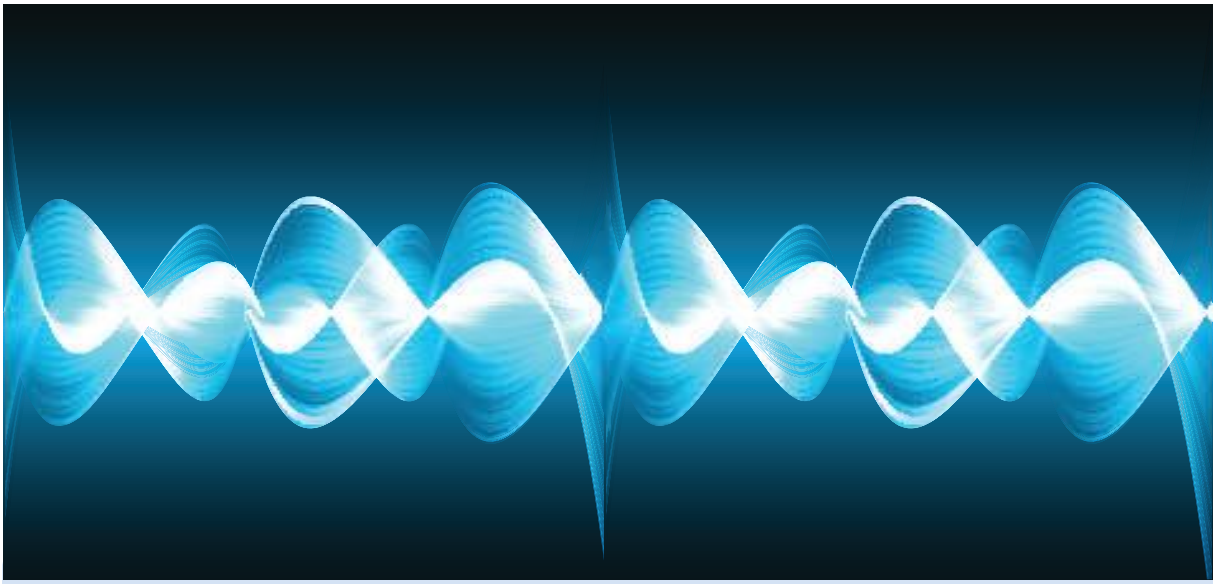
43. In a physics experiment Kim applied a force of 5.0 N to a wooden block over a distance 50 cm then increased the force to 10 N. She recorded data for the applied force and the block's displacement to plot the following graph.



Calculate the:
(a) work done in moving the block 150 cm.
(b) average power exerted by Kim if she took 10 s to displace the block 150 cm.

WAVES

5



SYLLABUS CHECKLIST

SCIENCE UNDERSTANDING – WAVES

☐ waves are periodic oscillations that transfer energy from one point to another

☐ mechanical waves transfer energy through a medium; longitudinal and transverse waves are distinguished by the relationship between the directions of oscillation of particles relative to the direction of the wave velocity

☐ waves may be represented by displacement/time and displacement/distance wave diagrams and described in terms of relationships between measurable quantities, including period, amplitude, wavelength, frequency and velocity. This includes applying the relationships:

$$v = f\lambda$$

$$T = \frac{1}{f}$$

☐ the mechanical wave model can be used to explain phenomena related to reflection and refraction, including echoes and seismic phenomena

☐ the superposition of waves in a medium may lead to the formation of standing waves and interference phenomena, including standing waves in pipes and on stretched strings

☐ This includes applying the relationships for:

- strings attached at both ends and pipe open at both ends: $\lambda = \frac{2l}{n}$
- pipe closed at one end: $\lambda = \frac{4l}{(2n-1)}$

☐ a mechanical system resonates when it is driven at one of its natural frequencies of oscillation; energy is transferred efficiently into systems under these conditions

☐ the intensity of a wave decreases in an inverse square relationship with distance from a point source.

This includes applying the relationship: $I \propto \frac{1}{r^2}$

5.1 NATURE OF WAVES

What is a wave?

Some common examples of waves that are part of our everyday life include water waves, sound waves, microwaves, radio waves and light waves. The most important feature of these waves (as with all waves) is that they carry energy and quite often information from one point to another.

Wave motion may be simply defined as a disturbance or vibration which transmits energy without the transport of matter. Mechanical waves, such as sound, are those that travel through a medium due to the vibration of the particles of the medium. Electromagnetic waves, such as light, do not need a medium to travel through. A periodic disturbance at a source will create a progressive wave as the disturbance spreads from the source. A pulse is a single wave or disturbance.

Types of waves

Waves are classified according to the motion of the particles of the medium transmitting them. There are two types – transverse and longitudinal waves.

Transverse waves: Those in which each particle vibrates in a direction perpendicular to that of the energy flow. Examples are light, radio and water waves. Waves set up in a string as shown below are transverse waves.

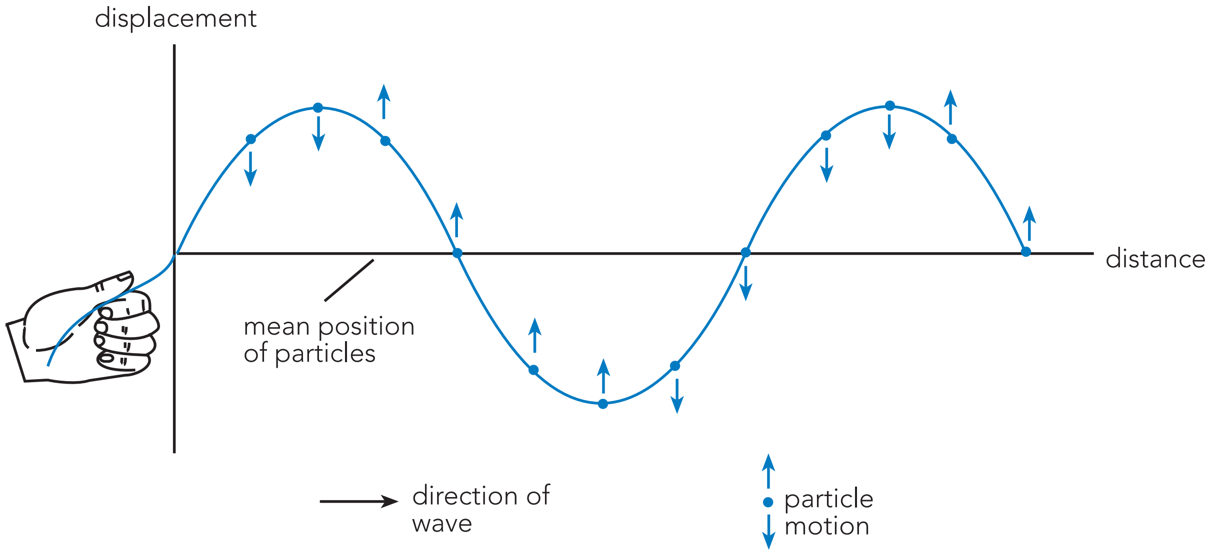


Figure 5.1 Transverse wave motion such as waves in a string. Each point on the wave vibrates at right angles to the direction of the wave.

Longitudinal waves: Those in which the particles vibrate along straight lines parallel to the direction of the energy flow. Example: sound waves.

Longitudinal waves can be set up in a slinky spring as shown below. They can also be created by a vibrating source, such as a loudspeaker. The loudspeaker will cause air next to it to be alternatively pushed away (compression) and drawn back (rarefaction). This sets up a series of pressure changes in the air which can be represented as shown below.

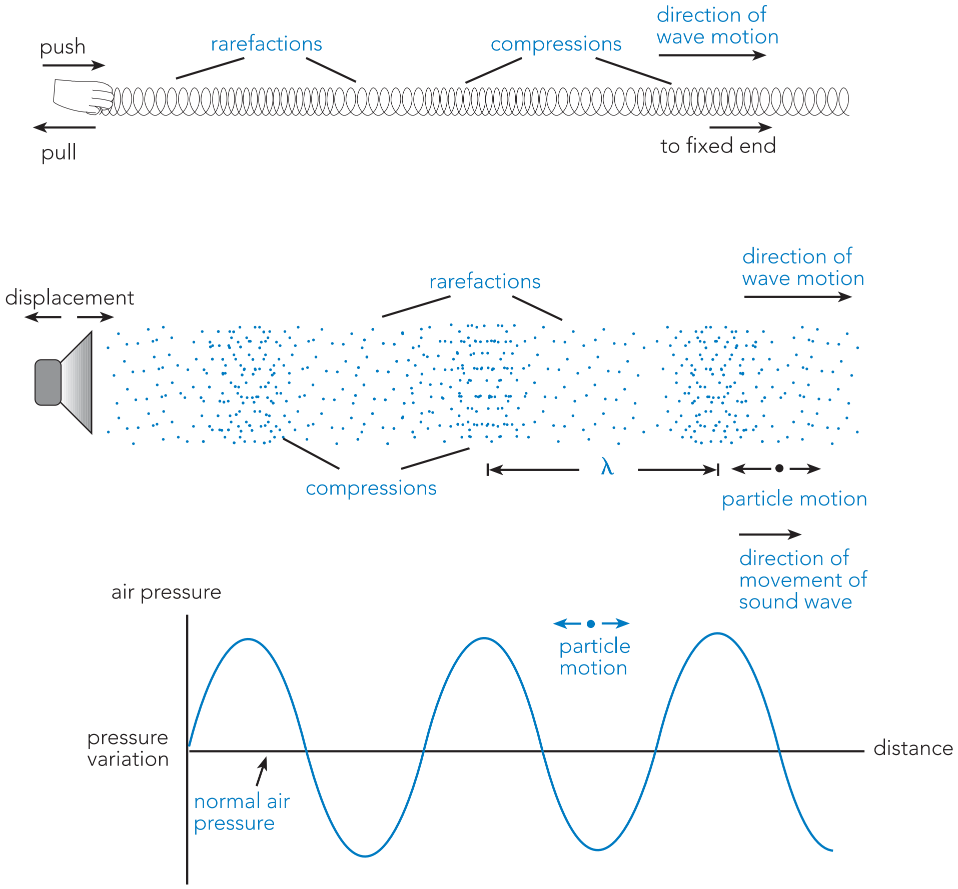


Figure 5.2 Longitudinal wave motion in a slinky spring and in air. Each particle in the wave vibrates back and forth parallel to the direction of the wave. The wave motion can also be represented graphically as shown. However, remember that although we can represent sound waves this way they do not have crests and troughs like transverse waves.

Wave graphs

Wave motion can be represented by a displacement/time graph or a displacement/distance graph.

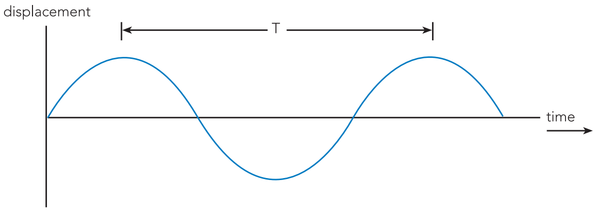


Figure 5.3 Displacement/time graph.

This graph represents the motion of a single particle as a wave passes through it. The crests and troughs represent the particle's maximum displacement from its mean position and the points at which it has zero velocity.

T is the period of vibration.

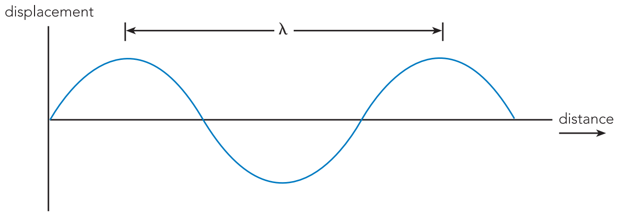


Figure 5.4 Displacement/distance graph.

This graph represents the displacement of a number of particles from their mean position at some instant in time. We can think of it as a "snapshot" which shows how the displacement of the medium varies over the distance from the source.

λ *represents the wavelength of the wave.*

Describing wave motion – Important terms

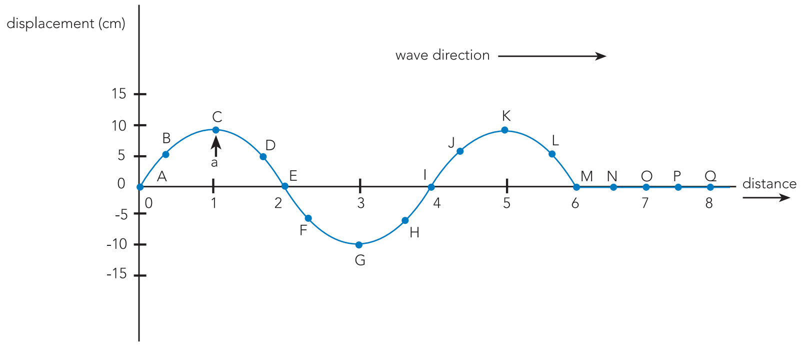


Figure 5.5 Describing the motion of a wave. Several points on the transverse wave shown above are labelled so as to help define the terms used to describe wave characteristics.

Phase: The stage of vibration that a particle has reached in its cycle of motion. Particles are in phase if they are moving in exactly the same manner at the same time. In the wave shown above for example, particles A & I or D & L are in phase, while particles C & G are 180° out of phase.

Wavelength (λ): The distance between any two consecutive points in a wave which are in phase. For example, the distance between points C & K, D & L, etc.

Amplitude (a): The maximum displacement of a particle from its mean position (i.e. height of a crest or depth of a trough). The amplitude of the wave shown above is 10 cm.

Frequency (f): The number of complete vibrations (or waves) per second. The unit of frequency is the hertz (Hz).

Period (T): The time taken to complete one vibration (or to produce one complete wave).

Note: $T = \frac{1}{f}$.

Velocity (v): The speed with which a progressive wave travels through a medium. (See wave equation next page).

Special Note: Individual particle motion must not be confused with wave velocity through a medium. Different particles are moving with different velocities at any given instant. In the wave shown above:

- D is moving upwards while B is moving downwards.
- C has an instantaneous velocity of zero.
- E is undergoing maximum velocity (upwards).

Question 5.1

Complete the following by referring to Figure 5.5. Give units where appropriate.

(a) The wavelength (λ) is ____________________

(b) The amplitude (a) is ____________________

(c) A point in phase with A is ____________________

(d) A point totally out of phase with A is ____________________

(e) Three points with zero velocity are ____________________

(f) A point undergoing maximum upward velocity is ______________________________

(g) If the velocity of this wave is 8.0 ms^{-1}, how long will it be before point Q begins to move? ________________________________

(h) If the frequency (f) of this wave is 2.0 Hz, what is its period (T)?

____

Wave velocity – The wave equation

For any given wave, its velocity, frequency and wavelength are related as shown by the wave equation:

$$v = f\lambda$$

v = wave velocity (ms^{-1})
f = frequency (Hz)
λ = wave length (m)

Velocity (and wavelength) are affected by the medium that a wave is travelling through whereas the frequency is dependent only on its source.

The speed of sound waves in various substances is shown in Table 5.1 below. Where the sound originates from the same source (say a tuning fork of frequency 512 Hz) the frequency remains constant no matter which medium it travels through. The velocity will change however, as will the wavelength by the same proportion.

Table 5.1 Speed of Sound (in selected substances).

SUBSTANCE	VELOCITY (ms-1)	SUBSTANCE	VELOCITY (ms-1)
Gases (25°C, 101.3 kPa)		**Solids** (thin rods)	
air, dry	3.46×10^2	aluminium	5.00×10^3
carbon dioxide	2.69×10^2	brass	3.48×10^3
helium	9.85×10^2	brick	3.65×10^3
nitrogen	3.49×10^2	copper	3.81×10^3
oxygen	3.30×10^2	iron (soft)	5.20×10^3
Liquids (25°C)		cork	5.00×10^2
glycerol	1.90×10^3	glass (crown)	4.54×10^3
benzene	1.31×10^3	iron (cast)	4.48×10^3
water, distilled	1.50×10^3	lead	1.20×10^3
water, sea	1.53×10^3	silver	2.68×10^3

Worked Example 5.1

One of the loudspeakers from a sound system is capable of producing good quality sound in the frequency range of 450 – 4000 Hz. Assuming the speed of sound to be 340 ms^{-1} find:

(a) the maximum distance between compression waves emitted by this speaker;

(b) the smallest time interval between successive compression waves.

$v = 340 \text{ ms}^{-1}$ $\quad \lambda_{(max)} = ?$

$f_{(min)} = 450 \text{ Hz}$ $\quad T_{(min)} = ?$

$f_{(max)} = 4000 \text{ Hz}$

(a) Since velocity is constant, the maximum wavelength will occur with the lowest frequency.

$$v = f\lambda$$

$$\therefore \lambda = \frac{v}{f} = \frac{340}{450} = 0.756 \text{ m}$$

$\therefore$ Max. distance between compressions will be 0.756 m.

(b) Smallest period (T) will be given by the highest frequency.

$$T = \frac{1}{f} = \frac{1}{4000} = 2.50 \times 10^{-4} \text{ s}$$

$\therefore$ Smallest time interval = 2.50×10^{-4} s

Question 5.2

Assuming that it was possible to transmit the sound from the speaker in Example 5.1 through sea water, calculate (using data from Table 5.1):

(a) The maximum wavelength of the sound.

(b) The time it would take the sound to reach a point in the sea water 1.00 km away.

Question 5.3

Ripples are generated in a pond when a small stone is dropped into it. After 4.00 seconds it was noticed that there were 24 ripples created and the furthest ripple was 2.00 m from the spot the stone was dropped. Determine the frequency, wavelength and velocity of the wave.

Intensity of a wave

As we have seen, waves transfer energy from one point to another. Sound waves, for example, transmit the energy produced by a source, such as a loudspeaker, in all directions. The sound travels away from the source as a spherical wave, and its intensity decreases rapidly with distance.

The intensity of a sound wave is defined as the amount of energy passing per second through an area of one square metre.

i.e. $\text{Intensity} = \dfrac{\text{energy}}{\text{time} \times \text{area}}$ Also, since $\text{Power} = \dfrac{\text{energy}}{\text{time}}$

We have

$$I = \frac{P}{A}$$

I = Intensity (Wm^{-2})
P = Power (W)
A = Area (m^2)

How intensity varies with distance

As we move away from a sound source, the sound energy is spread over a larger area and hence the sound intensity falls. The inverse square law applies as shown below.

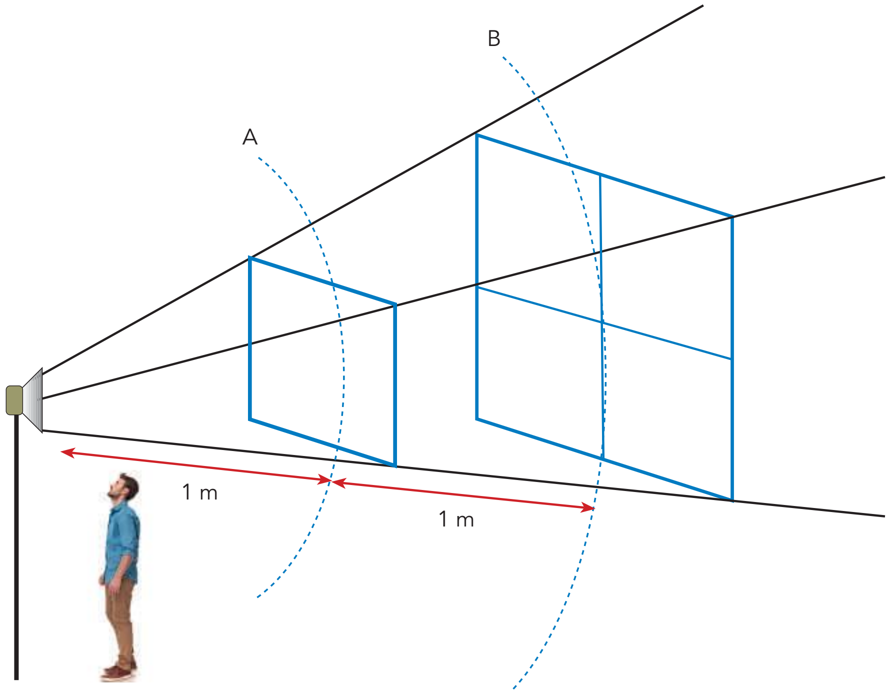


Figure 5.6 The intensity of a sound wave decreases in an inverse square relationship with distance from a point source. For example, at position B as shown above, the intensity of a sound wave will be ¼ of that at position A.

Sound travels from a source as a spherical wave. The intensity at a distance r from a point source is given by:

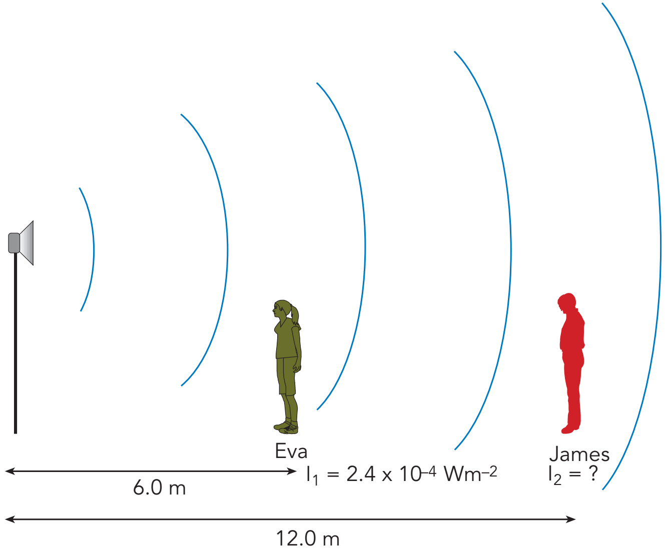
$$I \propto \frac{1}{r^2}$$

I = Intensity (Wm^{-2})
r = Distance from point source

This means, for example, that if the distance from the source doubles, the intensity will fall to ¼ of its original value. We can see from the diagram above that this is due to the fact that the sound energy is spread over 4 times the original area.

Worked Example 5.2

Eva and James are standing 6.0 m and 12.0 m respectively from a loudspeaker. If the intensity is 2.4×10^{-4} Wm^{-2} for Eva, what would it be for James?



There are two different ways this calculation can be done.

Method 1 Consider the inverse square law.

$$I \ \alpha \ \frac{1}{d^2} \quad \therefore \quad I d^2 = constant$$

$$Hence \quad I_2 d_2^2 = I_1 d_1^2$$

$$I_2 = 6.0 \times 10^{-5} \ Wm^{-2}$$

Method 2 Consider total acoustical power.

$$P = I A$$

where Eva is $P = (2.4 \times 10^{-4}) \ (4 \ \pi \ . \ (6.0)^2)$

$$= 0.109 \ W$$

where James is $P = I_2 A = 0.109$

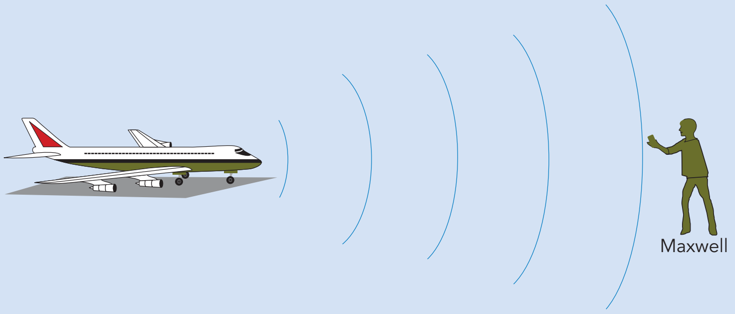
$$0.109 = (I_2) \ (4 \ \pi \times (12)^2)$$

$$I_2 = 6.0 \times 10^{-5} \ Wm^{-2}$$

Where A is the surface area of a sphere at the point under consideration.

Note:
(1) S.A. (sphere) = $4 \pi r^2$
(2) The acoustical power of the source, P, is constant.

Question 5.4



Maxwell is standing 200 m from a jet aircraft listening to the sound of the engines. He measures the intensity of the sound at that point and finds it to be 0.150 Wm^{-2}.

(a) Determine the total acoustical power of the sound source.

(b) Calculate the likely intensity of sound that Maxwell would experience if he walked 50 m closer to the aircraft.

(c) **Challenge:** How far from the aircraft would Maxwell need to be for the intensity to drop to 0.01 Wm^{-2}?

5.2 REFLECTION, REFRACTION, DIFFRACTION

Reflection of waves

When waves reach a boundary between two media refection will occur. Some transmission and absorption may also take place but the extent of this depends on the media involved.

Reflection of waves is most easily understood if we observe the action of water waves when they encounter a solid barrier (see diagrams below). The wavefronts are readily visible and we can see how they reflect and also create interference patterns. We can see for example that the angle of incidence and angle of reflection are equal.

Sound waves are reflected in a similar manner to all waves. They are best reflected by hard smooth surfaces such as tiled floors, walls and ceilings, but tend to be absorbed by soft and rough surfaces.

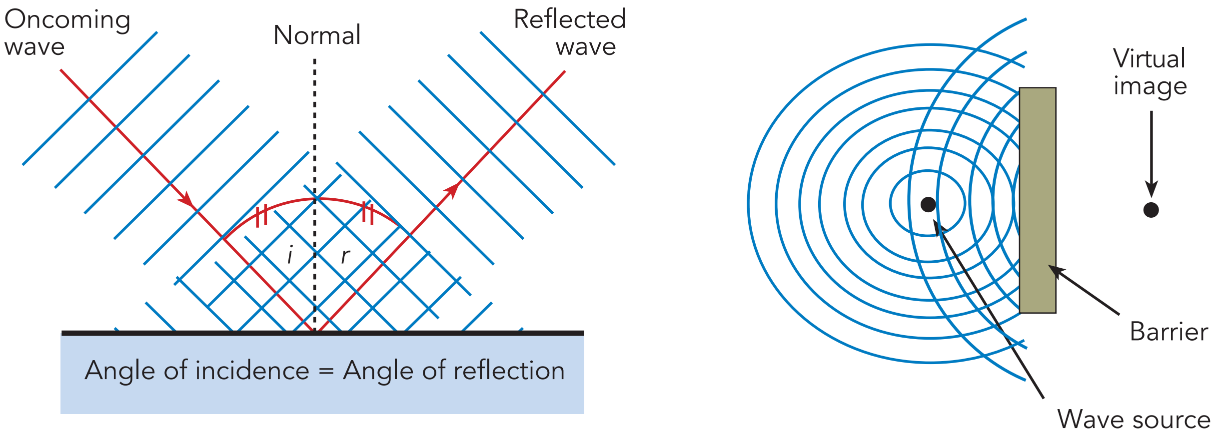


Figure 5.7 The reflection of waves such as water and sound.

The reflection of sound waves can cause echoes, makes depth sounding possible and gives rooms their acoustic properties. It also makes possible the operation of doctors' stethoscopes, speaking tubes and brass musical instruments. Echoes are heard when a reflected sound reaches a listener more than 1/10 of a second after the original sound.

Reflection of ultrasound

Ultrasounds are very high frequency sound waves which can be produced as highly directional beams since little diffraction will occur. There are many situations where the reflection of ultrasounds is very useful.

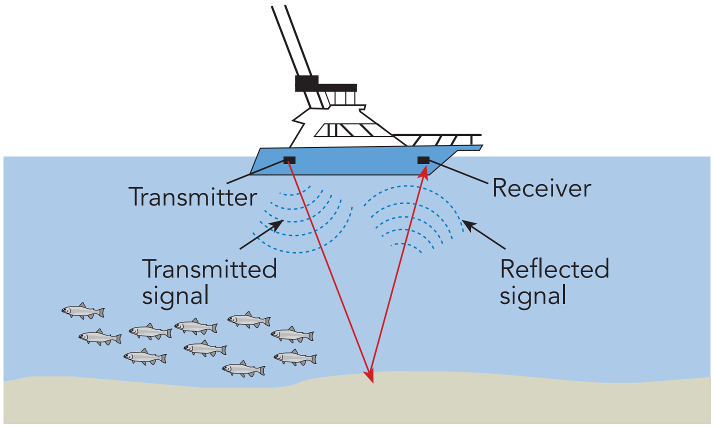


Figure 5.8 *Using sonar to locate fish and ocean floor.*

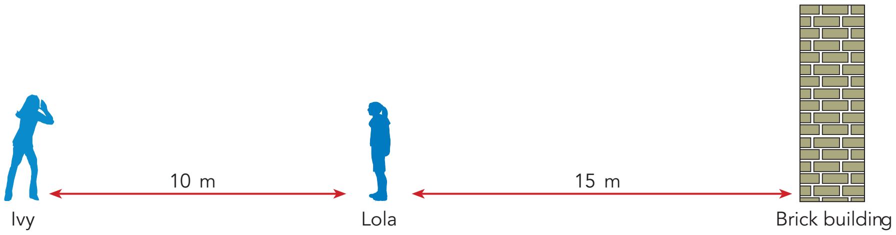
- Sonar (**so**und **na**vigation and **r**anging) has many marine applications such as depth sounding and the location of fish and submerged objects. The time taken for a short pulse to be reflected can be used to calculate the distance to the reflecting surface.
- Some animals, such as bats and dolphins, use ultrasound to detect objects around them. The very short wavelength of the sounds emitted allows even small objects to be detected.

- In medicine ultrasound waves are used by doctors to obtain pictures of internal parts of the body. Multiple reflections of ultrasound waves can be used to detect tumours, monitor heart function or check the growth of unborn babies.

Worked Example 5.3

Ivy and Lola are standing 25.0 m and 15.0 m respectively from a large building when Ivy calls out loudly. Assume the speed of sound to be 340 ms^{-1} and that good reflection of sound occurs from the building.

(a) Find the time delay between the two sounds Lola will hear.
(b) Will Lola detect an echo?
(c) Will Ivy detect an echo?



$v = 340 \text{ ms}^{-1}$

for Ivy	**for Lola**	
$d = 50$ m (echo)	$d_1 = 10$ m (direct sound)	$t_1 = ?$
$t = ?$	$d_2 = 40$ m (echo)	$t_2 = ?$

(a) Since $v = \frac{s}{t}$ $\quad t = \frac{s}{v}$

$$\therefore \quad t_1 = \frac{10}{340} = 2.94 \times 10^{-2}\,\text{s and } t_2 = \frac{40}{340} = 0.118\,\text{s}$$

$$\Delta t = t_2 - t_1 = 8.82 \times 10^{-2}\,\text{s}$$

(b) The sounds are too close together for Lola to detect an echo.

(c) For Ivy:

$t = \frac{50}{340} = 0.147\,\text{s}$ She will detect an echo.

Question 5.5

In Worked Example 5.3, suppose Lola calls out loudly, would Ivy hear an echo?

Question 5.6

A sonar device uses ultrasound pulses of 50 kHz to map the contours of the bottom of the ocean. If the pulses which are reflected from the bottom reach the ship exactly 0.125 s after being emitted what must be the depth of the ocean at this point? (You will need data from Table 5.1.)

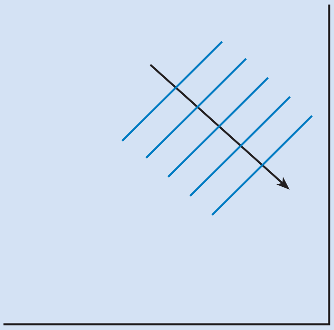
Question 5.7

The following diagrams show sound waves about to be reflected by:

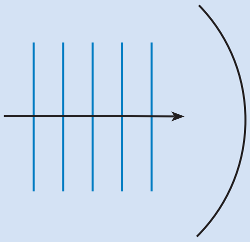
(a) the corner of a room (b) a circular reflector.

Carefully complete the diagrams to show what would happen in each case.

(a)



(b)



Refraction of waves

When waves travel from one medium into another of different density, their velocity (and wavelength) will change. Frequency is unaffected. This change in velocity can cause the wave to bend and change direction. This bending is referred to as refraction. The normal laws of refraction apply, that is the waves:

- bend *towards* the normal if they enter a medium where their speed is slower.
- bend *away* from the normal if they enter a medium where their speed is greater.

Refraction of water waves can be demonstrated using a ripple tank with different depth sections. The speed of water waves in the shallow sections is less as the wavelength becomes shorter. This causes the wave front to change direction towards the normal. Sometimes we can notice this effect on a shoreline, as can be seen below, if the incoming waves are moving obliquely to the change in depth of the water.

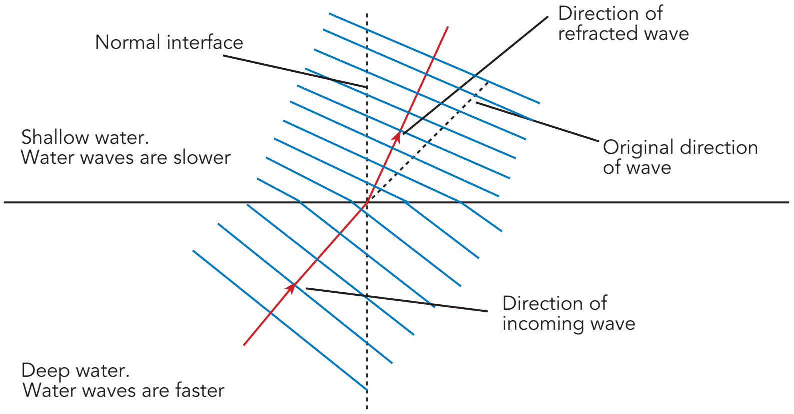


Figure 5.9 Refraction of water waves towards the normal as they progress from deep water to shallow water. Note the decrease in wavelength. Sound waves refract in a similar way.

Question 5.8

On a calm summer evening the air near the ground is rather cool while higher up it is warmer. Sound travels faster in warm air. Using wavefront diagrams carefully show how refraction of sound can allow the noise from an aircraft to be heard quite clearly at some point far away.

Diffraction of waves*

Waves, are able to bend around obstacles or around narrow openings placed in their path. The amount of diffraction depends both on wavelength and gap size.

- Larger wavelengths are more easily diffracted than smaller wavelengths.
- Diffraction is greatest when the wavelength is larger than the opening or obstacle.

Everyday sound waves are quite easily diffracted as their size (typically some 2 cm to 20 m) is similar to that of most obstacles and openings. This explains why it is quite easy to hear around the corners of a building even though there may be little reflected sound.

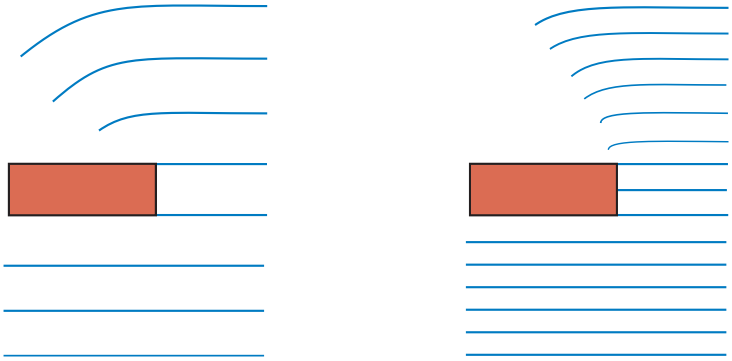
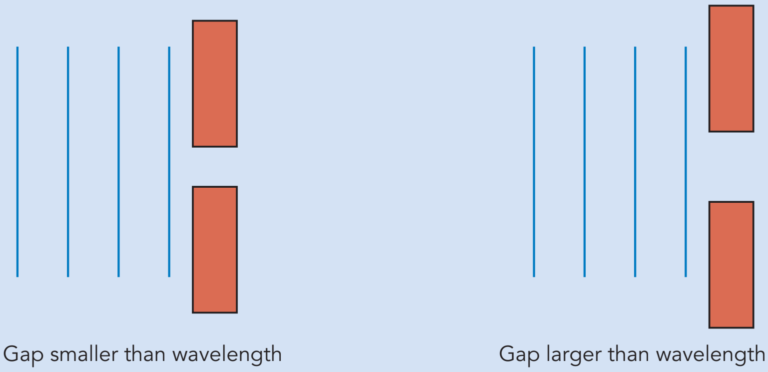


Figure 5.10 Large wavelengths are more easily diffracted.

Question 5.9

Complete the wave diagrams below to show how the amount of diffraction of a wave depends on its wavelength compared to that of the opening.



Seismic Waves

Seismic waves are caused by events such as earthquakes and travel through the earths crust in different forms and varying speeds. Seismic waves, like sound, are mechanical waves. They travel through the earths crust both as longitudinal and transverse waves.

P Waves: The longitudinal waves travel almost twice as fast as the tranverse waves and are the first to be felt after a seismic event. They are referred to as *P waves* (primary). Their velocity varies markedly for different materials and increases with depth. Velocity in the Earth's crust can range between 4.0 km/sec to 8.0 km/sec. In granite, for example, it is typically 5.5 km/sec. By comparison the velocity of P waves in liquids is much lower. In water it is some 1.5 km/sec. This large difference in velocities can cause refraction at boundaries.

S Waves: The tranverse waves are called *S waves* (secondary). They travel more slowly than P waves and, significantly, can only travel through solids. These waves are second to be felt after a seismic event, have more energy and are generally more destructive. Velocity in the earths crust can range between 2.5 km/sec to 4.0 km/sec. In granite, for example, it is typically 3.0 km/sec.

** May not be required for your course*

Seismic waves can be used to provide a great deal of information about the structure of the Earth. P waves for example are able to travel through solid and liquid materials with some refraction occuring at the boundaries. By analysing the movement, or otherwise, of P and S waves through the earth it is possible to get a better understanding of the earths layers.

The fact, for instance, that S waves are not able to travel right through the earth indicates the presence of a liquid section near the earths core. P waves do travel right through the globe but can also be refracted depending on their path. Detailed analysis of wave paths and velocities help to provide a better picture of the earths structure.

Seismic waves are also very useful in studying the Earth's crust and exploring for resources such as oil. Waves created by artificial sources are reflected by boundaries and discontinuites between rock layers. Refraction can also occur, in particular if liquid areas are encountered. The reflected waves are recorded by a series of geophones and analysed. The seismic cross section that is produced can indicate features such as rock layers, faults, folds and the presence of liquids.

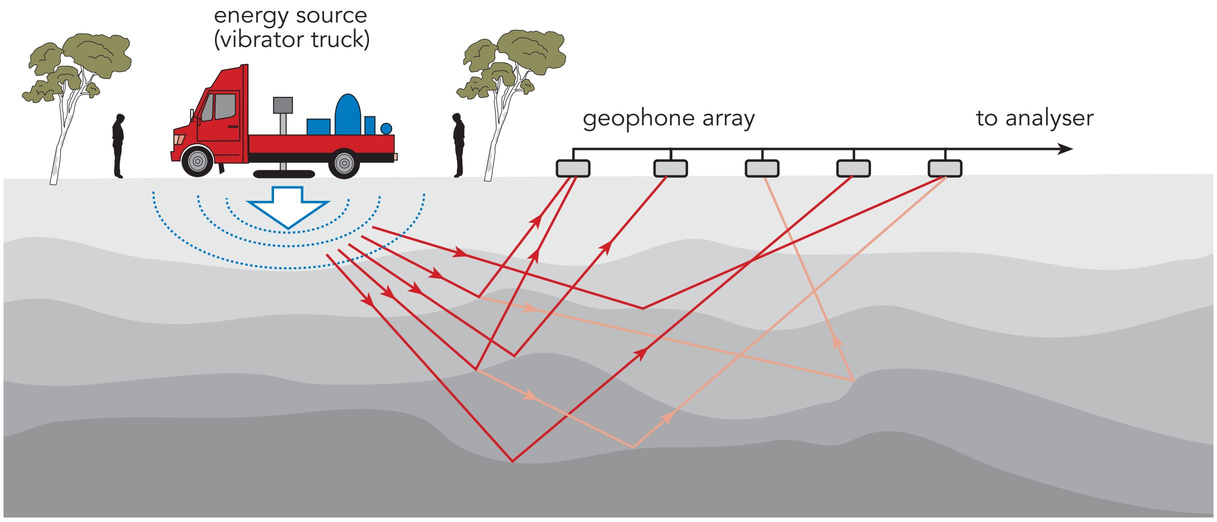


Figure 5.11 Reflection seismology. Seismic waves generated by an energy source such as a vibrator truck are transmitted through soil and rock layers and their reflections recorded and analysed. Sometimes small explosive charges are used. Waves are mostly reflected by layer boundaries or discontinuities. Refraction can also occur. The analysis of the very large number of recorded reflections results in a detailed cross section of the underlying rock layers.

Worked Example 5.4

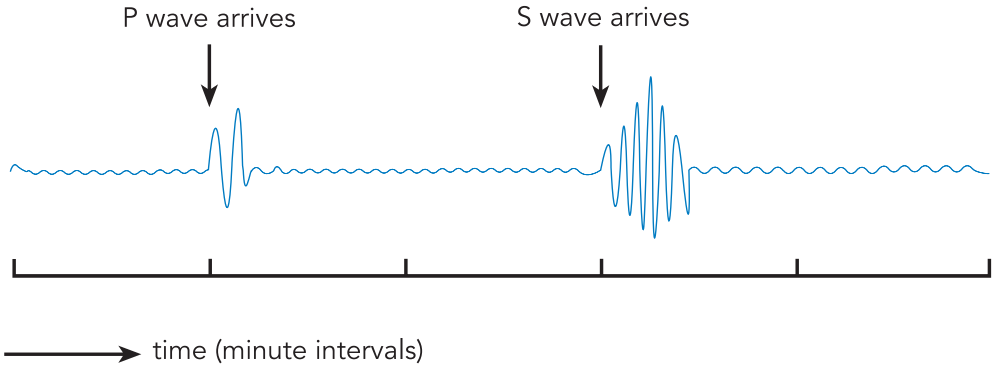
Earthquakes produce different kinds of waves which travel through the earths crust at different velocities. This means that they arrive at any particular seismic station at different times. P waves arrive first, followed by S waves. This time difference can be used to directly determine the distance of a seismic event. Analysis of data from many earthquakes gives a value of about 9.0 km for every second of time difference.

However, for the purpose of this worked example, we will use typical average velocities for the P and S waves involved. Assume these to be 5.1 km/sec and 3.2 km/sec respectively. A seismogram is shown below recording the arrival of P and S waves at a recording station. Use this data to answer the following.

(a) Determine the time difference between the arrival of the two different waves at the recording station.

(b) Calculate the distance of the seismic event from the recording station using the velocities given.

(c) The distance is usually determined from established data linking it directly to time difference. Use this direct conversion method to calculate the distance of the seismic event. Comment on any differences and suggest which method may be most useful.



(a) The time difference = 2.0 minutes (120 s)

(b) Let unknown distance = s (same for both P and S waves)

Let time for P wave to arrive = t

So time for S wave to arrive = t + 120

Since v = s/t we have s = vt

For P waves s = (5100)(t) For S waves s = (3200)(t + 120)

Since s is common we have

$$5100t = 3200t + 384000$$

$$1900t = 384000 \quad t = 202 \text{ s}$$

Hence distance s = (5100)(202) = 1030 km

(c) Conversion value given = (9.0 km /s)(Δt between P and S arrival)

Hence distance s = (9.0)(120) = 1080 km

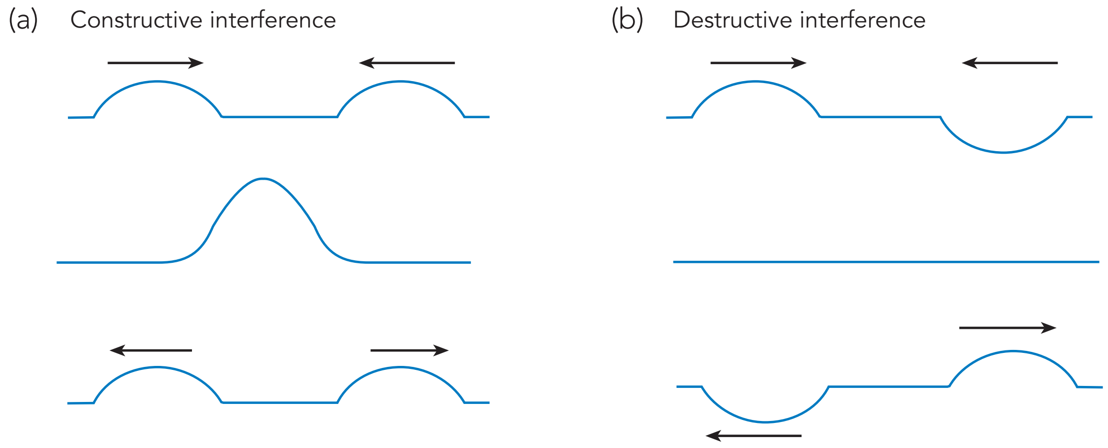
The calculation of distance using a conversion value is certainly the most convenient method. It is also likely to be the most accurate as the conversion factor is based on the analysis of recorded data from many seismic events. In contrast, the velocity of P and S waves can vary widely due to material encountered and path taken.

5.3 WAVE INTERACTIONS

Adding waves (superposition)

Whenever two waves pass through a point at the same time, interference will occur. However, each individual wave is unaffected and travels through the point as though no other wave existed. The combining of two waves is known as superposition and is simply the algebraic addition of the displacement of the two waves.

- Constructive interference is when two waves combine to give a greater resultant displacement. For similar waves this effect is a maximum when the waves are in phase.
- Destructive interference is when the two waves combine to give a smaller resultant displacement. This effect is a maximum for similar waves 180° out of phase.


(a) Constructive interference

(b) Destructive interference

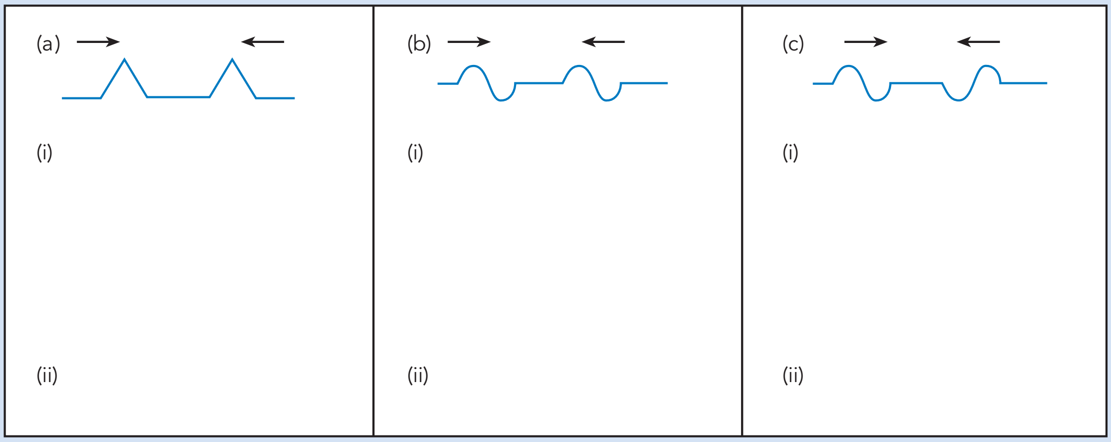
Figure 5.12 Superposition, showing (a) constructive and (b) destructive interference.

Question 5.10

Complete the following diagrams to show the resultant displacement when:

(i) the two pulses coincide totally;

(ii) the two pulses have passed each other.



Interference from two point sources

A very good example of this type of interference occurs when two loudspeakers emit the same sound (in phase) from two different points. Points of maximum reinforcement (ANTINODES) and total annulment (NODES) will occur as shown in the diagram below.

Example A

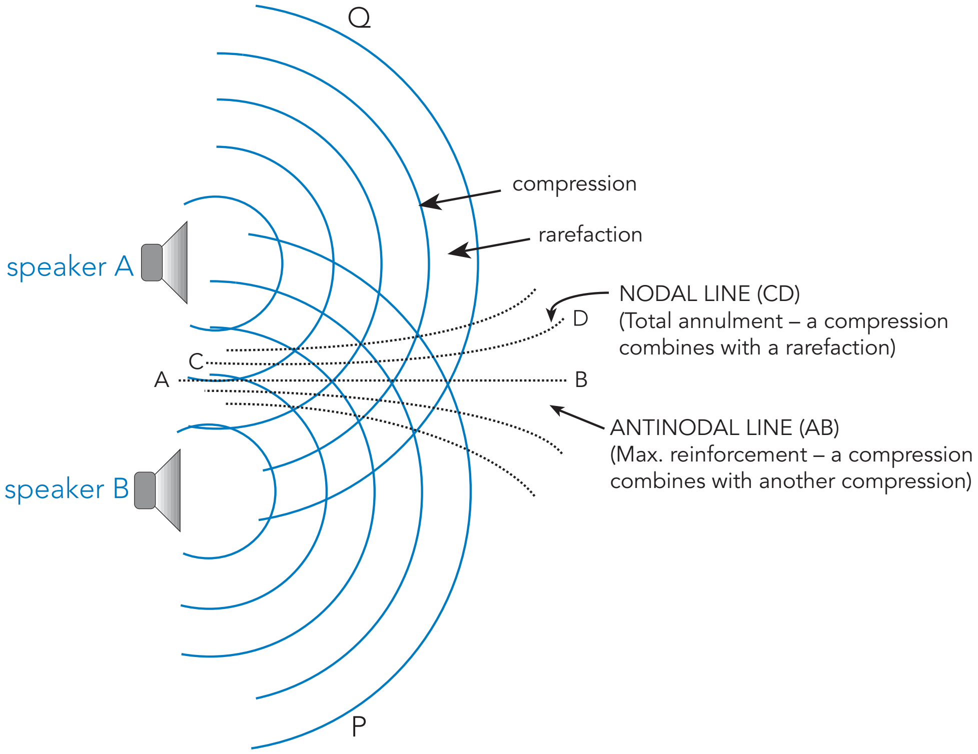


Figure 5.13(a) Interference between two point sources.

A similar interference effect (nodes and antinodes) will occur when two loudspeakers are facing each other and emitting the same sound in phase. (In fact, a standing wave pattern forms between the speakers.)

Example B

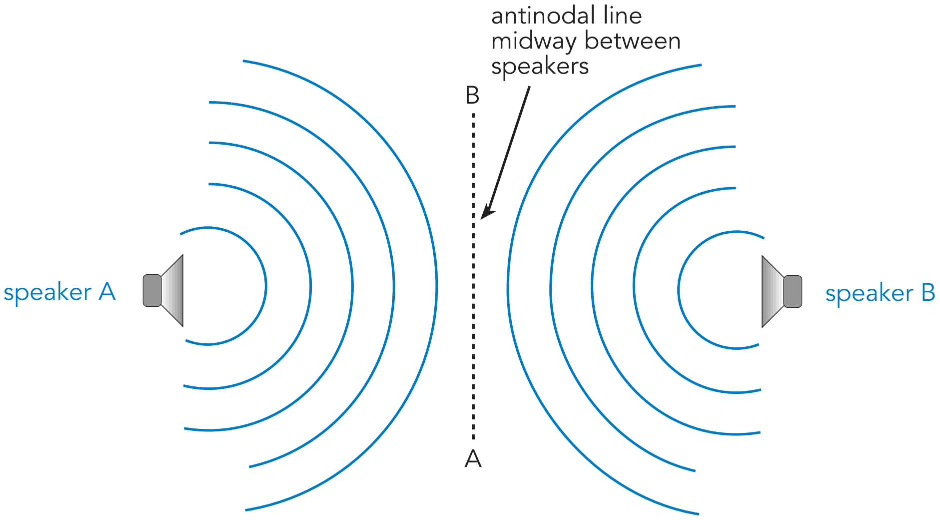


Figure 5.13(b).

Antinodal lines occur where there is constructive interference – a loud sound is heard.

Nodal lines occur where there is destructive interference – a soft sound is heard. (In theory no sound should be heard – why is some sound actually heard?)

Question 5.11

Describe what you would hear, and explain why, if you walked from:

(a) A to B in example A.

____

(b) P to Q in example A.

____

(c) A to B in example B.

____

Worked Example 5.5

Two loudspeakers (A and B) are set up as shown in Figure 5.13(a) so that they both emit sounds of 425 Hz which are in phase. The speakers are 2.40 m apart. Assume the speed of sound is 340 ms^{-1}.

(a) What is the wavelength of the sounds emitted?

(b) Melissa stands exactly midway between the speakers and then walks away so as to always remain equidistant from them. Describe what she hears. Explain why.

(c) Melissa now walks to a point C, 7.00 m directly in front of speaker A.

(i) How far is she from speaker B?

(ii) What will be the effect?

v = 340 ms^{-1}
f = 425 Hz
λ = ?
AB = 2.40 m

(a) $v = \lambda f \quad \therefore \lambda = \frac{v}{f} = \frac{340}{425}$

$= 0.800$ m

(b) If Melissa is always equidistant from the speakers the sounds reaching her will always be in phase. She will therefore always hear a loud sound.

(c) AB = 2.40 m
AC = 7.00 m
BC = ?

$(BC)^2 = (AC)^2 + (AB)^2$
$= 49 + 5.76$
$\therefore BC = 7.40$ m

Since the wavelength of the sound is 0.80 m then at point C the sounds are exactly half a wavelength apart (180° out of phase).

Melissa will “hear” silence.

Question 5.12

For the previous question assume Melissa walks parallel to the speakers (as in P to Q in Figure 5.13(a)).

(a) Describe what she would hear as she walked steadily past the speakers.

(b) The frequency of the sounds from both speakers is doubled. What will Melissa now hear if she repeats her experiment?

Beats

Beats occur when there are two sound waves of very similar frequency in the same medium. The effect is a constant rise and fall in the intensity of the sound.

- When sounds are temporarily in phase – high intensity results.
- When sounds are temporarily out of phase – low intensity results.

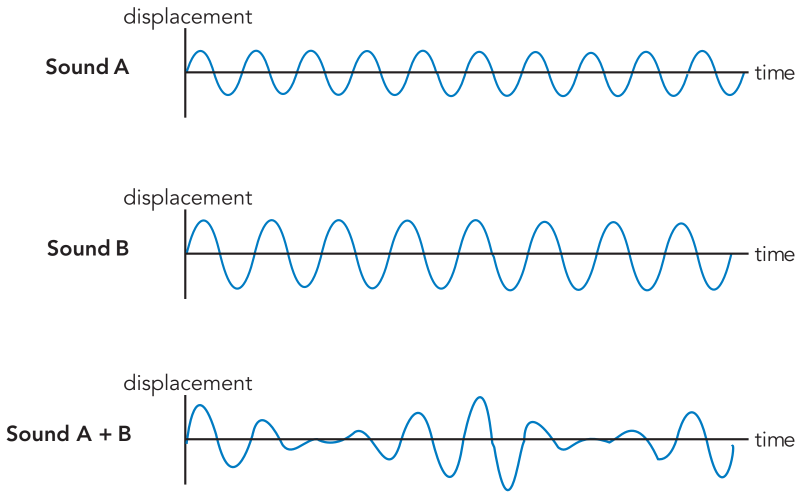


Figure 5.14 Sounds of two different frequencies forming beats.

Natural and forced vibrations

Whenever an object is struck, such as a tuning fork, and then allowed to vibrate without further interference, its vibrations are called free or natural vibrations. All bodies have a natural vibrating frequency and this depends upon their physical characteristics.

A body can also be forced to vibrate at a frequency which is not its natural frequency. Whenever this occurs we refer to it as a forced vibration. A typical example is a tuning fork placed on a bench. The bench is forced to vibrate at the frequency of the tuning fork and the sound is louder because of the larger vibrating surface area. The sounding box of a guitar also works in this way. The intensity of the sounds of all musical instruments is enhanced by the effect of forced vibrations.

Resonance

We are all familiar with the sound that can be created when we blow gently across the mouth of an open bottle. The frequency of the sound produced will depend on the dimensions of the bottle and is the result of the free vibration of the air inside. This is an example of resonance.

Resonance occurs whenever the frequency of a forcing vibration is equal to the natural frequency of the vibrating object. The amplitude of the vibrations is always greatly increased.

Common examples of resonance include:

- a person being pushed on a swing. If the applied and natural frequency are equal the swing's amplitude will increase.
- resonating air columns. This is made use of in organ pipes and similar musical instruments. Resonance will occur at the natural frequency of the air column.
- vibrating strings. The strings of guitars will resonate to a frequency dependent on their length, thickness and elasticity.

Vibrations in stretched strings

Stretched strings, such as guitar strings, will freely vibrate at a particular natural frequency, known as its fundamental frequency. This frequency depends upon the length of the string, its mass per unit length and the tension on the string.

Different modes of vibration (apart from the fundamental) are also possible. These are given by the following relation ship.

In general $\lambda = \frac{2l}{n}$ where n = 1, 2, 3

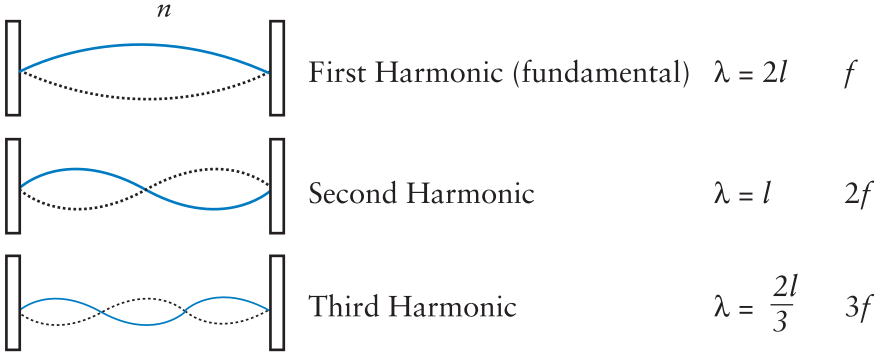


Figure 5.15 *Modes of vibration in a stretched string. All harmonics are possible.*

What are standing waves?

The vibrations that occur in stretched strings, as shown above, are an example of standing waves. When the string is initially plucked, a continuous wave will travel along the string to the fixed end and is then reflected back. This reflected wave will be opposite in phase and will combine with the original to form a standing wave pattern.

Standing waves, sometimes called stationary waves, are so called because they appear not to move. In fact, however, the string continually oscillates. *It is the relative position of the nodes and antinode that remains unchanged, giving the effect of a stationary wave.*

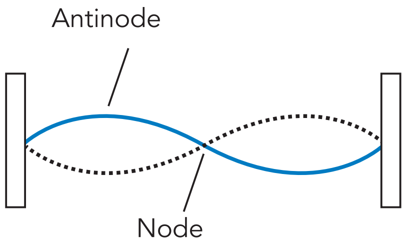


Figure 5.16 Typical standing wave pattern in a string. The fixed ends are always nodes since there is zero displacement.

- Standing waves are produced by two similar waves travelling in opposite direction.
- Nodes: where there is zero displacement (e.g. at fixed end). Nodes are $\frac{\lambda}{2}$ apart.
- Antinodes: where there is maximum displacement. Antinodes are $\frac{\lambda}{2}$ apart.

Standing waves in air columns (pipes)

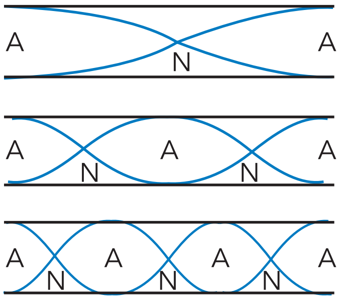
Air columns in pipes can be set vibrating by blowing across the open end (or using tuning forks, loudspeakers, etc). Different modes of vibrations are possible as in stretched strings.

The standing waves in air columns are again the result of two similar waves (longitudinal sound waves) travelling in opposite directions. The closed end of a tube will reflect a compression as a compression, while the open end will reflect a compression as a rarefaction (phase reversal).

- **Open pipes**

Open pipes are those that are open at both ends. Different modes of vibration are possible and these are given by the following relationship. There is always an antinode at the open ends.

In general $\lambda = \frac{2l}{n}$ where n = 1, 2, 3 (Note: Same as for stretched strings)



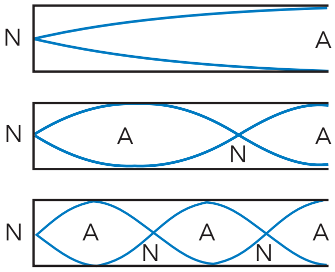
First Harmonic (fundamental)	$\lambda = 2l$	f
Second Harmonic	$\lambda = l$	$2f$
Third Harmonic	$\lambda = \frac{2l}{3}$	$3f$

Figure 5.17 Three simplest modes of vibration in open pipes. The lines drawn represent the displacement of the vibrating air particles. Note that the air particles actually vibrate longitudinally, back and forth along the pipe. The standing wave pattern is only shown like that of a stretched string for convenience. Maximum displacement occurs at each open end, creating antinodes as shown. Displacement of air particles is a minimum at the nodes.

- **Closed pipes**

Closed pipes are those that are closed at one end. Different modes of vibration are possible and these are given by the following relation ship. There is always a node at the closed end.

In general $\lambda = \dfrac{4l}{(2n-1)}$ where n = 1, 2, 3



First Harmonic (fundamental)	$\lambda = 4l$	f
Third Harmonic	$\lambda = \dfrac{4l}{3}$	$3f$
Fifth Harmonic	$\lambda = \dfrac{4l}{5}$	$5f$

Figure 5.18 Three simplest modes of vibration for closed pipes. Again, maximum particle displacement, or antinodes, occur at the open end. The closed end is always a node. Closed pipes can only resonate to alternate multiples of the fundamental frequency.

Open and closed pipes – points to note.

- At the open end of a tube there is always an antinode.
- At the closed end there is always a node.
- Antinodes are $\frac{\lambda}{2}$ apart, Nodes are $\frac{\lambda}{2}$ apart.

Worked Example 5.6

The human vocal tract can be modelled as a narrow tube which is opened at one end, the mouth, and closed at the other, where the vocal chords are. Typically, the effective length of the vocal tract is 16 cm. Detemine:

(a) the fundamental frequency at which this typical vocal tract will resonate.

(b) the next two higher harmonics it will resonate to.

λ = ?
l = $0.160\ m$
v = $3.46 \times 10^2\ ms^{-1}$

(a) For closed pipe fundamental occurs at:

$$\begin{aligned}\lambda &= 4l\\ &= (4)(0.160)\\ &= 0.640\ m\end{aligned}$$

since $v = \lambda f$

$$f = \frac{v}{\lambda} = \frac{346}{0.640} = 541 \text{ Hz}$$

Hence fundamental frequency $(f_1) = 5.41 \times 10^2\ Hz$

(b) Next resonant frequencies will be $3f_1$ and $5f_1$ (odd frequencies only for closed pipe), i.e. 1623 Hz and 2703 Hz.

Question 5.13

What are the similarities in the modes of vibration for:

(a) stretching strings and open pipes?

(b) open pipes and closed pipes?

Question 5.14

The human ear canal can be considered to be a narrow tube opened at one end, the outer ear, and closed at the other, where the ear drum is. Its effective length is typically 2.5 cm.

(a) To what fundamental frequency will this typical ear canal resonate?

(b) What are the next two harmonies that it will resonate to?

REVIEW QUESTIONS

Chapter 5: Waves

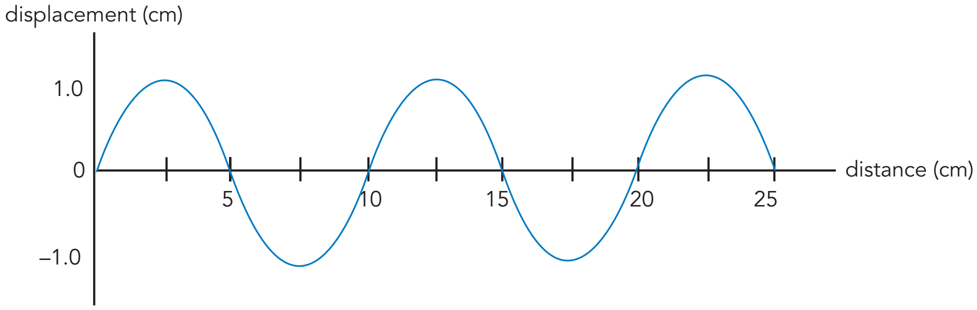
5.1 Nature of waves

1. Indicate whether each of the following is true or false. Alter any false statement so that they are true.
   (a) The velocity of a wave can be calculated from its wavelength and amplitude.
   (b) Sound waves are an example of longitudinal waves.
   (c) Compressions and rarefactions in a sound wave are 90° out of phase.
   (d) A wavelength is the distance between any two consecutive points in a wave which are in phase.
   (e) In a transverse wave, particles vibrate perpendicularly to the direction of the wave.

2. A typical value for the speed of sound is 340 ms^{-1}. Use this value to calculate the wavelength corresponding to the following sound frequencies:
   (a) A school siren with a frequency of 500 Hz.
   (b) The frequency of sound that humans can most easily detect (about 3000 Hz).
   (c) A middle C note played on a piano (264 Hz).
   (d) The sound from a dog whistle (15 kHz).
   (e) An ultrasound scanner operating at 3.5 MHz.

3. Julian and Brook, two keen surfers, are on a beach watching the waves coming in to the shore. They estimate the crests to be 20 m apart and note that 12 waves reach the shore each minute.
   (a) Determine:
      (i) the frequency of the waves.
      (ii) the period of the waves.
      (iii) the velocity of the waves.
   (b) If the surfers could successfully ride one of these waves from 200 m offshore how long would their surf ride last? (Assume that the waves are travelling directly to shore.)

4.

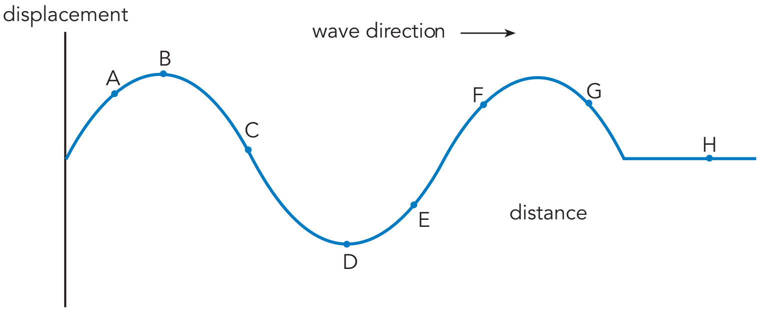


A ripple tank is used to generate water waves as shown in the displacement distance graph above. Determine:
   (a) the wavelength of the waves.
   (b) the amplitude of the waves.
   (c) the velocity of the waves given that the frequency is 3.25 Hz.

5. A ball thrown in the middle of a swimming pool causes a series of ripples in all directions. In an experiment it was noted that the ripples reached the edge of the pool (2.40 m away) in 6.50 s and that a total of 18 ripples had been formed in this time. For these ripples determine their:
   (a) period.
   (b) wavelength.
   (c) velocity.

6. During a practice session for a 100 m race, Paula decided to time her friend Beth by standing at the finish line with a stopwatch and getting another friend to fire a starting pistol at the start line. She started the stopwatch as soon as she heard the sound of the starting pistol and stopped it as Beth went over the finish line.
   (a) This method is likely to lead to timing errors. Explain why.
   (b) Paula timed Beth at 14.2 s for the 100 m sprint. What is the more likely correct time for this sprint? (Assume velocity of sound to be 344 ms^{-1}.)

7.



The motion of a water wave in a large ripple tank is illustrated above. Assume that at the instant shown, the wave is moving to the right and small corks are floating at points A to G. Which cork (or corks) shown:

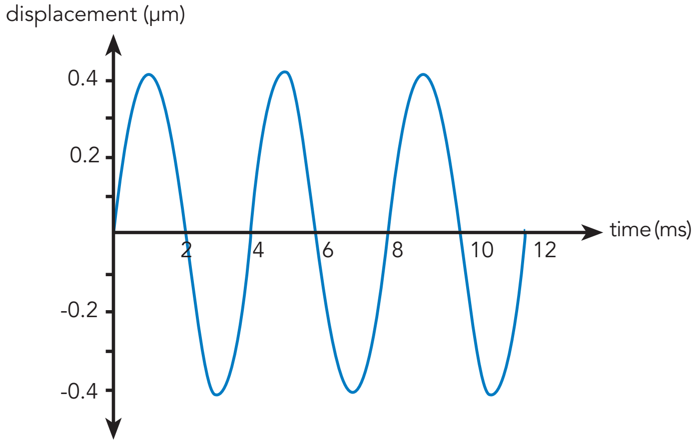
(a) are moving the fastest? ________

(b) are stationary? ________

(c) are moving vertically down? ________

(d) are moving in phase with each other? ________

8. The graph below represents the displacement from mean position of a molecule of air (X) as a sound wave passes by.



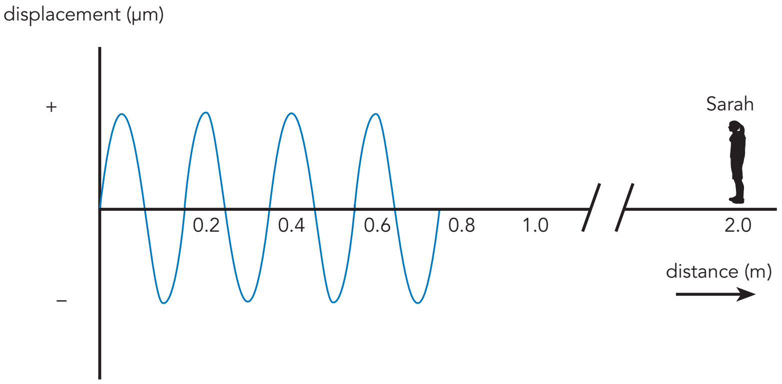
(a) Determine the period and frequency of this wave.

(b) The nearest air molecule moving in phase with molecule X is 1.40 m away. What is the speed of this sound wave?

(c) What is the maximum amplitude of the air molecule X?

(d) Select a point in time from the graph during which air molecule X would have maximum velocity.

9. Sarah is standing 2.0 m away from a loud speaker which is emitting a single frequency sound. The graph below shows the air pressure variation between the sound source and Sarah at a particular instant in time (t = 0).

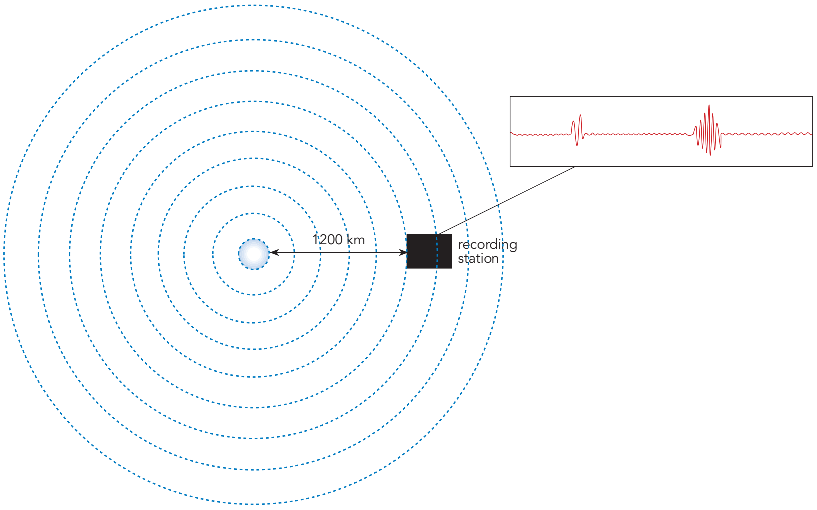


(a) Assuming the speed of sound is 340 ms^{-1}, determine the frequency and wavelength of this sound.

(b) If the graph shows the sound at t = 0, how long before Sarah hears the sound?

(c) Sketch an air pressure versus time graph for t = 0 to t = 5 ms for the position where Sarah is standing.

10. An seismic recording station is a distance of 1200 km from where an earthquake has just occured. It detects and records the arrival of both P and S waves.



(a) Assuming an average velocity of 5.2 km/sec and 3.3 km/sec for the P and S waves calculate the time difference of arrival of the two waves.
(b) A more direct method of calculating this distance is to use a conversion factor established from the study of many previous seismic events. Typically it is 9.0 km/sec. Use this value to determine the distance to the earthquake location and comment on any differences.
(c) Suggest how the actual location of the earthquake can be established. Explain your method clearly.

11. Maxwell is investigating how the intensity of the sound produced by an alarm bell varies with distance. When he is 5.0 m from the bell he finds the intensity to be 2.85×10^{-2} Wm^{-2}. If we assume no effects from sound reflections or absorption determine the likely intensities that Maxwell will find at distances of:
(a) 10.0 m from the bell.
(b) 20.0 m from the bell.

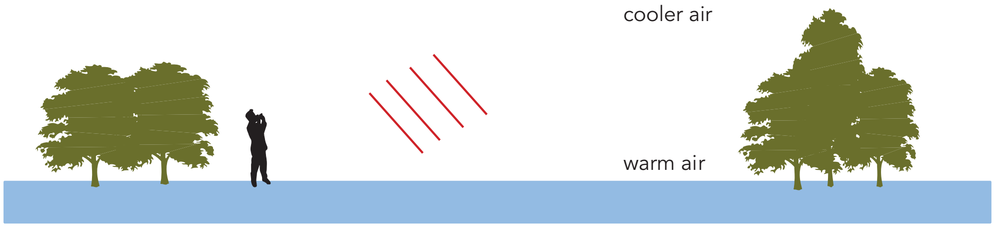
12. An observer standing 12.0 m from an operating jackhammer measures the sound intensity at that point and finds it to be 1.0×10^{-3} Wm^{-2}. She also finds that by wearing a set of high quality earmuffs the intensity can reduced by a factor of 100. Determine, for comparison, how far from the jackhammer she would need to stand to get the same amount of intensity reduction without the use of earmuffs.

5.2 Reflection, Refraction, Diffraction of Waves

13. Indicate whether each of the following is true or false. Alter any false statement so that they are true.
(a) When waves enter a medium of different density their frequency will change.
(b) The reflection of sound waves can cause echoes.
(c) A wave travelling from one media to another may change its direction of travel due to refraction.
(d) Longer wavelengths are less noticeably diffracted than smaller ones.
(e) Ultrasounds are very high frequency sound waves.

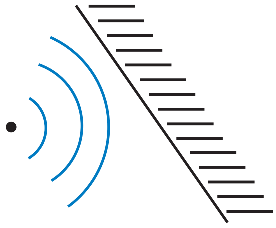
14. When sound waves enter different media, their speed, wavelength and direction can change. However frequency never changes. Explain why it is not possible for frequency to change.

15. On a warm, calm day the air near ground level is warmer than that further above. Complete the diagram below to show how sound is affected by the different layers of air as it travels away from a student shouting on an oval.



16. Complete the following diagrams to show how the sound waves are reflected.

(a) oblique flat surface



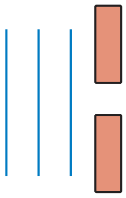
(b) convex surface

17. A sound wave travels from air into water. How are the following likely to be affected?

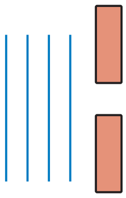
(i) speed
(ii) wavelength
(iii) frequency
(iv) direction
(v) intensity

18. Complete the following to show how diffraction varies with wavelength and magnitude of opening.

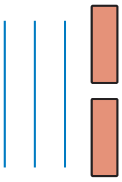
(i)



(ii)



(iii)



19. A music concert fan notices that he is able to distinguish the high frequency sounds of the music much better if directly in front of the band rather than at the side. Explain clearly how this is possible.

20. Dolphins can locate objects by emitting sounds of up to 150 kHz in short pulses.
   (a) Assuming the velocity of sound in sea water is to be 1530 ms^{-1} determine the wavelength of these sounds.
   (b) Why are the higher frequency sounds likely to be more effective in the location of objects by dolphins? Give two reasons.
   (c) What would be the minimum sized object the dolphins could easily detect by this method? Explain.

21. In our homes, we can readily hear sounds coming from nearby rooms even though we may not actually see the sound source.
   (a) Explain how this is possible.
   (b) Which type of sounds are we likely to hear best?

22. A partly open door has a gap of 15 cm through which sound can diffract. Which range of sound frequencies will diffract best through this gap?

23. Modern cameras are often fitted with ultrasonic focussing systems. These determine the distance of the subject from the camera by measuring the time delay between emitting the sound and detecting an echo.
   (a) Why are ultrasonic sounds used for this purpose?
   (b) What are the limitations of this method?
   (c) What would be the time delay for a subject 10.0 m from the camera?

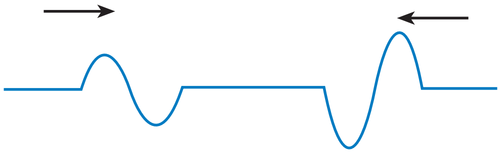
5.3 Wave Interaction

24. Indicate whether each of the following is true or false. Alter any false statement so that they are true.
   (a) Two similar waves travelling in the same medium will constructively combine if they are 180° out of phase.
   (b) Maximum reinforcement between two similar, but separated sound sources, occurs along the anti-nodal line.
   (c) Beats are produced by two waves of the same frequency travelling in opposite directions.
   (d) The sounds we hear from organ pipes are due to resonating air columns.
   (e) The length of a fixed string vibrating at its fundamental frequency is equal to one wavelength.

25. Complete the following diagrams to show the resultant displacement when the two wave pulses shown coincide totally.

(a)

(b)



26. Three similar tuning forks, X, Y and Z, are sounded together in pairs in order to determine the unknown frequency of one of them. The frequencies of X and Y are 440 Hz and 445 Hz respectively. When Z is sounded with X, 10 beats are heard in 5 seconds. When it is sounded with Y, 15 beats are heard in 5 seconds. What is the frequency of tuning fork Z?

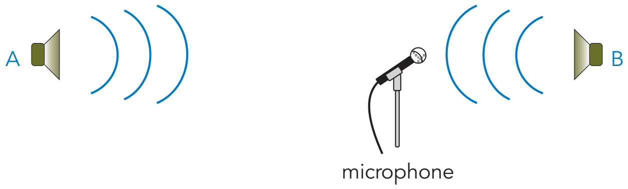
27. Beats and standing waves are each caused by the interaction of two separate wave motions occurring in the same medium. Describe the similarities and differences between the two wave motions causing each of these effects.

28. Two speakers, A and B, are emitting sound waves in the same direction. The wave-lengths are 1.40 m and 1.50 m respectively. Assume the velocity of sound is 340 ms^{-1}.

(a) What will be the distance between successive in phase positions?

(b) What will be the time difference between the occurrence of maximum sound intensities at any given point?

29.



Two speakers, A and B, are emitting sounds of equal frequency and intensity towards each other as shown. A microphone connected to a CRO is used to check the sound intensity level at all points between A and B.

(a) Describe how the sound intensity level may vary between A and B.

(b) What type of wave pattern exists between the two speakers.

(c) What is the name given to points of:

  (i) minimum intensity?

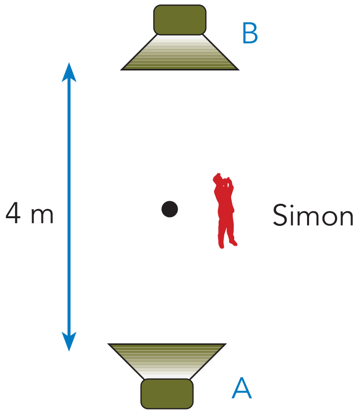
  (ii) maximum intensity?

(d) What is the significance of the distance between successive points of equal intensity?

30. Simon connects two speakers (A and B) to a frequency generator and tests the sound he hears as he walks directly between them. The speakers are 4.0 m apart as they are sounded together as Simon walks from A to B.

(a) Is he likely to hear a loud or soft sound when he is midway between the speakers? Explain.

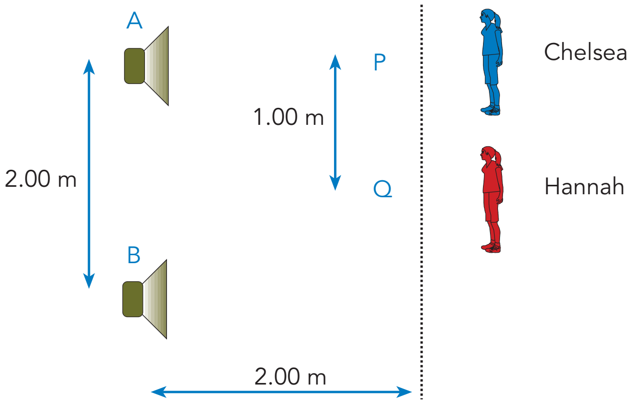
(b) He walks from the midpoint 1.0 m towards B and encounters two points of minimum and two points maximum sound intensity. Determine the wavelength of the sound being used.



31. Chelsea and Hannah connect two speakers (A and B) to a single frequency sound source and then investigate the loudness of the sound produced at different points of the laboratory. The speakers are 2.00 m apart and Hannah stands at a position Q which is exactly midway between the speakers and a perpendicular distance of 2.00 m from them.

(a) If Hannah begins to walk towards Chelsea, in what way will the sound that she hears vary? Explain.

(b) Chelsea, who is standing directly in front of speaker A, as shown, cannot hear any sound at this position. Determine the minimum frequency of the sound being emitted by the two speakers (assume the speed of sound is 340 ms^{-1}).

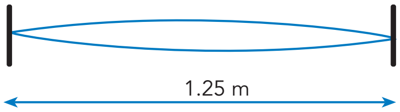


32. Samuel plucks a harp string 1.25 m long so that it is vibrating at its fundamental frequency.

(a) What name is given to this type of wave pattern?

(b) Sketch two other possible modes of vibration for this string.

(c) What is the maximum wavelength that this string can have when vibrating?



33. Rebecca and Pamela set up a resonating air column in the laboratory using an “A” note tuning fork (440 Hz). They then measured the sound intensity levels at different points inside the pipe. The pipe was 1.20 m in length. Beginning at one end of the pipe they found:

(i) maximum intensity at 0.00 m, 0.40 m, and 0.80 m.

(ii) minimum intensity at 0.20 m and 0.60 m.

(a) From the above information only – determine the wavelength of the sound.

(b) Determine the speed of sound in this experiment.

(c) Did the two students use an open or closed pipe as a resonating air column? Explain.

TRIAL TEST 1:
HEATING PROCESSES

Time allowed: 60 minutes
Total marks: 60

Section One – Short response	18 marks
Section Two – Problem solving	30 marks
Section Three – Comprehension	12 marks

SECTION ONE – SHORT RESPONSE (18 MARKS)

1. Heat and temperature are often confused as being the same thing although this is not the case. In terms of the kinetic theory of matter explain the difference between these two terms.

[2 marks]

2. On a cold, frosty morning Alan put on a woollen jumper to keep warm when he stepped outside to go for a 5.0 km run. After running a short distance he felt hot and removed the jumper even though the temperature was still low.

   (a) Briefly explain why the jumper kept Alan warm before the run.

   (b) Why did Alan feel hot after running a short distance?

[3 marks]

3. Briefly explain each of the following:

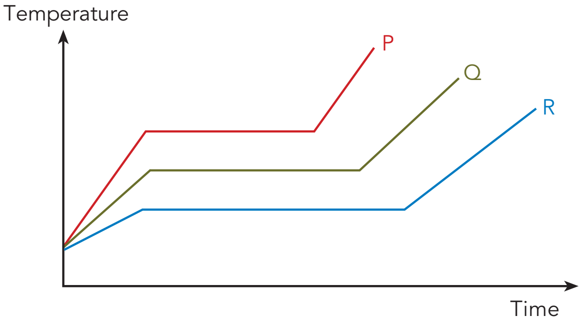
   (a) You can tell the direction that a wind is blowing by holding up a wet finger.

   (b) A metal door handle feels colder than the door it is attached to.

   (c) A refrigerator can be referred to as a heat pump.

[3 marks]

4. Equal masses of solids P, Q and R are heated at an equal rate for a period of time in which all three solids have melted. The graph below shows the heating curve for each of the three solids.



(a) Which solid has the highest specific latent heat of fusion? (Give a reason for your answer).

[2 marks]

(b) Which solid has the highest specific heat capacity? (Give a reason for your answer).

[2 marks]

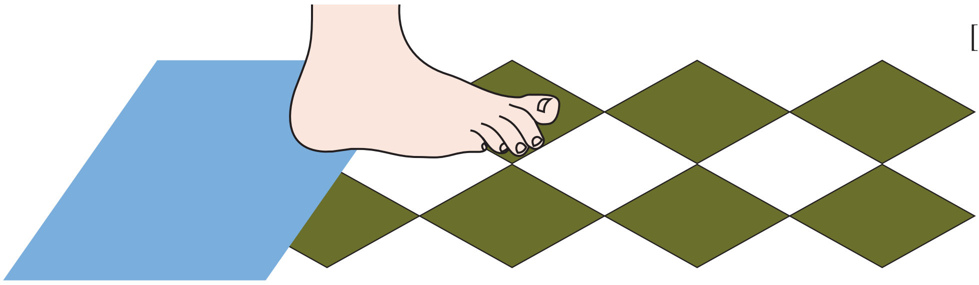
5. (a) On a cool day if you step with bare feet from a carpeted floor to an adjoining ceramic tiled floor the tiled floor will feel much colder. Which of the following is the most likely reason for this observation?

(i) Carpet is a much warmer substance than ceramic tiles.
(ii) Ceramic tiles are better conductors of heat than carpet.
(iii) The ceramic tiles are at lower temperature than the carpet.

[1 mark]

(b) If the temperature of the room is increased this effect becomes less noticeable. At what specific temperature would this effect not be noticeable at all and why?

[2 marks]

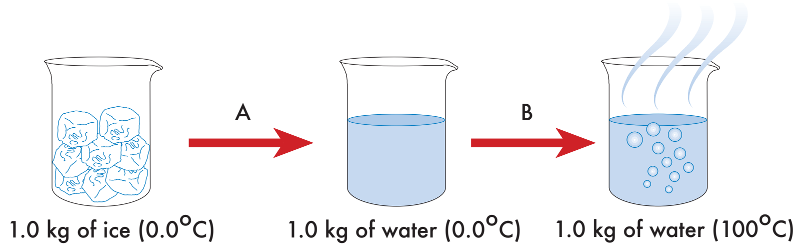


6. Calculate the specific heat capacity of glass if 754 J of heat is needed to raise the temperature of 25.0 g of glass from 15.0°C to 60.0°C.

[3 marks]

SECTION TWO – PROBLEM SOLVING (30 MARKS)

7. 1.0 kg of pure ice at 0.0°C was placed in a beaker as shown and heated (A) until it all melted and (B) until the water boiled. Assume there was no loss of heat to the surroundings.



(a) Which step, (A) or (B), caused the greatest increase in the potential energy of the water molecules? Explain your answer.

[2 marks]

(b) Which would have required more energy, melting the ice (A) or heating the water (B) from 0.0°C to 100°C? Show all calculations.

[4 marks]

(c) The time taken for steps (A) and (B) to occur was 20 minutes in total. Assuming that heat continues to be applied at the same rate, how much longer will it take for all the water to be boiled away? Show all calculations.

[4 marks]

8. A drinking vessel containing 200 g of soft drink at room temperature (25.0°C) is cooled to 5.00°C by the addition of 50.0 g of ice at –5.00°C. Assume all of the ice melts and that no heat transfer occurs between the soft drink and the vessel or the air above it,

Specific heat of ice = 2.10×10^3 J kg^{-1} ºC^{-1}, Specific heat of water = 4.18×10^3 J kg^{-1} ºC^{-1}, Latent heat of fusion of ice = 3.34×10^5 J kg^{-1}

(a) Calculate the total amount of heat required for the ice to reach melting point and melt with the resulting water reaching the final temperature of the mixture.

[6 marks]

(b) Using the result in (a) determine the specific heat capacity of the cool drink.

[4 marks]

9. Paula is doing some running exercises in preparation for a sports day. Paula is 65 kg and is generating excess heat at a rate of 1500 W. Paula's body temperature will increase unless she is able to lose this excess heat in some way.

(a) Sweating is one means by which heat loss can occur. Discuss how sweating helps Paula keep cool and in what other ways her body can lose heat.

[2 marks]

(b) What increase would there be in her body temperature after 10.0 minutes if she did not lose heat energy by sweating or other ways? Assume the specific heat capacity of the human body is 3500 J kg^{-1} K^{-1}.

[4 marks]

(c) Assuming Paula lost 70% of the excess heat by sweating determine the mass of sweat produced in this way. Assume the latent heat of vaporisation of sweat to be 2.40×10^6 J kg^{-1}.

[4 marks]

SECTION THREE – COMPREHENSION (12 MARKS)

10. The following is a partial extract of a technical article on glazing reproduced with permission from www.yourhome.gov.au. Read the extract and answer the following question:

Glazing

Windows in a typical insulated home can account for more heat gain or loss than any other element in the building fabric. In summer, heat gain through an unshaded window can be 100 times greater than through the same area of insulated wall. One square metre of ordinary glass can let in as much heat as would be produced by a single bar radiator. In winter, heat lost through a window can be ten times more than through the same area of insulated wall.

Heat flow

Heat flow through glazed elements such as a windows, glass doors or fixed glass panels is determined by the combined effect of the glass, frame and seals. Heat flows through glazed systems in several ways:

- Conduction
- Convection
- Radiation.

Conduction

Conduction is the movement of heat energy through the glass and frame materials from the air on the warmest side to the air on the colder side. The greater the difference in temperatures the more heat flow. Different frame and glass materials have varying ability to conduct heat, specified by the U-value. The lower the U-value the less heat is transmitted.

The table shows the difference between element and system U-values.

Convection

Convection is the movement of heat energy by air that passes over the surface of the glazing unit, taking heat away from the glass and frame. Higher air speed causes greater convected heat transfer. Minimising convective heat transfer can be achieved by reducing air movement adjacent to the surfaces of glazing units through shielding the exterior by walls, screens and plants and by shielding the interior with curtains and pelmets. It can also be achieved through double glazing which creates a still gas layer between the panes.

INDICATIVE VALUE OF CONDUCTED HEAT PERFORMANCE

COMPONENTS	U-VALUE
Aluminium frame	10.0
Timber frame	2.8
3mm clear glass	5.9
Double glazing (uncoated) – 2 x 3mm glass with 6mm air gap	3.1
SYSTEMS	
Aluminium frame with 3mm clear glass	6.9
Aluminium frame with double 3mm clear glass and 6mm gap	3.8
Timber frame with 3mm clear glass	5.5
Timber frame with double 3mm clear glass and 6mm gap	3.0

Note: Values for specific products may be significantly different.

Solar radiation

When sunlight strikes a sheet of glass, some of the solar radiation is transmitted straight through, some is reflected and some is absorbed by the glass. The heat energy absorbed by the glass is then radiated to both the inside and outside as infrared radiation. The sum of reflected, absorbed and transmitted heat always equals 100%. For example for 3mm clear glass: 83% of solar radiation is transmitted, 8% reflected and 9% is absorbed. 3% is then radiated inside and 6% outside.

The total amount of solar heat that passes through the glass is the sum of the heat transmitted plus that part of the heat absorbed in the glass which is subsequently re-radiated and convected inside.

(a) Heat transfer through a window can occur in three main ways. List these.

____

____

____

[3 marks]

(b) The article lists a table of indicative U values for different materials.

(i) What is the U value a measure of? ______________________________

(ii) Which of the listed components is likely to allow the greatest heat transfer by conduction?

____

(iii) Which of the listed systems is likely to best reduce heat transfer by conduction?

____

[3 marks]

(c) How can convective heat transfer through a window be minimised?

____

____

____

[2 marks]

(d) When sunlight strikes a glass window most of the solar radiation passes through the glass. For the example given (3mm glass) what is the total percentage of heat that passes through the glass? Explain clearly how this occurs.

____

____

____

____

[4 marks]

END OF TEST (60 MARKS)

TRIAL TEST 2:
IONISING RADIATION AND NUCLEAR REACTIONS

Time allowed:	**60 minutes**	**Section One –** Short response	18 marks
Total marks:	**60**	**Section Two –** Problem solving	30 marks
		Section Three – Comprehension	12 marks

SECTION ONE – SHORT RESPONSE (18 MARKS)

1. How many (i) protons, (ii) neutrons do each of the following contain?

(a) ${}^{14}_{6}\text{C}$ (i) ______________ (ii) ______________

(b) ${}^{35}_{17}\text{Cl}$ (i) ______________ (ii) ______________

(c) ${}^{212}_{84}\text{Po}$ (i) ______________ (ii) ______________ [3 marks]

2. Complete the following table.

	ALPHA PARTICLE	**BETA PARTICLE**	**GAMMA RADIATION**
What it is			
Symbol			
Charge			
Can be deflected by magnetic field			
Stopped by			

[5 marks]

3. Write a symbol for and name the missing particle(s) in each of the following.

(a) ${}^{228}_{88}\text{Ra} \rightarrow {}^{228}_{89}\text{Ac} +$

____

[1 mark]

(b) ${}^{212}_{84}\text{Po} \rightarrow {}^{208}_{82}\text{Pb} +$

____

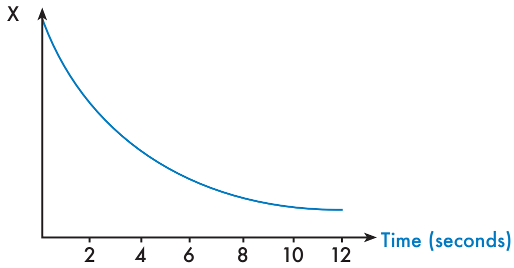
[1 mark]

(c) ${}^{238}_{92}\text{U} \rightarrow {}^{234}_{90}\text{Th} +$ ________ ; ${}^{234}_{90}\text{Th} \rightarrow {}^{234}_{91}\text{Pa} +$ ________

____

[1 mark]

4. A radioactive sample containing X atoms has a decay curve as shown in the diagram.



(a) Estimate the half-life for the sample.

[1 mark]

(b) Estimate the percentage of the sample remaining after 9 seconds.

[1 mark]

5. Inhalation of radioactive alpha emitting dust particles over a period of time can cause respiratory problems. Briefly explain why this dust can be responsible for such problems.

[2 marks]

6. Nuclear fission occurs when a slow moving neutron strikes a uranium–235 nucleus, is absorbed, and creates an unstable uranium-236 nucleus.

(a) Write an equation for this reaction.

[1 mark]

(b) If the uranium-236 splits into $^{141}_{56}\text{Ba}$ and $^{92}_{36}\text{Kr}$ use an equation to show how many neutrons are also released.

[1 mark]

(c) What is the importance of the neutrons that are released?

[1 mark]

SECTION TWO – PROBLEM SOLVING (30 MARKS)

For Questions 7, 8 and 9 use the following data.

1 u = 1.6605×10^{-27} kg

mass of proton = 1.00728 u

mass of neutron = 1.00866 u

mass of electron = 0.000549 u

1 eV = 1.602×10^{-19} J

atomic mass of $^{14}_{6}\mathrm{C}$ = 14.00324 u

atomic mass of $^{14}_{7}\mathrm{N}$ = 14.00307 u

atomic mass of $^{208}_{82}\mathrm{Pb}$ = 207.97665 u

7. (a) Which has the greatest mass, an atom of lead-208 or the sum of the masses of its components?

[2 marks]

(b) Use the data above to verify your answer.

[6 marks]

(c) What is thought to be the cause of this mass difference?

[2 marks]

8. Calculate the binding energy per nucleon in joules for lead-208.

[10 marks]

9. (a) When a neutron combines with a nitrogen-14 nucleus the radioactive carbon-14 isotope is formed as well as a single proton. Write an equation for this nuclear reaction.

[2 marks]

(b) Calculate the energy released in MeV from this reaction.

[8 marks]

SECTION THREE – COMPREHENSION (12 MARKS)

10. Read the following article and then answer the questions on the next page.

Cyclotron-produced radioisotopes

Cyclotron-produced radioisotopes are used mainly to make radiopharmaceuticals for use in two diagnostic imaging systems – positron emission tomography (PET) and single photon emission computed tomography (SPECT).

Both methods involve the use of minute quantities of low-level radioactive chemicals that can be detected by the highly sensitive imaging equipment in hospitals. The radioactive materials decay rapidly and do not harm the patient.

SPECT is a sophisticated camera system that produces images of slices of the body by photographing the low-energy gamma rays emitted from radioactive tracers introduced to pinpoint disease or organ function. The radioactive tracers used contain a radioisotope compound that is specific for the organ or disease being studied. If the body slices are added together, a three-dimensional image of the organ being studied is obtained.

SPECT radiopharmaceuticals produced at the National Medical Cyclotron include:

- gallium-67, which is used to diagnose soft tissue tumours and some inflammatory lesions. It has a half-life of 78 hours.
- thallium-201, which is used to assess heart conditions. It has a half-life of 73 hours.
- iodine-123, which is used to diagnose certain thyroid diseases. It has a half-life of 13 hours.

Iodine-123 labelled tracers are also commonly used to monitor neurodegenerative diseases and cancer.

PET is a highly sensitive system that uses positron-emitting radioisotopes. A positron is a positively charged electron particle. When a positron collides with an electron the two particles annihilate one another, releasing energy as two gamma rays which shoot off in exactly opposite directions. These two rays strike crystals in a ring of detectors around a patient, enabling sophisticated computers to then turn the information into an image.

The only PET radiopharmaceutical currently routinely produced at the National Medical Cyclotron is fluorine-18. This is labelled onto a glucose molecule to form fluorodeoxyglucose (FDG). This is used to diagnose brain disease, heart viability, coronary artery disease and, increasingly, to assess the spread of cancers such as malignant melanomas. It has a half-life of 110 minutes.

Text and image courtesy of the Australian Nuclear Science and Technology Organisation

(a) How is a radiopharmaceutical different from a radioisotope?

____

[2 marks]

(b) Radiopharmaceuticals are used in diagnostic imaging systems such as PET and SPECT. Give the full name for these imaging systems.

PET ____

SPECT ____

[2 marks]

(c) (i) What is a positron?

____

[1 mark]

(ii) Use an equation to show what happens when a positron interacts with an electron.

____

[1 mark]

(iii) Explain how this interaction allows imaging of a patient's body to occur.

____

____

____

____

[2 marks]

(d) List the isotope/s involved in the diagnosis of:

(i) heart disease ____________________________________

(ii) soft tissue tumours ________________________________

[2 marks]

(e) The radiopharmaceuticals used for medical imaging all have a fairly short half life. What are main advantages of this?

____

____

____

[2 marks]

END OF TEST (60 MARKS)

TRIAL TEST 3:
ELECTRICAL CIRCUITS

Time allowed:	**60 minutes**	**Section One –** Short response	18 marks
Total marks:	**60**	**Section Two –** Problem solving	30 marks
		Section Three – Comprehension	12 marks

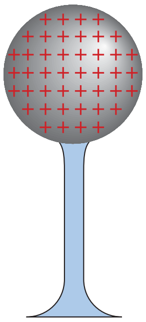
SECTION ONE – SHORT RESPONSE (18 MARKS)

1. Draw a diagram showing:

(a) forces acting between two positive charges a small distance apart from each other.

(b) the charge distribution on a balloon which has been rubbed with a woollen cloth.

(c) two points, X and Y, where X is at a higher electrical potential than Y with reference to the positively charged metal sphere below.



[3 marks]

2. Electric current can be defined as a measure of the rate of flow of electric charge which passes a particular point in an electric circuit. Indicate the unit and symbol for each of these quantities by completing the following table.

	UNIT	SYMBOL
size of an electric current		
electric charge		
time		

[3 marks]

3. (a) Define “potential difference”.

[1 mark]

(b) A CRT monitor has a potential difference in its picture tube of 3.00×10^{3} V across which electrons (with charge of 1.60×10^{-19} C) are accelerated. Calculate the energy acquired by the electrons as they are accelerated through this potential difference.

[2 marks]

4. (a) State Ohm’s Law.

[1 mark]

(b) Complete and fully label the graph grid below to illustrate Ohm’s Law for metal X and metal Y where the resistance of X is greater than the resistance of Y. Assume both X and Y are ohmic conductors.

[2 marks]

5. Show using suitable circuit diagrams:

(a) The design for a two way switch.

[1 mark]

(b) How to connect a minimum number of 2 Ω resistors to give an effective resistance of 5 Ω.

[2 marks]

6. A light globe in an outdoor entertainment area is rated at 100 W and operates from a 240 V power supply.

(a) Calculate the current which flows through the globe.

[1 mark]

(b) Determine the resistance of the globe's filament while operating.

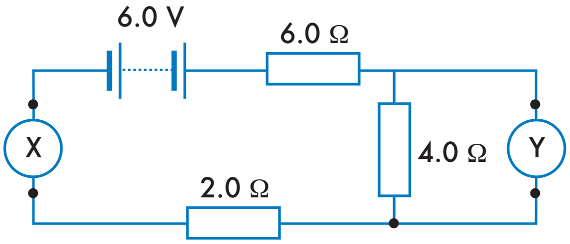
[1 mark]

(c) How is the measured resistance of the globe prior to it being turned on likely to compare with your result in (b)? Explain.

[1 mark]

SECTION TWO – PROBLEM SOLVING (30 MARKS)

7. Rob has set up a circuit as shown to investigate current flow (I) and potential difference (V) for different parts of the circuit.



(a) Rob wishes to determine the current flowing in the 4 Ω resistor. In which position, X or Y, should she place an ammeter to do this? Explain your choice.

[2 marks]

(b) From the data in the circuit diagram calculate the current that is likely to be flowing through the 4 Ω resistor.

[2 marks]

(c) Calculate the potential difference across the 4 Ω resistor.

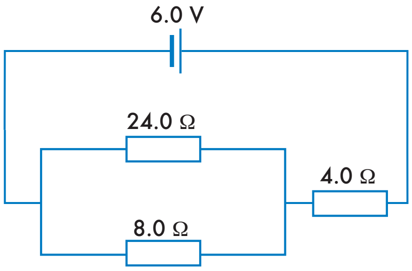
[2 marks]

(d) Calculate the power consumed by the whole circuit.

[2 marks]

8. For the following circuit diagram, calculate:

(a) the total resistance of the circuit,



[3 marks]

(b) the current flowing through each resistor, and

[6 marks]

(c) the power dissipated in the 8.0 Ω resistor.

[3 marks]

9. A physics student was given a “black box” which had two resistors connected in some way inside the box and to two terminals on the box. One of the resistors was known to have a resistance of 4.0 Ω while the resistance of the other was unknown. To determine the resistance of the unknown resistor, the student connected a variable power supply, an ammeter and the box in series and obtained the following readings:

APPLIED VOLTAGE	CURRENT
6.0 V	2.0 A
9.0 V	3.0 A

(a) Draw a circuit diagram of the circuit which is most likely in the box. Explain why you have chosen this particular circuit.

[4 marks]

(b) What is the value of the unknown resistor?

____

____

____

[6 marks]

SECTION THREE – COMPREHENSION (12 MARKS)

10. Read the following newspaper article "The Luckiest Night of Ben Franklin's Life" which appeared in the Washington Post on Friday, April 5, 1991, then answer the questions which follow.

The Luckiest Night of Ben Franklin's Life

Three Hints: A Kite, A Key & A Storm

By Joel Achenback
Washington Post Staff Writer

Why wasn't Ben Franklin electrocuted when he flew that kite in the thunder-storm?

Because lightning didn't strike the kite.

Had it done so, "then it's bye-bye," says Martin Uman, professor of electrical engineering at the University of Florida and author of "All About Lightning". (Someday we will do away with these prolonged identifications and simply stick with "expert").

"He was lucky he didn't get killed," Uman says. "He didn't know quite what he was doing."

Thank you, thank you, Mr Uman. For years, since we were wee babes, we had been bothered by the Franklin experiment, because it seemed about as wise as sticking a knife in a wall socket, or pulling on a mule's tail, or dangling your younger brother over the edge of a balcony.

Franklin himself never described the kite experiment. The secondhand account of Joseph Priestly states that Franklin flew a kite with string that could conduct electricity. At the bottom of the string was a key. Franklin did not touch either the string or the key, but was instead linked by a short piece of silk thread that didn't conduct electricity.

The payoff came when a sizeable spark jumped from the key to Franklin's knuckle. Lightning did not cause the spark. What did? Energy. Put it that way. There is always a flow of electrons between the sky and the ground and it's magnified during a thunderstorm. This doesn't always result in the massive surge we call lightning; usually, we can't see it. Franklin's kite string, however, provided a channel for that energy flow, but it still was a relatively modest current. The year after Franklin's experiment, a Swedish physicist tried something similar with a metal rod. Lightning struck. Alas, he became a fritter.

One other thing: Is it safe to talk on the phone in a thunderstorm? Uman says no. The current can jump right out of the receiver if lightning hits the phone line. "People get killed every year. Lots of people get their eardrums blown out."

(a) Explain why the author believes that Franklin's experiment seemed about as wise as sticking a knife in a wall socket.

[2 marks]

(b) Compare the properties of the string and the silk thread used in the experiment and suggest why Franklin used the string and the silk thread in the way that he did.

[2 marks]

(c) A spark jumped from the key to Franklin's knuckle. How was the key able to acquire electrical energy to produce a spark in the first place and explain why the spark jumped to his knuckle?

[2 marks]

(d) The author described the current in the string as a "relatively modest current". What factors would determine if the current was to be relatively modest or very large?

[3 marks]

(e) What precautions should the Swedish physicist have taken to avoid becoming a 'fritter'?

[3 marks]

END OF TEST (60 MARKS)

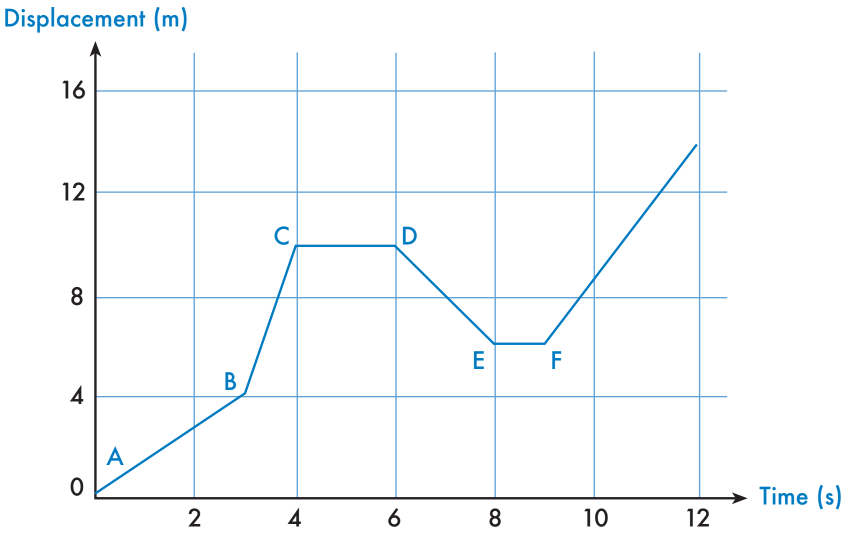
TRIAL TEST 4:
LINEAR MOTION AND FORCE

Time allowed: **60 minutes**
Total marks: **60**

Section One – Short response 18 marks
Section Two – Problem solving 30 marks
Section Three – Comprehension 12 marks

SECTION ONE – SHORT RESPONSE (18 MARKS)

1. Consider the following *s* / *t* graph and answer the questions below.



(a) Describe the state of motion represented by the intervals:

(i) A → B

(ii) C → D

[1 mark]

(b) Determine the velocity during the intervals:

(i) A → B

(ii) E → F

[1 mark]

(c) Determine the average velocity for the whole journey.

[2 marks]

2. List the following as either vector or scalar quantities.

Speed, mass, acceleration, weight, area, energy temperature, velocity.

Vectors____

Scalars ____

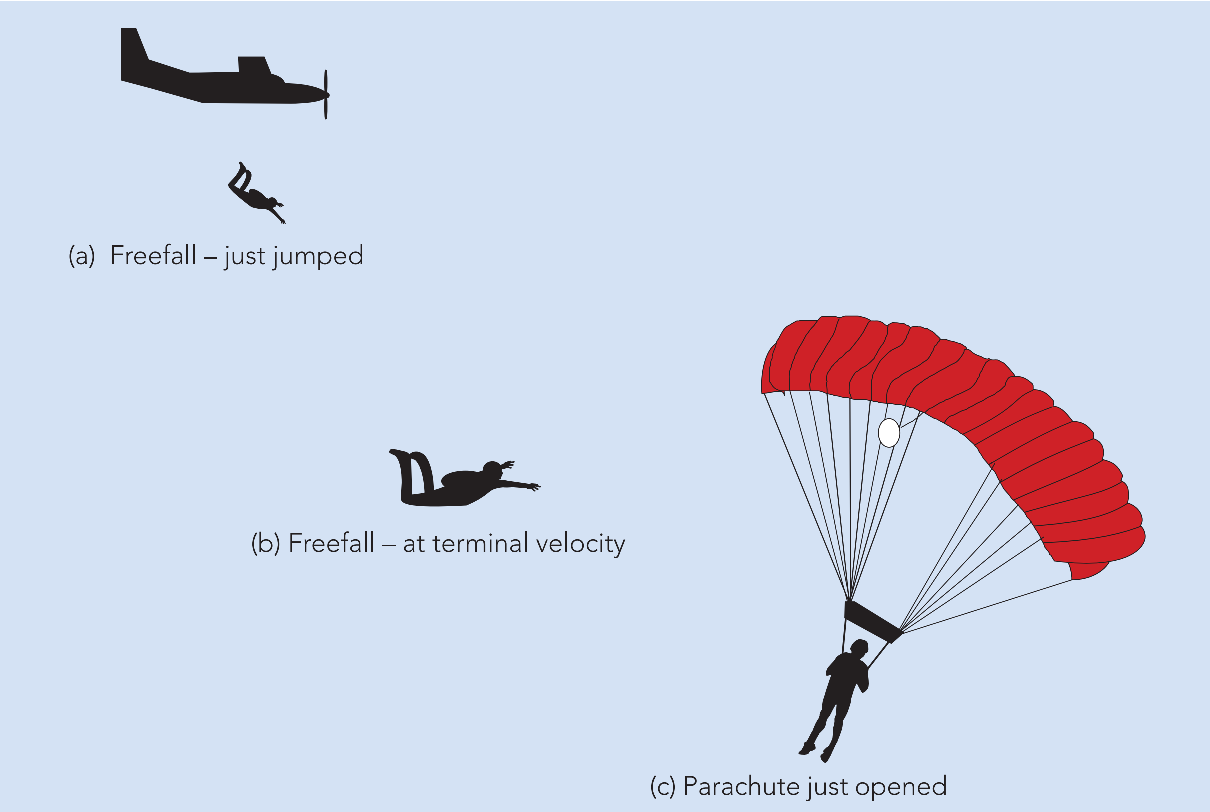
[2 marks]

3. Charlotte and Sophia are pulling on a cart with forces of 80.0 N West and 60.0 N East. Draw a vector diagram for this situation and find the resultant force.

[3 marks]

4. A skydiver dives from an aircraft in flight and initially goes into free fall without opening her parachute. After achieving maximum velocity she opens the parachute as she prepares to reach the ground safely.

Draw force diagrams to **show the forces acting** on the skydiver in each of the following cases. Also in each case indicate the resultant force.



(a) Freefall – just jumped

(b) Freefall – at terminal velocity

(c) Parachute just opened

[3 marks]

5. Jeremy throws a ball vertically into the air and it reaches a maximum height of 25.0 m above the point that he released it.

(a) Calculate the initial velocity of the ball.

[1 mark]

(b) As the ball returns Jeremy allows it to fall to the ground rather than catching it. If the velocity of the ball as it reaches the ground is 22.8 ms^{-1} determine the height from which Jeremy initially threw the ball.

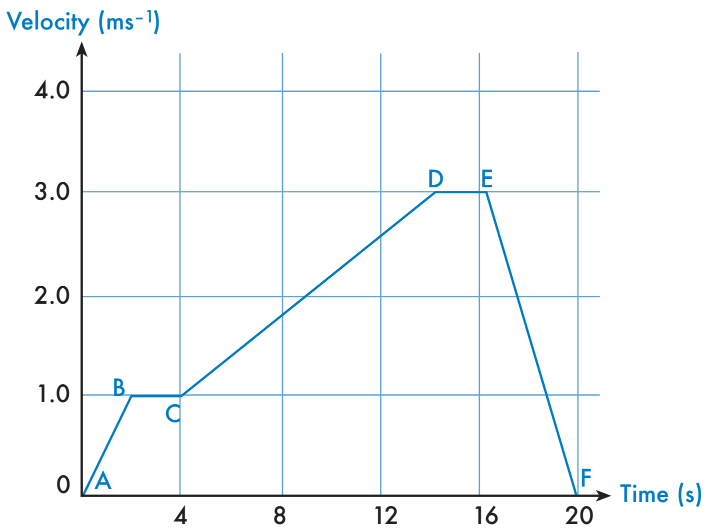
[3 marks]

6. Chelsea averaged a power output of 425 W when she won a race to run up the 24 flights of stairs in a building. If each flight of stairs is separated by 3.00 m and Chelsea has a mass of 55.0 kg, calculate the time taken for her to reach the top of the stairs.

[2 marks]

SECTION TWO – PROBLEM SOLVING (30 MARKS)

7. Consider the following v/t graph and answer the questions below.



(a) Describe the state of motion represented by the intervals:

(i) A → B ______________________

(ii) E → F ______________________

[2 marks]

(b) Determine the displacement:

(i) at $t = 4.0$ s.

____

____

(ii) during the fourth second.

____

____

[3 marks]

(c) (i) When is acceleration a maximum?

____

____

(ii) Determine acceleration at $t = 10.0$ s.

____

____

[3 marks]

8. John is going for his favourite bike ride at a steady 18.0 kmh^{-1} when he passes his stationary friend Jason. Jason immediately sets off after John and accelerates at 2.4 ms^{-2} until he reaches his top speed 3.0 s later. He then continues at this top speed as he cycles towards John.

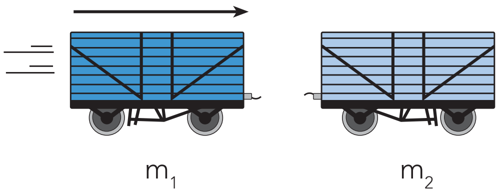
(a) Does Jason catch John? Show clearly all calculations.

[5 marks]

(b) If so, how far did he travel before he reached John?

[5 marks]

9. In the railway marshalling yards a carriage of mass 5.0×10^4 kg, m_1 , was shunted against a stationary smaller carriage, m_2 , which has half the mass of the shunted carriage. The heavier carriage was travelling at 4.0 ms^{-1} and the two couple together on impact.



(a) Calculate the velocity with which the two carriages move off;

[4 marks]

(b) Compare the kinetic energy of the larger carriage before the coupling with that of both carriages after coupling.

[4 marks]

(c) Has the principle of conservation of energy been obeyed? Explain your answer.

[4 marks]

SECTION THREE – COMPREHENSION (12 MARKS)

10. During a physics experiment to obtain data for a velocity-time graph for Bronwyn riding her bicycle on a level road, Mike wrote the following:

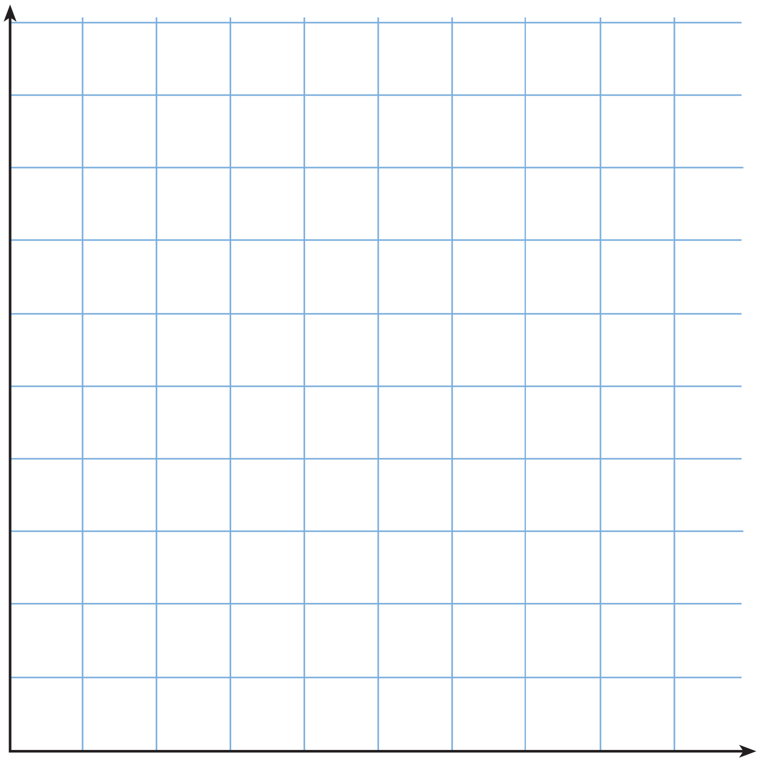
Bronwyn accelerated her bike uniformly from rest and called out when she reached a velocity of 6 ms^{-1}*. This took her 10 s. For the next 10 s she maintained a constant velocity of 6 ms*$^{-1}$ *before accelerating uniformly for 5 s when she told me afterwards that her velocity was 14 ms*$^{-1}$*. She maintained this velocity for a further 15 s before applying the brakes uniformly. It took her 10 s to stop.*

(a) Use what Mike wrote to:

(i) tabulate the data

[2 marks]

(ii) draw a velocity-time graph.



[3 marks]

(b) Use your graph to determine the:

(i) acceleration between 20 s and 25 s.

[2 marks]

(ii) deceleration when braking.

[2 marks]

(iii) total distance travelled by Bronwyn.

[3 marks]

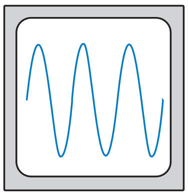
END OF TEST (60 MARKS)

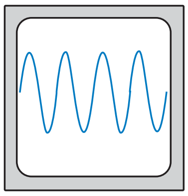
TRIAL TEST 5:
WAVES

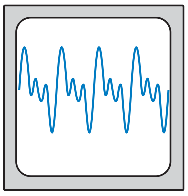
Time allowed:	**60 minutes**	**Section One –** Short response	18 marks
Total marks:	**60**	**Section Two –** Problem solving	30 marks
		Section Three – Comprehension	12 marks

SECTION ONE – SHORT RESPONSE (18 MARKS)

1. Three different sounds A, B and C were played into a microphone connected to a cathode ray oscilloscope (CRO). Their individual traces are shown below. Assume similar settings of the CRO for each sound.


Sound A


Sound B


Sound C

Describe the difference/s that a listener would notice between:

(a) Sounds A and B.

(b) Sounds B and C.

[2 marks]

2. Under similar conditions sound waves of all frequencies travel at the same speed. From your knowledge of the nature of sound explain clearly why this statement must be correct.

[2 marks]

3. A loud sound travelling in cool air, encounters a region of warm air. Indicate briefly how each of the following may be affected as the sound passes through to the warm air and beyond.

(a) Velocity ______________________________

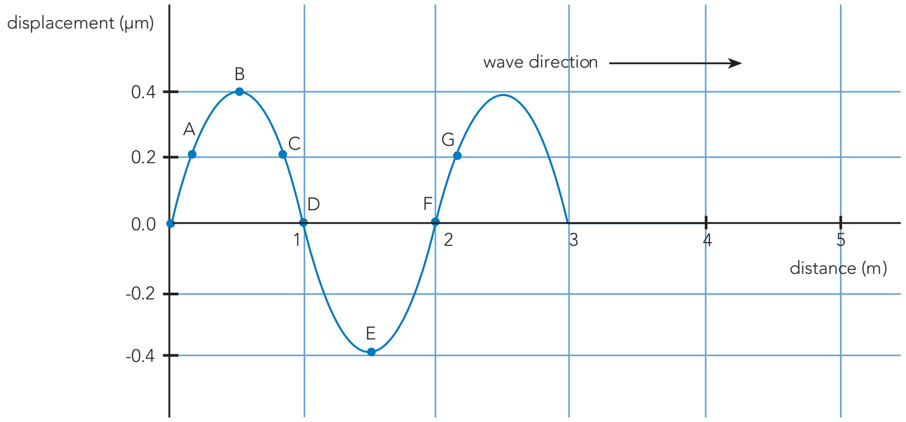
(b) Direction ______________________________

(c) Wavelength ______________________________

(d) Frequency ______________________________

[4 marks]

4. The graph below shows the displacement of air molecules from their mean position at an instant in time, $t = 0$.



(a) From the graph determine the following:

(i) amplitude ______________________________

(ii) wavelength ______________________________

(iii) two points in phase ______________________________

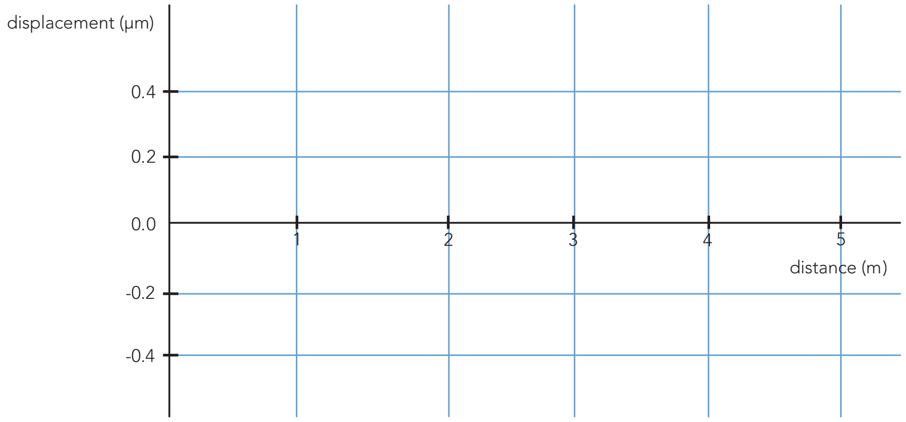
(iv) two stationary points ______________________________

(v) a point moving away from its mean position ______________________________

(vi) two points moving with greatest speed ______________________________

[3 marks]

(b) Redraw the graph above to show how it will look at $t = \frac{T}{2}$ (T = period).



[3 marks]

5. Echo sounding devices are often used to determine the depth of oceans and rivers. These devices emit short pulses of ultrasound (about 50 kHz) towards the ocean floor and then detect the reflected sound.

(a) Explain how it is possible to measure ocean depth in this way.

[1 mark]

(b) Why are such high frequency sounds used for this purpose?

[1 mark]

(c) If the delay time between sounding and receiving a signal is 110 ms what is the depth of the water? (You may need to refer to physical data tables.)

[2 marks]

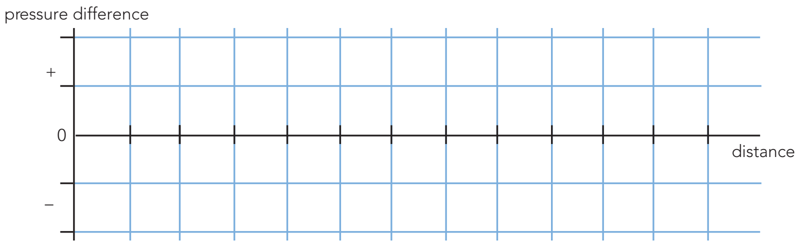
SECTION TWO – PROBLEM SOLVING (30 MARKS)

6. A loudspeaker emits a sound of 1.00 kHz towards a microphone as shown. The microphone is 2.00 m from the speaker. Assume the speed of sound is 340 ms^{-1}.

(a) Determine the wavelength of the sound being emitted.

[1 mark]

(b) Complete the graph below to show how air pressure varies with distance from the microphone 4.00 ms after the commencement of the sound. Assume that initially a compression wave leaves the cone. Pressure levels are arbitrary. Select appropriate distance units.

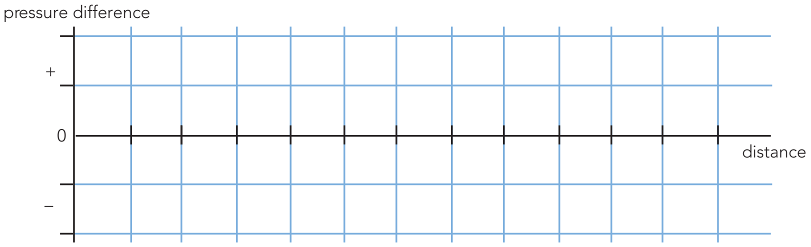


[4 marks]

(c) How long will it take sound to reach the microphone after the commencement of the sound?

[1 mark]

(d) Sketch a pressure difference versus time graph as would be recorded at the microphone for the first 0.010 seconds of sound emitted by the speaker.



[4 marks]

7. Paula and Melissa carried out an experiment using a sound level meter to take readings of the sound from a CD player. Their results for different distances are shown below.

DISTANCE FROM CD PLAYER (m)	2	4	6	8	10	12
SOUND INTENSITY (Wm^{-2})	1.0×10^{-3}	2.5×10^{-4}	1.12×10^{-4}	6.31×10^{-5}	4.0×10^{-5}	1.58×10^{-5}

(a) By what factor did the intensity of the sound change between:

(i) 2 m and 4 m

(ii) 4 m and 8 m

[3 marks]

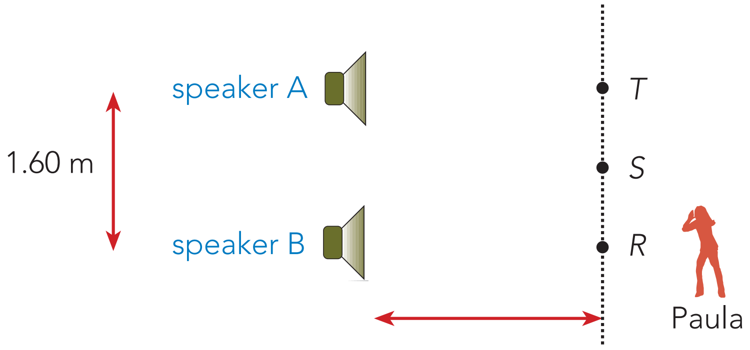
(b) Use the data to construct a graph of sound intensity versus distance from the source.

[4 marks]

(c) Using the graph (or data) determine the relationship between sound intensity and the distance of a sound from its source.

[3 marks]

8. Paula and Jake connect two similar speakers (*A* and *B*) to a sound frequency generator so that each speaker will emit sounds that are in phase and of equal frequency and intensity. They investigate the intensity of the sound produced at points along a line parallel to the speakers. They use a frequency of 685 Hz. Dimensions of the layout of the experiment are shown below.



Paula walks along the line from R to T and notices that maximum sound intensities occur at *R* and *T* (directly in front of the speakers) and at *S* (a point equidistant from each speaker). Quiet spots are noticed in between.

(a) What is the cause of this effect? Explain clearly.

[2 marks]

(b) From the diagram determine the difference in the distance between *AT* and *BT*.

[3 marks]

(c) Use your result in (b) to determine the velocity of sound during this experiment.

[3 marks]

(d) Paula and Jake decide to double the frequency of the sounds from each of the speakers while keeping the intensities equal. Describe the difference that Paula will notice as she again walks from R to *T*.

[2 marks]

SECTION THREE – COMPREHENSION (12 MARKS)

9. Read the following article and then answer the questions on the next page.

Locating earthquakes

The actual location of a seismic event such as an earthquake can be found if the seismic recordings from at least three recording stations are combined and analysed. Seismic waves are caused by events such as earthquakes and they travel through the earth's crust in different forms and varying speeds. Seismic waves travel through the earth's crust both as longitudinal and transverse waves.

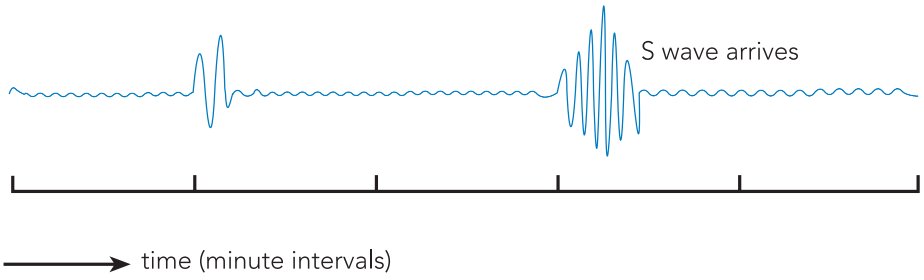
The longitudinal waves travel almost twice as fast as the transverse waves and are the first to arrive after a seismic event. They are referred to as *P waves* (primary). They tend to be heard rather than felt. Their velocity in the earth's crust can range between 4.0 km/sec to 8.0 km/sec, in water it is 1.5 km/sec and in air, the usual speed of sound, about 0.33 km/sec.

The transverse waves travel more slowly and are second to be felt. They are called *S waves* (secondary). These waves have more energy, move at right angles to their direction of travel and are generally more destructive. Their velocity in the earth's crust can range between 2.5 km/sec to 4.0 km/sec. S waves do not travel through liquids or air.

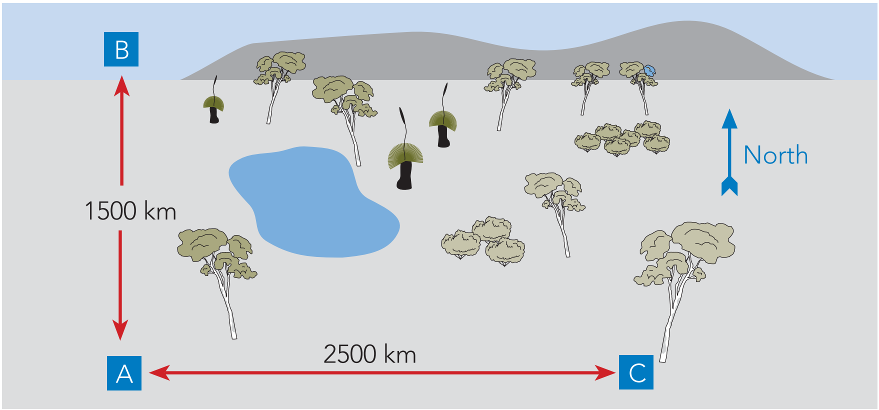
The difference in time of arrival between P and S waves provides a simple and direct way of calculating the distance of a seismic event. Conversion tables have been established by analysing data from many earthquakes and these give distances of about 9.0 km for every second of time difference. To find the actual location an earthquake event the first step is to find its distance from three different recording stations. These distances can then be plotted to scale as circles around each recording station. The epicentre is where the circles intersect.

The seismic recording from a recording station A is shown below. Similar recording were also made at two other stations B and C, located 1500 km due North and 2500 km due East of recording station A. Their relative positions are also shown below. Use all the information and data given to answer the following questions.

Seismogram – Recording station A



Seismic Stations



(a) Why do you think P waves (primary waves) are so called?

[2 marks]

(b) P waves tend to be both felt and heard while S waves can only be felt. Explain the likely reason for this difference.

[2 marks]

(c) A seismogram for the arrival of P and S waves at a recording station A is shown above. Use it to determine the time difference of arrival of the P and S waves at recording station A.

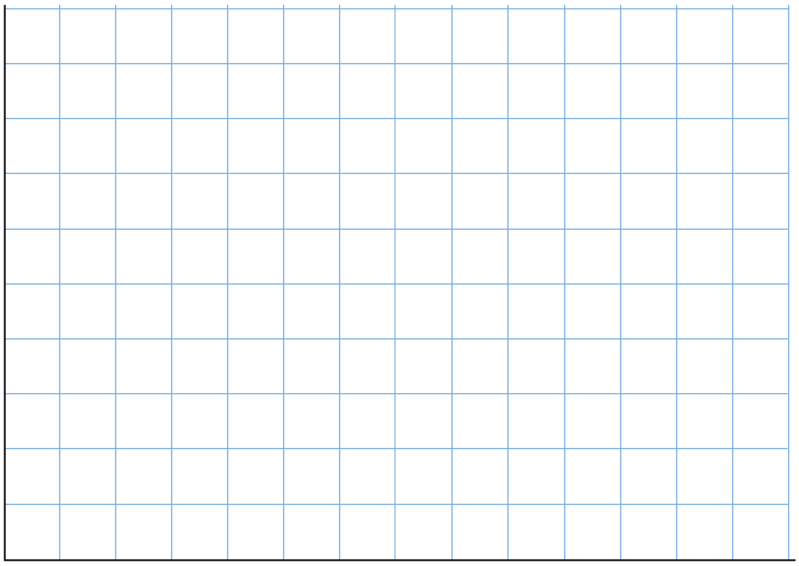
[2 marks]

(d) Assuming, as given above, a value of 9.0 km for every second of S-P time difference, calculate the distance of the seismic event from station A.

[2 marks]

(e) Similar analysis of the recordings at stations B and C establish that they are 1200 km and 1750 km from the seismic event. The relative locations of stations A, B and C are given above. Use the graph grid below to show these locations to scale. Then, by also drawing circles to scale, representing the distances of each station from the seismic event, determine the approximate location of the epicentre.

[4 marks]



END OF TEST (60 MARKS)

ANSWERS TO CHAPTER AND REVIEW QUESTIONS

CHP 1: HEATING PROCESSES

1. Chapter Questions

1.1 *Heat refers to energy that is transferred from one body to another. A body does not actually contain heat but contains internal energy.*

1.2

(a) (i) *cold water*
    (ii) *hot nail*

(b) *The average kinetic energy of the atoms of metal will fall while that of the molecules of water will rise until they are the same.*

1.3

(a) *The ocean contains the greatest amount of internal energy due to its vast size.*

(b) *On entering the water your body (at 37°C) transfers heat to the cooler ocean water and feels cold. Even though the ocean has in total more internal energy the average kinetic energy of the water particles is less than those of your body. Hence heat is continually transferred from you to the ocean water.*

1.4

(a) *The hand from the icy water would feel warm whereas that from the warm water would feel cold.*

(b) *The skin of the hand in the icy water would have reached a temperature close to zero while held there. When placed in the tap water which is at a comparatively higher temperature heat would flow to the hand giving the sensation of warmth. The reverse occurs to the hand going from warm to cold.*

1.5

The fans keep air moving past your skin. This has a cooling effect as it aids the evaporation of moisture from your body by continually removing air saturated with water vapour from your sweat.

1.6

- *Wet clothes will dry out even on a cold day.*
- *Water spilt on the floor will eventually disappear (evaporate), even on cold days.*

1.7

Wind increases the evaporation of water off a wet body. This evaporation draws a lot of heat from the body (latent heat of vaporisation) and will eventually lead to hypothermia.

1.8

Evaporative air conditioners depend on the evaporation of water to create a cooling effect. On humid days evaporation is more difficult to achieve and hence they are not as effective.

1.9.

The room will not change in temperature. The refrigerator is simply a heat pump, drawing heat from inside the fridge and letting it out behind the fridge. If the fridge door is open there is no net effect. In fact the temperature of the room may increase because the energy used by the motor and pump will be converted to heat energy.

1.10

(a) *Heat from the fire reaches your face and hands by radiation. Other parts of your body not facing the fire are shielded from radiation and feel cool.*

(b) *Hot air near and above the burning logs is less dense than cold air and rises. As it rises it causes a vertical flickering of the flames.*

(c) *Wood is a very poor conductor of heat. One end of the stick can be quite cold while the other end is actually burning.*

1.11

Air is an excellent insulator. Also trapped air is not able to move and transfer heat by convection.

1.12

(a) *The Earth is at a much lower temperature than the sun. Cooler bodies radiate longer wavelengths.*

(b) *The Earth's temperature would be much lower since much of the heat that the atmosphere now re-radiates back to Earth would escape into space. In effect the greenhouse effect of the atmosphere would be reduced.*

1.13

In the late afternoon the sun's rays reach us more obliquely. This means that they pass through more atmosphere, hence more absorption, and they cover a larger surface area in the ground, hence less intensity.

1.14

(a) *Useful energy* = *(efficiency)(energy input)*
$= (35/100)(38 \times 10^6) = 13.3 \times 10^6$ *J per L of fuel* $= 13.3$ *MJ*

(b) *For each 100 km*
fuel used = *8.5 L*
useful energy = $(8.5 \times 13.3 \times 10^6)$
$= 1.13 \times 10^8$ *J* = *113 MJ*

(c) Energy lost = energy input – useful energy output

For each 100 km = $(8.5 \times 38 \times 10^6) - 1.13 \times 10^8$ J

= 2.10×10^8 J = 210 MJ

1.15

(a) Total surface area of panels

= 4×1.60 = 6.40 m^2

Solar energy per hour

= $(6.40)\ (900)\ (60 \times 60)$

= 20.7×10^6 J = 20.7 MJ

(b) Electrical energy

= (efficiency) (solar energy input)

= $(21.5/100)\ (20.7 \times 10^6)$

= 4.45 MJ per hour

1. Review Questions

1.

(a) True.

(b) False. True statement: The temperature of a body will decrease when the average kinetic energy of the particles in that body decreases.

(c) True.

(d) False. True statement: A temperature of 100 K is less than 100°C. (100 K = –173°C)

(e) True.

2.

(a) Heat is a form of energy which is transferred from one place to another due to a difference in temperature between them.

(b) Internal energy refers to the sum of the kinetic and potential energies of the molecules in an object.

(c) The temperature of an object is its degree of hotness (or coldness) on a chosen temperature scale. Temperature is a measure of the average kinetic energy of the individual molecules in the object.

3. The piece of lead possesses internal energy not heat. Heat is energy transferred from the lead as a result of change in temperature (e.g. a piece of lead heated by a Bunsen burner then placed in a beaker of cold water – heat is transferred from the lead to the water because of their difference in temperature).

4. No. Correctly speaking, the term 'internal energy' should have been used.

5. No. The internal energies of the lead and water may be different but both the water and the lead are at the same temperature. Heat will only be transferred from one to the other if they each have a different temperature.

6. Electrical resistance, voltage generated at junction of two metals, expansion.

7.

(a) The mercury-in-glass thermometer uses the property that the length of a column of mercury changes with a change in temperature.

(b) The platinum resistance thermometer uses the property that the electrical resistance of platinum changes with a change in temperature.

8.

(a) (i) ice point, 0°C; steam point, 100°C
   (ii) absolute zero, 0 K; ice point, 273 K, steam point, 373 K

(b) ice point: the temperature of melting pure ice
steam point: the temperature at which pure water can exist in equilibrium with its vapour (at standard atmospheric pressure)

9.

(a) (i) 310 K (ii) 253 K (iii) 387 K

(b) (i) –93°C (ii) 20°C (iii) 77°C

10. The ice must be pure. Impurities will lower the freezing point of water.

11.

(a) False. True statement: When a substance is heated while in a solid phase there is an increase in the kinetic energy of its particles.

(b) False. True statement: Substances with a low specific heat capacity require relatively less heat to increase their temperature.

(c) True.

(d) True.

(e) False. True statement: As liquids change to gases heat is absorbed.

12.

(a) They were both at the same temperature.

(b) The jam has a higher specific heat capacity than the pastry and can transfer a larger amount of heat to the tongue, compared to pastry, when it is tasted. (It is the water content of the jam which is responsible for the higher specific heat – and burning Cathy's tongue!)

13. Paraffin oil, as it is most likely to have a smaller specific heat capacity than water.

14. As a coolant due to its very high specific heat capacity.

15. m = 1.50 kg
T_1 = 25.0°C
Q = 3.00×10^5 J
c = 4.18×10^3 J kg^{-1}C^{-1}
T_2 = ?
$Q = m\,c\,\Delta T$
$3.00 \times 10^5 = 1.50 \times 4.18 \times 10^3 \times \Delta T$

$$\Delta T = \frac{3.00 \times 10^5}{1.50 \times 4.18 \times 10^3}$$

$\therefore \Delta T$ = 47.8°C

$\therefore$ Temperature after 2 mins = 47.8 + 25.0
= 72.8°C

16. m = 150 kg
T_1 = 20.0°C
T_2 = 65.0°C
c = 4.18×10^3 J kg$^{-1°}$C^{-1}
Q = ?

(a) $Q = m\,c\,\Delta T$
$= 150 \times 4.18 \times 10^{3} \times 45.0$
$= 28.2 \times 10^{6} J$
(= 28.2 MJ)

(b) Lie $= \dfrac{2.82 \times 10^{7}}{7.00 \times 10^{3}}$
$= 4031$ s
$= 67.2$ minutes

17. $T_{1\ iron} = 90.0°C$
$T_{2\ iron} = T$
$T_{1\ water} = 20.0°C$
$T_{2\ water} = T$
$m_{water} = 30.0\ g = 0.030\ kg$
$m_{iron} = 50.0\ g = 0.050\ kg$
$c_{iron} = 4.50 \times 10^{2} J\ kg^{-1°}C^{-1}$
$c_{water} = 4.18 \times 10^{3} J\ kg^{-1°}C^{-1}$

Heat lost by iron = Heat gained by water
$m\,c\,\Delta T_{iron} = m\,c\,\Delta T_{water}$
$0.050 \times 4.50 \times 10^{2} \times (90.0 - T) =$
$0.030 \times 4.18 \times 10^{3} \times (T - 20.0)$
$2025 - 22.5\ T = 125.4\ T - 2508$
$147.9\ T = 4533$
$T = 30.6°C$
$\therefore$ Final temperature $= 30.6°C$

18. In addition to No. 15
$T_{1\ alum} = 20.0°C$
$T_{2\ alum} = T$
$m_{alum} = 0.200\ kg$
$c_{alum} = 9.00 \times 10^{2} J\ kg^{-1°}C^{-1}$

Heat lost by iron = Heat gained by water + heat gained by aluminium

$m\,c\,\Delta T_{iron} = m\,c\,\Delta T_{water} + m\,c\,\Delta T_{alum}$
$0.050 \times 4.50 \times 10^{2} \times (90.0 - T) =$
$0.030 \times 4.18 \times 10^{3} \times (T - 20.0) +$
$0.200 \times 9.00 \times 10^{2} \times (T - 20.0)$
$2025 - 22.5\ T = 125.4\ T - 2508 + 180\ T$
-3600
$327.9\ T = 8133$
$T = 24.8°C$
$\therefore$ Final temperature $= 24.8°C$

19. The heat is used to overcome attractive forces between the molecules in the solid. This loosens the molecules from their 'fixed' positions to allow them to 'flow' over each other.

20. $m_{kettle} = 3.00\ kg$
$c_{kettle} = 4.00 \times 10^{2} J\ kg^{-1°}C^{-1}$
$\Delta T_{kettle} = 80.0°C$
$m_{water} = 1.00\ kg$
$c_{water} = 4.18 \times 10^{3} J\ kg^{-1°}C^{-1}$
$\Delta T_{water} = 80.0°C$
$L_{v} = 2.26 \times 10^{6} J\ kg^{-1}$
$m_{s} = ?$
$Q = 2.00 \times 10^{3} J\ s^{-1}$
Ht supplied = Ht of kettle + Ht of water + Ht of Vap'n
$Q = m\,c\,\Delta T_{k} + m\,c\,\Delta T_{w} + m\,L_{v}$

$10.0 \times 60.0 \times 2.00 \times 10^{3} =$
$(3.00 \times 400 \times 80.0) + (1 \times 4180 \times 80.0) +$
$m \times 2.26 \times 10^{6}$

$m = \dfrac{0.770 \times 10^{6}}{2.26 \times 10^{6}}$

$= 0.34\ kg$

Mass of water vaporised $= 3.40 \times 10^{-1} kg$
Mass of water left in kettle $= 6.60 \times 10^{-1} kg$

21. No. The breeze does assist in the rate at which her sweat evaporates from her body. As the sweat evaporates, the latent heat of vaporisation required is supplied by Hannah's body. This loss of heat results in the cooling sensation that she experiences.

22. Ice. As the ice melts it requires a large amount of heat (latent heat of fusion) which is additional to the heat gained by the water at 0°C in the mixture. As a consequence the soft drink will cool more effectively with the ice as most of the heat supplied to the ice will come from the soft drink.

23. $m = 0.050\ kg$
$L_{f} = 3.34 \times 10^{5} J\ kg^{-1}$
$Q = ?$
$Q = mL$
$= 0.050 \times 3.34 \times 10^{5}$
$= 1.67 \times 10^{4} J$

24. $m_{ice} = 0.050\ kg$
$L_{f} = 3.36 \times 10^{5} J\ kg^{-1}$
$c_{w} = 4.18 \times 10^{3} J\ kg^{-1°}C^{-1}$
$m_{w} = 0.300\ kg$
$T_{1} = 20.0°C$
$T_{2} = T$
Heat gained by ice = Heat lost by water
$m\,L + m\,c\,\Delta T = m\,c\,\Delta T$
$= (0.050)(3.34 \times 10^{5}) + (0.050)$
$(4.18 \times 10^{3})(T - 0)$
$= (0.300)(4.18 \times 10^{3})(20.0 - T)$
$1.67 \times 10^{4} + 209T = 25080 - 1254T$
$1463\ T = 8380$
$T = 5.7°C$
$\therefore$ Final temperature of water $= 5.7°C$

25. Steam at 100°C condensing to water at 100°C on the arm releases the latent heat of vaporisation acquired during the formation of the steam. It is this heat which is responsible for producing the more severe burn.

26.
(a) True.
(b) False. True statement: Heat transfer by convection currents can occur in gases and liquids.
(c) True.
(d) False. True statement: Radiation of heat is possible through a vacuum.
(e) True.

27. *Liquid sodium is used as a coolant because itis a good conductor and very effective at removing heat from the reactor.*
28. ***Gases:*** *Collisions between gas molecules at different temperatures result in the transfer of heat from high temperature molecules to low temperature molecules. This continues until all molecules are (on average) equally energetic.*

    Liquids: *The molecules which are at a high temperature transfer heat due to their more energetic movements by collision with cooler molecules. Heat is transferred to cooler regions of the liquid by this process.*

    Metals: *Electrons which are free to move about the metal lattice are able to rapidly transfer energy to the cooler regions of the metal by collisions with other electrons and metal atoms.*
29. *Water and glass are poor conductors of heat. The transfer of heat by conduction to the ice from through the glass and water occurs slowly.*
30. *By fluffing its feathers the bird traps air around it beneath the outer layer of feathers. The pockets of trapped air reduce heat loss from the bird's body because air is a poor conductor of heat.*
31. *Pockets of air trapped between the fibres of the coat reduce heat loss from our body by conduction because both air and the fibres are poor conductors of heat.*
32. *Both the bricks and the insulating material have a low thermal conductivity. The insulating material slows down the rate of heat loss by conduction.*
33. *Conduction involves the transfer of heat as molecules of the liquid collide with cooler molecules in the liquid. Convection is the transfer of heat through the liquid by the liquid's heated molecules actually moving through the liquid. The heated portion of the liquid expands, becomes less dense than the surrounding liquid and so rises through the liquid.*
34. *The heat can be transferred from the fins by radiation and convection. The vertical fins can cool by convection by allowing the hot surrounding air to rise as a convection current.*
35. ***Conduction:*** *The flask consists of a double glass wall which contains a vacuum preventing conduction. The cork/plastic stopper is made of a material which is a poor conductor of heat.*

    Convection: *The vacuum prevents convection. When the stopper is removed, heat can be lost by convection through the top of the flask.*

    Radiation: *The glass walls of the flask are silvered to reduce radiation and reflect any radiated heat back into the flask.*
36. *Radiation. Most of the heated air rises, through convection, up the chimney.*
37. *Joan's woollen clothing reduced the transfer of body heat to the outside cold air, enabling her to remain warm. The low temperature around Peta's arms and legs resulted in heat loss from her body to the surroundings. Peta's body shivered to increase her metabolism so as to produce more heat to replace that which was lost to the surroundings.*
38. *The efficient functioning of a refrigerator relies on the heat extracted from within the refrigerator to be released outside of the refrigerator – from the coils at the back of the refrigerator. Heat dissipated from the coils must be dispersed (mainly by convection) from the coils if the refrigerator is to be efficient. An air gap around the refrigerator enables the convection to occur.*

39.

(a) *False. True statement: Energy from the sun is mostly short wavelength radiation.*

(b) *True.*

(c) *True.*

(d) *False. True statement: Dark coloured materials are the best absorbers of heat.*

(e) *True.*

40. *The intensity is less due to the effect of the atmosphere and the angle of the sun. The atmosphere always absorbs and reflects some of the solar radiation. At a latitude of 32^0 the radiation from the sun is spread over a larger area and this further reduces the intensity.*
41. *The greenhouse effect is caused by gases in the atmosphere trapping heat being radiated by the Earth. This allows most of the heat that would have otherwise being lost to space to heat up the atmosphere and also be partially returned to Earth.*

    The gases mainly responsible for the greenhouse effect are water vapour (H_2O) and carbon dioxide (CO_2). Methane (CH_4), ozone (O_3), chlorofluorocarbons (CFC's) and nitrous oxide (N_2O) also contribute.

    An increase in greenhouse gases would most likely contribute to global warming and cause significant changes to our environment.

42.

(a) *Useful energy = (efficiency)(energy input)*
= $(27/100)(35 \times 10^6)$
= 9.45×10^6 J per L of fuel
= 9.45 MJ

(b) *For each 10 km*
fuel used = 0.95 L
useful energy = $(0.95 \times 9.45 \times 10^6)$
= 8.98×10^6 J = 8.98 MJ

(c) *Energy converted = $(0.95 \times 35 \times 10^6)$*
= 33.2×10^6 J = 33.2 MJ

43.

(a) P = 60 W = 60 Js^{-1}

3% = 60 × 3/100 = 1.8 Js^{-1}

(b) The remainder of the energy is converted to heat. This warms the light bulb and fittings and is dissipated into the surroundings.

(c) Fluoro 5 times more efficient (15/3) = 5

Wattage needed = 60/5 = 12 W

44. Air high on the mountains gets very cold, contracts and becomes more dense. This cold air then flows down the mountain slopes into the valleys.

CHP 2: IONISING RADIATION AND NUCLEAR PHYSICS

2. Chapter Questions

2.1.

(a) $^{232}_{90}Th \rightarrow ^{228}_{88}Ra + ^{4}_{2}He$, alpha particle

(b) $^{24}_{12}Mg^{*} \rightarrow ^{24}_{12}Mg + \gamma$, gamma ray

(c) $^{3}_{1}H \rightarrow ^{3}_{2}He + ^{0}_{-1}e$, electron ($\beta^{-}$)

(d) $^{11}_{6}C \rightarrow ^{11}_{5}B + ^{0}_{+1}e$, positron ($\beta^{+}$)

2.2.

(a) 25% original nuclei remain

∴ 2 half-lives have elapsed

∴ 1 half-life = 7.6 / 2 = 3.8 days

(b) Nuclei reduced by (½) for each half-life.

To have less than 1% $(½)^{?} \leq 1/100$

We know $(½)^{6} = 1/64$ and $(½)^{7} = 1/132$

∴ require a little less than 7 half-lives

(7 × 3.8 days) ≈ 25 days

(c) Radum 226

(d) Polonium 218

$^{222}_{86}Rn \rightarrow ^{218}_{84}Po + ^{4}_{2}He$

2.3.

(a) Specimens older than say 50,000 years will have very little carbon-14 activity (less than 0.2%). This makes precise measurements difficult. Specimens that are say only 100 years old will have a carbon-14 to carbon-12 ratio which is only very slightly (< 1%) different to modern day specimens. Again, errors in measurements will make accurate datings impossible.

(b) • Carbon-14 concentration in the atmosphere was the same in the past as it is today.

• The rate of decay of carbon-14 has always been constant.

2.4.

(a) Thorium, Radium, Thallium, Lead, etc.

(b) Uranium-238 or lead-206 depending on the age of the rock. U-238 has a very long half-life and probably more than half remains. If the rock was more than one half-life of age, the majority of all the other daughter isotopes would have all decayed to Pb-206, since they have relatively short half-lives.

(c) Radon-222 or polonium-214. Radon is a gas with a short half-life. Po-214 has an extremely short half-life.

(d) Approximately 4.5 billion years. Uranium-238 eventually decays to lead-206. Most of the isotopes in the decay series have relatively short half-lives. Hence if half the U-238 has decayed one half-life has elapsed.

2.5.

- high activity: high number of decays per second – this ensures easier detection
- physical half-life: time taken for half of the radioisotope to decay. Short half-life means the patient is not exposed for long periods. biological half-life: time taken for body to expel half of the radioisotope by normal bodily functions. Short biological half-life also means minimum exposure to patient.

2.6.

(a) Absorbed dose simply considers radiation energy absorbed by the body. Dose equivalent factors in the different biological effects of α, β, γ radiation.

(b) Dose equivalent measured in sievert gives more accurate measure of biological effect.

2.7.

(a) LD50/30 means that 50% of exposed people would die within 30 days.

(b) absorbed dose = $\frac{\text{energy absorbed}}{\text{mass of tissue}}$

∴ energy absorbed = (4) (85)

= 340 J

(since QF for γ radiation = 1)

2.8.

(a) The Earth's atmosphere acts as a shield and absorbs cosmic radiation.

(b) Pilots and air crew are exposed for a much greater time during their working life. A record of total exposure would ensure that a "safe limit" was not surpassed.

(c) dose = rate × time

= (5 uSv) (200 h) = 1000 uSv

yearly dose at ground level

= (0.03) (24) (365)

≈ 263 uSv

Pilot receives the equivalent of about four yearly doses during his flights.

2.9. Graph shows highest BE/nucleon for medium sized atoms. Light atoms can combine to a more stable state and release binding energy. Large atoms can do so by splitting.

2.10.

for A = 200 BE / nucleon ≈ 7.7 MeV/nucleon

for A = 100 BE / nucleon ≈ 8.2 MeV/nucleon

Energy released ≈ (200) (0.5) ≈ 100 MeV

2.11. Energy released = (0.21534) (931.5)

= 200 MeV

2. Review Questions

2.1 Radiation

1.

(a) True.

(b) False. True statement: In radioactive β^- decay the atomic mass number increases by one.

(c) True.

(d) True.

(e) False. True statement: The activity of a radioactive sample is measured in bequerels (Bq)

2.

(a) Atomic number: the number of protons in the nucleus of all atoms of a particular element.

(b) Mass number: the number of protons and neutrons in the nucleus of an atom.

(c) Isotope: isotopes are atoms which have the same proton number but different number of neutrons.

(d) Nuclide: refers to an atom with a particular number of protons and a particular number of neutrons.

(e) Atomic mass unit: the unit of atomic mass is equal to 1/12 of the mass of the ${}^{12}_{6}\mathrm{C}$ atom.

3. (a) 6,6
(b) 1,0
(c) 5,6
(d) 92,143

4. (a) ${}^{23}_{11}\mathrm{Na}$
(b) ${}^{16}_{8}\mathrm{O}$
(c) ${}^{39}_{19}\mathrm{K}$
(d) ${}^{90}_{38}\mathrm{Sr}$

5. The nuclei have too few or too many neutrons which cause instability and radioactive decay.

6. ***Radioactive decay:*** occurs when an unstable nucleus disintegrates to acquire a more stable state and emits radiation in the process.
Radiation: emitted when an unstable nucleus decays and may be energetic particles (alpha particle, beta particle) or energy in the form of electromagnetic radiation with a very short wavelength (gamma rays).

7. Alpha particle: consists of two protons and two neutrons (identical to a helium nucleus).
Beta particle: electron.
Gamma radiation: electromagnetic radiation of very short wavelength.

8.

(a) alpha (b) beta (c) alpha
(d) beta (e) gamma (f) beta
(g) gamma (h) alpha (i) gamma
(j) alpha, beta, gamma (k) beta

9.

(a)

(i) The thin piece of paper would absorb alpha particles, only some beta particles and no gamma radiation. The slight drop in count rate suggests the source does not emit alpha particles.

(ii) The magnetic field deflects some radiation (e.g. beta) away from the detector and not other (e.g. gamma).

(iii) Gamma rays are not deflected by a magnetic field nor the sheet of aluminium – the count rate should be the same in both cases. Beta particles are absorbed by this thickness of aluminium.

(b) Beta and gamma radiation.

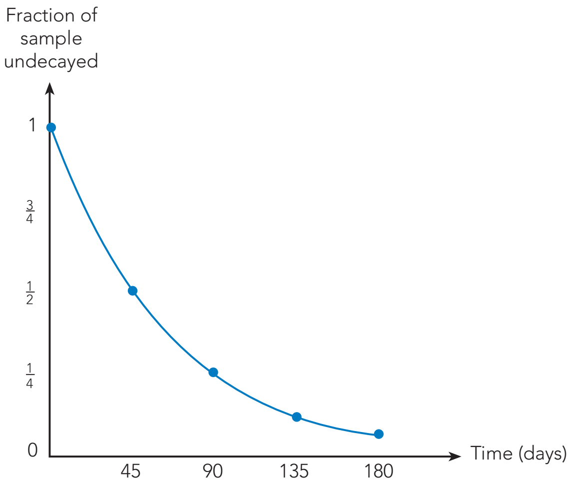
10.

(a) ${}^{A}_{Z}\mathrm{X} \rightarrow {}^{A-4}_{Z-2}\mathrm{Y} + {}^{4}_{2}\mathrm{He}$ (b) ${}^{A}_{Z}\mathrm{X} \rightarrow {}^{A}_{Z+1}\mathrm{Y} + {}^{0}_{-1}\beta$

11. (a) ${}^{4}_{2}\mathrm{He}$ (b) ${}^{90}_{39}\mathrm{Y}$ (c) ${}^{14}_{6}\mathrm{C}$ (d) ${}^{226}_{86}\mathrm{Rn}$

12.

50% of the atoms decay over 45 days.
∴ half-life of = 45 days.
½ of the sample remains undecayed after 45 days
¼ of the sample remains undecayed after 90 days
∴ of the sample remains undecayed after 135 days
1⁄16 of the sample remains undecayed after 180 days
1⁄16 of the sample remains undecayed after 6 months.



13. Half life of the sample is 3 minutes.

LIE (mins)	0	3.00	6.00	9.00	12.0	15.0
Fraction of Activity	1	½	¼	⅛	1⁄16	1⁄32

LIE (mins)	18.0	21.0	24.0	27.0	30.0
Fraction of Activity	1⁄64	1⁄128	1⁄256	1⁄512	1⁄1024

After 30.0 minutes the activity will be reduced to ½ of its original rate.
∴ Activity 1⁄1024 × 4.30 × 10^4
= 42.0 decays per second.

14. Many radionuclides with a short half-life would have an unsuitably low dose rate by the time they arrived in Australia and then were distributed to the appropriate hospitals.

15. The radionuclide concentrates in the organ to which the imaging is to apply. Successful imaging will rely on sufficient radionuclide to be concentrated in the organ and for the radionuclide to have enough activity. To prevent excessive radiation exposure to nearby and other body tissue a radionuclide with a short half-life is used, i.e. its activity will quickly fall away to a very low level.

2.2 Radiation – Effects and Uses

16.
(a) True.
(b) True.
(c) False. True statement: Radioisotopes used in medical diagnosis typically have short-lives.
(d) False. True statement: Alpha particles are more ionising than gamma rays.
(e) True.

17. The localisation and concentration of the radioactive iodine results in the surrounding thyroid cancer receiving a much higher radiation dose than other body tissues. This higher radiation dose is sufficient to destroy the thyroid cancer cells.

18. (i) detect defects in welds, alloys, pipes
(ii) food preservation
(iii) sterilisation of insect pests
(iv) sterilisation of medical dressings

19.
(a) (i) watches with luminous dials (0.01 millisievert/annum)
(ii) colour T.V. sets (< 0.01 mSv/annum)
(iii) ceramics/glass tinted with thorium salts
(b) The exposures are considered to be trivial and are not dangerous.

20. The radiation dose is higher because the subsonic airliner takes longer to complete the trip. The crew member receives a lower radiation dose at the lower altitude but the time of exposure is longer due to the longer flight time.

21.
(a) ${}^{232}_{90}\text{Th} \rightarrow {}^{228}_{88}\text{Ra} + {}^{4}_{2}\text{He}$
(b) Alpha particles are more likely to penetrate the softer/thinner internal tissues than the tougher external skin layer – such as on the arms, hands and legs.
(c) Do not eat/smoke in dust prone areas, thoroughly wash hands before eating.

22.
(i) cosmic radiation
(ii) radionuclides in the soil/rocks
(iii) radioactivity of our body tissues (containing potassium-40)
(iv) radon – in houses

23. alpha, alpha, beta

24.
(a) The radon-222 gas can be inhaled, its decay products being deposited on the linings of both the air passages and the lungs. Some decay products have a long half-life and irradiate the tissue linings for many years.
(b) (i) Provision of adequate ventilation.
(ii) Sealing porous building materials.

25. Ionising radiation may
(i) kill a body cell, preventing further cell division
(ii) damage a cell which divides to produce abnormalities in the daughter cells.

26. Alpha particle: it can only penetrate a small section of the body tissue before being absorbed. It therefore rapidly loses its energy causing ionisations to occur in cells which are close together.

27.
(i) keep an adequate distance from the source
(ii) use shielding techniques.

2.3 Nuclear Energy

28.
(a) True.
(b) False. True statement: Nuclear fusion of two small nuclei to form a larger one causes the release of energy due to an overall decrease in mass.
(c) True.
(d) True.
(e) False. True statement: The purpose of graphite moderators in nuclear reactors is to slow down the neutrons.

29.
(a) ${}^{238}_{92}\text{U}$

mass of protons = $92 \times 1.00728\ u$
= $92.66976\ u$
mass of neutrons = $146 \times 1.00866\ u$
= $147.26436\ u$
mass of electrons = $92 \times 0.00055\ u$
= $0.05060\ u$
Total mass = $239.98472\ u$

The sum of the mass of the individual particles is greater than their combined mass within the atom.

(b) When the atom is formed some of the mass of the constituent particles is converted into energy ($E = mc^2$) leaving the mass of the atom less than the sum of the masses of its constituents.
(c) Mass defect.

30. Mass defect = $239.98472\ u - 238.05080\ u$
= $1.93392\ u$
(a) Convert u to kg where
$1\ u = 1.6605 \times 10^{-27}\ kg$
$1.93392\ u = 1.93392 \times 1.6605 \times 10^{-27}\ J$
$E = mc^2$
$= 3.21127 \times 10^{-27} \times (3.00 \times 10^{8})^2$
$\therefore$ Binding energy = $2.890 \times 10^{-10}\ J$
Binding energy per nucleon
$= 2.890 \times 10^{-10} \div 238$
$= 1.214 \times 10^{-12}\ J$

(b) *Binding energy*

$= 2.890 \times 10^{-10} \div 1.6 \times 10^{-19}$

$= 1.805 \times 10^{9}$ eV

Binding energy per nucleon

$= 1.805 \times 10^{9} \div 238$

$= 7.59$ MeV

31.

$^{232}_{92}U \rightarrow {}^{228}_{90}Th + {}^{4}_{2}He + \text{energy}$

∴ *Mass difference*

$= m_{LHS} - m_{RHS}$

$= 232.037156u - (228.028741u + 4.002602u)$

$= 0.005813\ u$

$= 9.6525 \times 10^{-30}$ kg

Energy released $= m\,c^2$

$= 9.6525 \times 10^{-30} \times (3.00 \times 10^{8})^2$

$= 8.6872 \times 10^{-13}$ J

$= (8.6872 \times 10^{-13}) \div (1.6 \times 10^{-19})$

$= 5.43$ MeV

32. *A moderator, usually made of graphite, slows down the neutrons and increases the probability of neutron capture.*

33.

(a) $^{1}_{0}n + {}^{235}_{92}U \rightarrow {}^{141}_{56}Ba + {}^{92}_{36}Kr + 3\ {}^{1}_{0}n + \text{energy}$

(b) *Mass difference*

$= m_{LHS} - m_{RHS}$

$= (1.00866 + 235.04393) -$

$(140.91440 + 91.92630 + 3.02598)$

$= 236.05259 - 235.86668$

$= 0.18591\ u$

$= 3.08704 \times 10^{-28}$ kg

Energy released

$= m\,c^2$

$= 3.08704 \times 10^{-28} \times (3.00 \times 10^{8})^2$

$= 2.77833 \times 10^{-11}$ J

$= (2.77833 \times 10^{-11}) \div (1.602 \times 10^{-19})$

$= 1.73646 \times 10^{8}$ eV

∴ *Energy released* = 174 MeV

34.

From Q.30, energy released by 1 atom

$= 2.78 \times 10^{-11}$ J

With 40% efficiency, energy released

$= 0.4 \times 2.78 \times 10^{-11}$

$= 1.11 \times 10^{-11}$ J

No. of atoms required to release 300×10^{6} J *in 1 sec*

$$= \frac{300 \times 10^{6}}{1.11 \times 10^{-11}}$$

$= 2.70 \times 10^{19}$ *atoms per sec*

No. of atoms fissioned in 1 year

$= 2.70 \times 10^{19} \times (365 \times 24 \times 60 \times 60)$

$= 8.52 \times 10^{26}$ *atoms*

Now, 235.04393 g of contains 6.02×10^{23} *atoms*

∴ *mass required*

$$= \frac{8.52 \times 10^{26}}{6.022 \times 10^{23}} \times 235.04392$$

$= 3.33 \times 10^{5}$ g

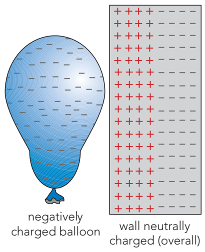
Mass of $^{232}_{92}U$ *required* = 333 kg *per year*

CHP 3: ELECTRICAL CIRCUITS

3. Chapter Questions

3.1. *Protons are located in the nucleus of atoms and are not free to move.*

3.2. *The charged balloon (say negatively charged) induces an opposite charge on the surface of the wall it is near. Attraction between opposite charges results.*



3.3. $\text{No } (e^-) = \dfrac{1}{1.6 \times 10^{-19}} = 6.25 \times 10^{18}$

3.4.

$$P = \frac{W}{t} = \frac{qV}{t} = \left(\frac{q}{t}\right)(V)$$

$\therefore P = V\,I$

3.5. *As temperature rises atoms vibrate more strongly. This inhibits the flow of charge from atom to atom.*

3.6.

(a) (i) *At 1.5 V* $I \approx 18$ A

$$\therefore R = \frac{V}{I} \approx \frac{1.5}{18} \approx 8.3 \times 10^{-2}\ \Omega$$

(ii) *At 3.0 V* $I \approx 23$ A

$$\therefore R = \frac{V}{I} \approx \frac{1.5}{23} \approx 6.5 \times 10^{-2}\ \Omega$$

(b) $P = V\,I = (3)\,(23)$

$= 69$ W

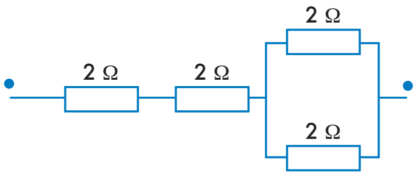
3.7.

(a) *C would conduct most current. The greater the cross-sectional area the smaller the resistance.*

(b) *B would conduct least current. Resistance increases with length.*

3.8. *Parallel circuits offer several paths for current to flow. Hence resistance is alwasy lowered when resistors are placed in parallel.*

3.9.



3. Review Questions

3.1 Electricity

1.

(a) *True.*

(b) *False. True statement: The friction between two surfaces rubbing together, such as shoes on a carpet, can cause a static charge due to the transfer of electrons.*

(c) *True.*

(d) *True.*

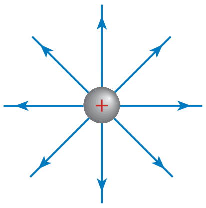
(e) *False. True statement: The rate of flow of an electric charge in a conductor is called the current.*

2. *No. Some electrons from the surface atoms of the woollen cloth are transferred to the rod leaving the cloth with an equal amount of positive charge. The negative charge is not created and a conservation of charge occurs between the rod and the woollen cloth.*

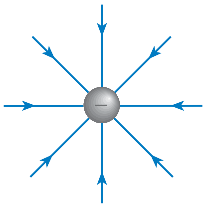
3. *A metal rod is a good conductor and any charge on the rod will quickly flow along the rod and through the body to the Earth. An insulator does not have 'free' charge carriers (electrons) to enable the charge to flow throughout the insulator.*

4.

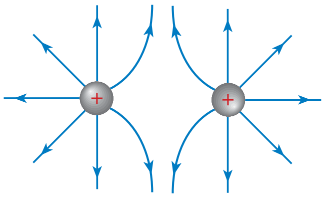
(a)



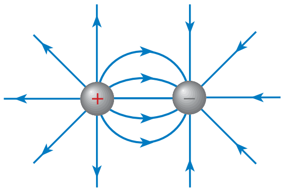
(b)



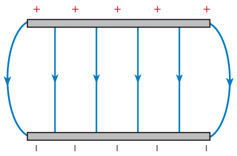
(c)



(d)



(e)



5. *Electric current is the rate of flow of electric charge past a point in a conductor and may be conventional current or electron current. Conventional current refers to the direction of current flow round a conducting circuit and is shown as the direction in which a flow of positive charge moves (i.e. from a positively charged point to a negatively charged point).*

6. $q = I\,t$

$= 3.50 \times (30.0 \times 60)$

$= 6.30 \times 10^3$ C

7. $q = I\,t$

$200 = I\,(3.00 \times 60)$

$$I = \frac{200}{3.00 \times 60} = 1.11 \text{ A}$$

$\therefore$ *Current in the lamp* $= 1.11$ A

8.

(a) $P = V\,I$

$2.40 \times 10^3 = V \times 10$

$\therefore V = 240$ V

(b) $$P = \frac{\text{Work}}{\text{time}}$$

Work $= P \times$ time

$= 2.4 \times 10^3 \times 3600$

$= 8.64 \times 10^6$ J

$\therefore$ *Amount of heat energy* $= 8.64 \times 10^6$ J

(c) $q = I\,t$ OR $W = V\,q$

$= 10 \times 3600$ $\quad 8.64 \times 10^6 = 240\,q$

$= 3.60 \times 10^4$ C $\quad \therefore q = 3.60 \times 10^4$ C

9.

(a) $P = V\,I$

$2.50 = 4.50\,I$

$\therefore I = 0.556$ A

(b) $q = I\,t$

$= 0.556 \times 30.0$

$= 16.7$ C

(c) $W = V\,q$ OR $W = P\,t$

$= 4.50 \times 16.7$ $\quad = 2.50 \times 30.0$

$= 7.50 \times 10^1$ J $\quad = 7.50 \times 10^1$ J

3.2 Electrical Circuits

10.

(a) *True.*

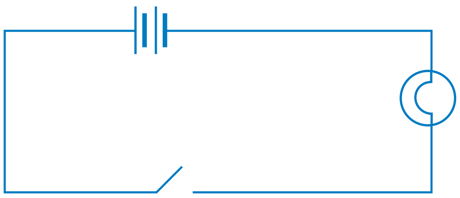
(b) *True.*

(c) *False. True statement: The electrical resistance of a thick copper wire is less than that of a thin copper wire of the same length. Thick copper wire provides more paths for the electric current.*

(d) *True.*

(e) *False. True statement: It is possible to combine 4.0 Ω resistors to give an overall resistance of 6.0 Ω. (Two 4.0 Ω resistors in parallel combined in series with one 4.0 Ω resistor).*

11.



12. *The current through a conductor is proportional to the potential difference across it provided its temperature remains constant.*

13.

(a) $P = VI$

$100 = 12.0\ I$

$\therefore I = 8.33\ A$

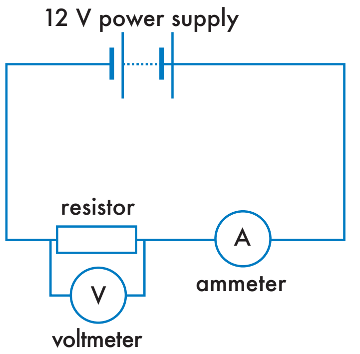
(b) $V = IR$

$12.0 = 8.33\ R$

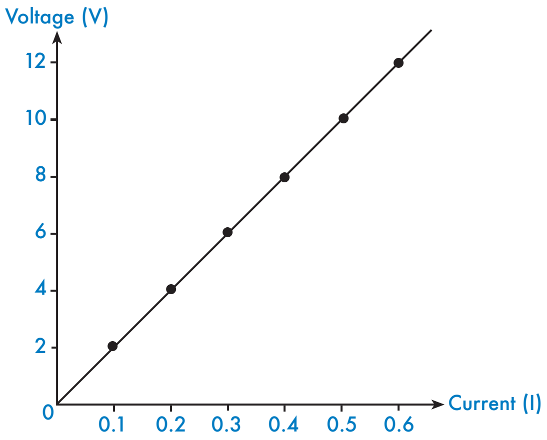
$\therefore R = 1.44\ \Omega$

14\.

(a)



(b)



Resistance = gradient

$$= \frac{10 - 4}{0.5 - 0.2}$$

$$= \frac{6}{0.3}$$

$= 20$

$\therefore$ Resistance $= 20\ \Omega$

15\.

(a) $V = IR$

$3.00 = 0.300\ R$

$\therefore R = 10.0\ \Omega$

(b) $P = VI$

$= 3.00 \times 0.300$

$\therefore P = 0.900\ W$

16\.

(a) Potential difference across each globe

$$= \frac{12.0}{16} = 0.75\ V$$

(b) Power $= \dfrac{V^2}{R}$

$$R = \frac{(12)^2}{24} = 6.00\ \Omega$$

Resistance of circuit $= 6.00\ \Omega$

$\therefore$ Resistance of each globe $= \dfrac{6.00}{16}$

$= 0.375$ ohm

17\. Total resistance

$= 15$ globes $\times\ 0.375$ ohm

$= 5.625$ ohm

Power consumption $= \dfrac{V^2}{R}$

$$= \frac{(12.0)^2}{5.625}$$

$= 25.6\ W$

18\. Maximum power output $= VI$

$= 240 \times 10$

$= 2400\ W$

$\therefore$ Number of 75 W light globes which would blow the fuse $= \dfrac{2400}{75}$

$= 32$

$\therefore$ Maximum number of light globes to be used

$= 31$

19\.

(a) $R_T = R_1 + R_2$

$= 11 + 7$

$= 18\ \Omega$

$\therefore$ Resistance of circuit $= 18\ \Omega$

(b) $V = IR$

$9.0 = I \times 18$

$\therefore I = 0.50\ A$

$\therefore$ Current through circuit $= 0.50\ A$

20\.

(a) $$\frac{1}{R_T} = \frac{1}{18} + \frac{1}{6}$$

$$= \frac{1 + 3}{18}$$

$$= \frac{4}{18}$$

$\therefore R_T = 4.5\ \Omega$

$\therefore$ Resistance of circuit $= 4.5\ \Omega$

(b) $V = IR$

$9.0 = I \times 4.5$

$\therefore I = 2.0\ A$

(c) $I_1 = \dfrac{9.0}{1.8}$

$= 0.5\ A$

(d) $I = I_1 + I_2$

$2.0 = 0.5 + I_2$

$\therefore I_2 = 1.5\ A$

$\therefore PD = IR$

$= 1.5 \times 6.0$

$= 9.0\ V$

21\.

(a) In parallel section: $\dfrac{1}{R_T} = \dfrac{1}{48} + \dfrac{1}{24}$

$$= \frac{1 + 2}{48} = \frac{3}{48}$$

$\therefore R_T = 16\ \Omega$

$\therefore$ Total resistance of circuit $= 8.0 + 16$

$= 24\ \Omega$

(b) $V = IR$

$6.0 = I \times 24$

$\therefore I = 0.25\ A$

(c) P.D. across parallel section $= I R_T$

$= 0.25 \times 16$
$= 4.0\ V$
$\therefore$ P.D. across 24 Ω resistor = 4.0 V

(d) $P = I^2 R$
$= (0.25)^2 \times 8.0$
$= 0.50\ W$
$\therefore$ Power dissipated through 8.0 Ω resistor = 0.50 W

22.
(a) $V = I R$
$= 0.50 \times 20$
$= 10\ V$

(b) P.D. across the rheostat = 12 – 10 = 2.0 V
$\therefore V = I R$
$2.0 = 0.50 R$
$R = 4.0\ \Omega$
$\therefore$ Resistance of the rheostat = 4.0 Ω

23. Electrical energy from the power source is converted to internal energy in and released as heat from the coil. The potential difference across the coil produces a current in the coil which in turn releases energy in the form of heat. This heat raises the temperature of the water.

24.
(a) Electrical energy supplied $= P \times t$
$= 2400 \times 50.0 = 1.20 \times 10^5\ J$

(b) No. Some of the internal energy transformed from the electrical energy in the kettle will be used to heat the kettle and escape to the surroundings.

25. A fuse is a short thin piece of wire which has a low melting point. When an electric current which is larger than what it is designed to carry passes through the fuse, it heats up, melts and breaks the circuit. This prevents the larger currents from flowing into and damaging electrical appliances or from causing a fire due to an appliance overheating.

26.
(a) $P = V I$
$180 = 240 I$
$\therefore I = 0.75\ A$
$\therefore$ Use a 2.00 A fuse.

(b) Components in the television set may be damaged by the excessive current or a fire may start in the television set before the 10.0 A fuse is made to ‘blow’ by this larger current.

27. An earth leakage circuit breaker can:
(i) switch off an electric current in a very short time
(ii) quickly stop an electric shock or reduce the chances of an electrocution occurring
(iii) prevent a fire occurring in an electrical appliance due to a fault causing a current to flow through earth wires.

28. Wires may be damaged in the accident or by moving the damaged vehicle causing short circuits. The large currents supplied by the car’s battery can cause leads which are short circuited to overheat and start a fire. Also, hot wires and sparks could ignite spilt petrol.

29. Parallel: so that either of them can supply an electric current to the car’s circuits in the event that one breaks down while the car is in use.

30.
(a) $P = V I = 12.0 \times 3.50 \times 10^2 = 4.20 \times 10^3\ W$

(b) $R = \dfrac{V}{I} = \dfrac{12.0}{3.50 \times 10^2} = 3.43 \times 10^{-2}\ \Omega$

(c) The battery to starter motor wire is much thicker for it to have a small resistance (less than $3.43 \times 10^{-2}\ \Omega$) and to carry a very large current.

CHP 4: LINEAR MOTION AND FORCE

4. Chapter Questions

4.1
(a) speed is a scalar, velocity is a vector and involves direction.

(b) $t = 160\ s$
(i) distance = 400 + 200 ≈ 600 m
displacement = 200 m
(ii) $\therefore$ average speed $= \dfrac{600\ m}{200\ s} = 3.00\ ms^{-1}$

(iii) instantaneous velocity is given by the slope of the graph at t = 160 s. Slope is the same from t = 100 to t = 220 hence

instantaneous vel $= \dfrac{-400\ m}{120\ s} = -3.33\ ms^{-1}$

4.2
(i) ***return journey***

average speed $= \dfrac{350\ m}{65\ s} = 5.4\ ms^{-1}$

average vel $= \dfrac{250\ m}{65\ s}$

$= 3.8\ ms^{-1}$ 37°N of W

(ii) ***the whole journey***

average speed $= \dfrac{700\ m}{130\ s} = 5.4\ ms^{-1}$

average vel = 0 (since zero displacement)

4.3 Scalars: mass, density, volume, work done, speed, distance, area, temperature
Vectors: velocity, momentum, weight, acceleration, impulse

4.4 The car is slowing down hence acceleration is negative.

4.5 The car is constantly changing direction hence its velocity (although not its speed) is changing. A changing velocity means acceleration is occurring.

4.6 *The stopping distance includes the distance travelled while the driver is reacting and beginning to apply the brakes.*

4.7

(a) *Maximum displacement is:*
60 m + 20 m = 80 m from starting point

(b) (i) $t = 80, s = 80 - (20 \times 2) = 40\ m$
(ii) $t = 100, s = 80 - (40 \times 2) = 0\ m$

4.8

(i) *Both vehicles are travelling at the same speed.*

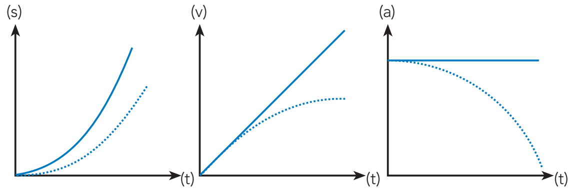
(ii) $a = \dfrac{v - u}{t} = \dfrac{30 - 0}{15} = 2.0\ ms^{-2}$

(iii) *Areas under the two graphs are equal when* $t = 22.5\ s$

4.9

(a) (i) *Surface area.* (ii) *Speed.*

(b)



(i) *s/t graph would be less steep and eventually straight*
(ii) *v/t graph – less steepness and eventually flat*
(iii) *a/t graph – starts at* $9.8\ ms^{-2}$ *but eventually goes to zero.*

4.10

(a) *A → B uniform acceleration (≈* $9.8\ ms^{-2}$*)*
B → C acceleration becomes less and eventually zero
C → D constant velocity (no acc.)
D → E rapid uniform deceleration
E → F constant velocity
F → G rapid uniform deceleration

(b) *Estimate area under graph*

(i) $\approx [(30 \times 45)\text{-}(10 \times 20)] + [5 \times 95] \approx 1625$
$\therefore \approx 1600\ m$

(ii) *Maximum acceleration* $\approx \dfrac{5 - 45}{3}$
$\approx -13\ ms^{-2}$ *(parachute opens)*

(iii) *Height when parachute opened*
≈ area under graph for $t \geq 30\ s$
$\approx 5 \times 95 \approx 500\ m$

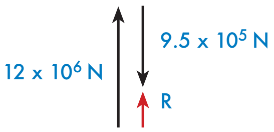
(iv) *Terminal velocity =* $45\ ms^{-1}$ *(parachute unopened).*

4.11

(a)

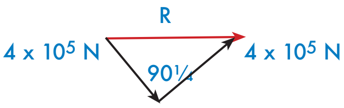
R = –6000 N (car is probably braking) car accelerates to the left

(b)



$R = 2.5 \times 10^5$ *N upwards*
rocket is accelerating upwards

(c)



$R^2 = (4 \times 10^5)^2 + (4 \times 10^5)^2$
$= 5.66 \times 10^5$ *N to the right*
cargo boat accelerating to the right

4.12

(a) *Your body tends to remain at rest (relative to the ground) while the car is accelerating forward. Relative to the car, you are moving backwards.*

(b) *Since the engine is turned off, the net force acting on the car is the frictional force opposing its motion.*

4.13

The negative (–) sign indicates the opposite direction to the sedan's initial velocity.

4.14

(a) *Impulse is the same since it is just the change in momentum.*

(b) *Force windscreen exerts on passenger equals* 1.26×10^3 *Ns.*

4.15

(a) *between* $\approx t = (17.5 - 20.0)\ s$
i.e. greatest slope

(b) $F_{max} \approx 5\ N$

(c) *Ft = area under graph ≈ 220 Ns.*

4.16

(a) *The hand pushes on the cricket ball (action) as it is being bowled and the cricket ball pushes back on the hand with an equal and opposite force (reaction). This means that relative to the hand the ball does not move although both hand and ball are being accelerated to a higher velocity by the bowler. When the hand no longer pushes on the ball the ball no longer accelerates but continues to move with whatever velocity it has.*

(b) *When you are in free fall the force acting on you is your weight or attraction due to the Earth (action). You are also attacting the Earth towards you with an equal and opposite force (reaction). In fact the Earth is also falling towards you (as you fall towards it) but at an almost insignificant rate due to its large mass.*

(c) *Your weight force acts down on the couch (action) while your couch pushes back up on you with an equal and opposite reaction force (reaction). This means there is no net force between you and the couch and you remain comfortably at rest.*

4.17

Although the forces are equal they are acting on different masses. The football has a smaller mass and accelerates the greatest amount. The foot, which is attached to the body, accelerates to a smaller extent and in the opposite direction (that is, it eventually stops).

4.18

The stretched rubber balloon forces the air out as it returns to its normal size. Since overall momentum is maintained, the air rushing out in one direction (action), causes the balloon to move in the opposite direction (reaction).

4.19

(a) $W = m\,g_e = (52)\,(9.8)$
$= 510$ N (on Earth)

(b) $W = m\,g_m = (52)\,(1.6)$
$= 83.2$ N (on the moon)

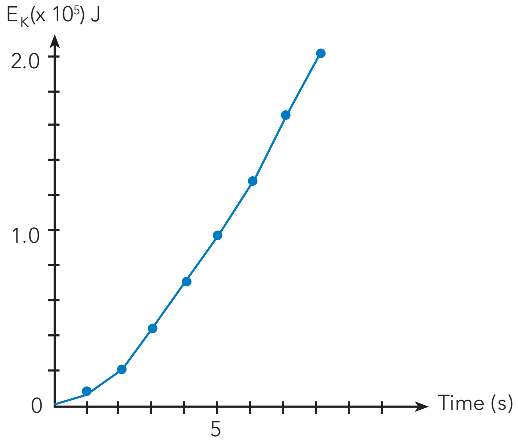
(c) $m = \frac{W}{9.8} = \frac{83.2}{9.8}$

$= 8.50$ kg

4.20

(a) *Values need to be calculated for graph.*

t (s)	v (ms^{-1})	E_K (× 10^5 J)
1	3	0.045
2	6	0.18
3	9	0.405
4	12	0.72
5	14	0.98
6	16	1.28
7	18	1.62
8	20	2.00



(b)

(i) *Power output at t = 2.0 s*

$$P = \frac{E_k}{t} = \frac{0.18 \times 10^5}{2} = 900\ W$$

(average to this point)

(ii) *Power output at t = 6.0 s*

$$P = \frac{E_k}{t} = \frac{0.28 \times 10^5}{6} = 2.13\ kW$$

(average to this point)

Note: To find instantaneous power rating at a given time we would need to look at the slope of the E_K/t graph at that point.

(e.g. at t = 6, slope $\approx \frac{2 \times 10^5}{7} \approx 2.8 \times 10^4$ *W)*

4. Review Questions

4.1 Motion in a Straight Line

1.

(a) *False. True statement: Speed is the rate at which distance is travelled. Velocity is the rate of change of displacement, a vector quantity.*

(b) *True.*

(c) *False. True statement: The gradient or slope of a v/t graph indicates the acceleration of a body at that point.*

(d) *True.*

(e) *False. True statement: A ball thrown vertically upwards in the air will experience an acceleration of 9.8 ms^{-2} at the top of its flight. (velocity will be zero at the top but a gravitational force, and hence acceleration, will be exerted on the ball at all times during its flight)*

2.

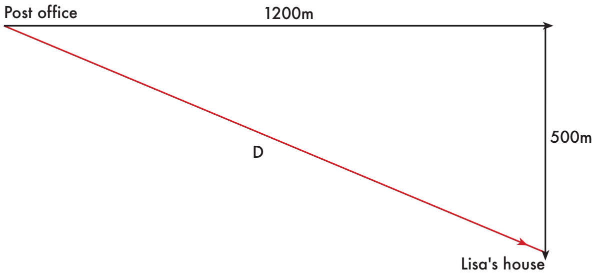
(a) *Displacement is the distance moved in a particular direction from a reference point. Distance, a scalar quantity, is independent of direction.*

(b) *Speed is the rate of change of distance while velocity is the rate of change of displacement (i.e. the rate of change of distance in a given direction).*

3.

(a) *Total distance*
= 600 m + 500 m + 400 m + 400 m + 600 m
= 2500 m

(b)

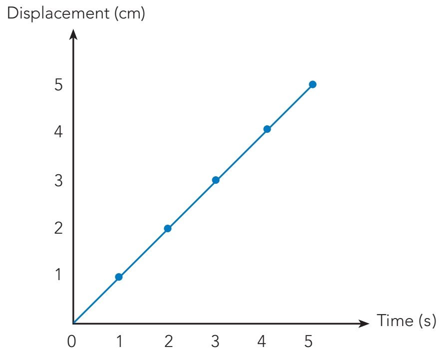


Displacement:

$D^2 = (1200)^2 + (500)^2$
$= 1.44 \times 10^6 + 2.5 \times 10^5$
$D^2 = 16.9 \times 10^5$
$\therefore\ D = 1300$ m
$\therefore$ *Total displacement = 1300 m*

4.

(a)



(b) *average velocity = gradient*

$$= \frac{\Delta s}{\Delta t}$$

$$= \frac{3.2 - 0.8}{4 - 1}$$

$$= \frac{2.4}{3}$$

$$= 0.8 \ cm \ s^{-1}$$

5.

(a) *0-2 s, vehicle is uniformly accelerating*
2-5 s, vehicle has a constant velocity
5-7 s, vehicle is uniformly decelerating
7-9 s, vehicle has a constant velocity

(b) *Displacement = area under the graph*

$= \frac{1}{2}\ (2 \times 30) + (3 \times 30) + \frac{1}{2}\ (2 \times 10) + (2 \times 20) + (2 \times 20)$

$= 30 + 90 + 10 + 40 + 40$

$= 210 \ m$

(c) *Acceleration 0-2 s = gradient of graph*

$= \frac{30 - 0}{2 - 0} = 15 \ ms^{-2}$

Acceleration 5-7 s = gradient of graph

$= \frac{20 - 30}{7 - 5} = -5 \ ms^{-2}$

From 0-2 s, the vehicle is accelerating at 15 ms^{-2} *which represents a faster rate of change of velocity than for 5-7 s where the vehicle is decelerating at a slower rate of change of velocity.*

6. $s = ut + \frac{1}{2} \ at^2$

$= 0 + \frac{1}{2} \ g t^2$

$= \frac{1}{2} \times 9.8 \times (5)^2$

$= 122.5 \ m$

∴ *Depth of ravine* $= 1.22 \times 10^2 \ m$

7.

(a) *Let upwards be positive*

$v^2 = u^2 + 2gs$

$0 = u^2 + 2(-9.8)20$

$u^2 = 392$

$u = 19.8 \ ms^{-1}$

Initial velocity $= 19.8 \ ms^{-1}$

(b)

(i) *Lie taken to reach max. height*

$v = u + at$

$0 = (+19.8)+(-9.8)t$

$(-9.8)t = -19.8$

$t = 2.02 \ s$

(ii) *Lie taken to fall 30 m*

$s = ut + \frac{1}{2} \ gt^2$

$30 = 0 + \frac{1}{2} \times 9.8 \times t^2$

$30 = 4.9t^2$

$t^2 = 6.12$

$t = 2.47 \ s$

∴*Lie taken to reach the water*

$= 2.02 \ s + 2.47 \ s$

$= 4.5 \ s$

8. ***Scalar quantity:*** *Specified by a number and units (if any) i.e. only has magnitude, e.g. temperature.*

Vector quantity: *As well as magnitude a vector quantity also has direction, e.g. displacement.*

9.

SCALAR	VECTOR
distance	acceleration
mass	force
volume	displacement
time	velocity

4.2 Force and their Effects

10.

(a) *True.*

(b) *True.*

(c) *False. True statement: When a bus brakes suddenly passengers tend to lurch forward due to inertia.*

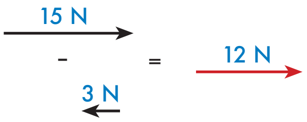
(d) *False. True statement: Safety air bags in a car reduce impact forces on passengers by increasing the impact time for them to stop during a collision.*

(e) *True. The forces they exert on each other are equal but will give them different separation velocities due to their different masses. Lighter person moves off faster.*

11.

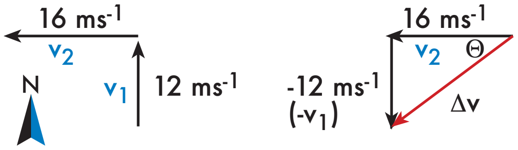
∴ *Force received by the young child and trolley is 25 N.*

12.



∴ *Force received by the young child and trolley is 12 N.*

13.



∴ *Change in velocity* $= 20 \ ms^{-1}$, *W 36.9°S*

14.

(a)

John's velocity $= 60 \ kmh^{-1} + 2 \ kmh^{-1}$

$= 62 \ kmh^{-1}$ *forwards*

(b)

John's velocity $= 60 \ kmh^{-1} + (-2 \ kmh^{-1})$

$= 58 \ kmh^{-1}$ *forwards*

15.

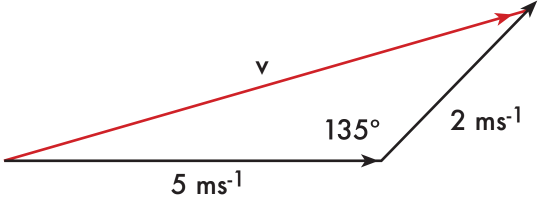
$v^2 = (5^2) + (2^2) - (2)(5)(2)\cos 135^\circ$

$= 25 + 4 - 20\,(-0.7071)$

$= 43.14$

$\therefore v = 6.6\ ms^{-1}$

$\therefore$ *New velocity* $= 6.6\ ms^{-1}$



16. *Horizontal Component* $= 20 \times \cos 30^\circ$

$= 17.3\ N$

Vertical Component $= 20 \times \sin 30^\circ$

$= 10\ N$

17.

(i) *Cause moving objects to increase their acceleration.*

(ii) *Change the direction in which objects are moving.*

(iii) *Change the shape of objects.*

(iv) *Oppose other forces acting on an object to prevent it from moving.*

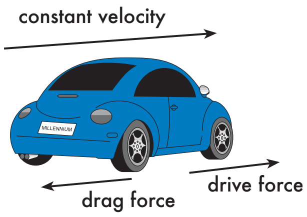
18.

(a) *The metal washer will fall into the glass jar.*

(b) *The force of friction between the cardboard and the glass jar acts for only a short period of time when the cardboard is quickly flicked by Jayesh's finger. The inertia of the metal washer on top of the fast moving cardboard restricts its motion, causing it to be left behind and fall into the glass jar.*

19. *Every body continues in a state of rest or uniform motion in a straight line unless acted upon by some unbalanced external force.*

20. *No. By applying pressure on the accelerator Mary is causing the car to provide a drive force to overcome external drag forces such as friction with the road and wind resistance. The net effect of the drive and drag forces is to enable the car to move at constant velocity since the total force acting on the car is zero.*



21.

(a) *The sudden braking of the train would normally have caused Chris to lean forward (Newton's First Law of Motion) resulting in him pushing the bottle past the glass.*

(b) *No. The inertia of the cool drink would have carried some of it forward past the glass and onto the table as the train braked.*

22. *The rate of change of momentum of a body is directly proportional to the external force acting on the body and occurs in the direction of the force.*

23. *No. Acceleration is caused by a force. Forces are not caused by accelerations. Therefore, the driver's stomach organs receive an acceleration due to a force acting on the driver.*

24.

(a) *The inertia of the egg carton carried it forward during braking (Newton's First Law).*

(b) *When the egg carton hit the floor, the rate of change of momentum of the eggs in the carton is decreased by the soft cardboard material. This longer time for the change in momentum produces a smaller force to act on the eggs – small enough not to break them.*

25. *If a body A exerts a force on a body B, then B exerts an oppositely directed force of the same size on A.*

26. *Susan. Since her starting blocks are attached to the ground then she will receive a reaction force in the direction she is running from the starting blocks as she pushes off against them (Newton's Third Law). Jacky's starting blocks will move off away from her as she pushes against them and provide little to no force to move forward (she will most likely fall to the ground).*

27. *As Li made contact with the hard squash court floor while wearing the soft, thick rubber soled shoes, his feet and legs would receive less impulsive force. The softer shoe enables the change in momentum to occur over a longer period of time directing less force (and subsequently less pain) to his feet and legs.*

28. *The air bag increases the time taken for the driver to undergo a change of momentum. The driver is subjected to a smaller force which may otherwise have been sufficiently large (due to the more rapid change of momentum as the driver hits the steering wheel in the absence of the air bag) to cause serious injuries to the driver.*

29. *Let the direction of the 80 kg skater be positive.*

Momentum before the collision =

Momentum after the collision

$m_1v_1 + m_2v_2 = (m_1 + m_2)\ v_3$

$(80)(3)+(60)(-5)=(80 + 60)\ v_3$

$240 - 300 = 140\ v_3$

$-60 = 140\ v_3$

$\therefore v = -0.4$

The common velocity is 0.4 ms^{-1} *in the original direction of the 60 kg skater.*

30. *If Peta 'follows through' when hitting the ball her bat will be in contact with the ball for a longer period of time. This will increase the impulse resulting in the ball experiencing a larger change in momentum. Therefore,*

the 'follow through' increases the speed at which the ball leaves Peta's softball bat (increasing the chance of her hitting the ball past the nearby fielders).

31. $Ft = mv - mu$
$F \times 0.1 = (0.1)(0)\text{-}(0.1)(10)$
$0.1F = 0 - 1$
$\therefore F = -10N$
∴ *Force = 10 N in the opposite direction to which the ball was moving.*

32.
(a) *resultant force*
F = *applied force – retarding force*
= 15 N – 3 N = 12 N
$F = m\,a$
$12 = 60\,a$
$\therefore a = 0.2\ ms^{-2}$
(b) $F = \dfrac{\Delta p}{\Delta t}$

$\Delta p = F \times \Delta t$
$= 12 \times 4$
$= 48\ kgms^{-1}$
∴ *Change in momentum* = $48\ kgms^{-1}$
(c) $s = ut + \frac{1}{2}at^2$
$= 0 + (\frac{1}{2})(0.2)(4)^2$
$= 1.6\ m$
∴ *Distance travelled* = 1.6 m

33.
(a) *The mass of an object is a measure of the matter in it.*
(b) *The inertia of an object is its reluctance to resist changes in its motion (i.e. its reluctance to start moving, or to stop moving once it has started).*

4.3 Work, Energy, Power

34.
(a) *True.*
(b) *False. True statement: Kinetic energy is possessed by a body due to its motion.*
(c) *False. True statement: A car travelling at 40* kmh^{-1} *will have four times as much kinetic energy as when it travels at 20* kmh^{-1}. *Kinetic energy is proportional to velocity squared.*
(d) *False. True statement: Work can be determined from the area under a force/displacement graph. The area under a force/time graph is a measure of impulse.*

35.
(a) $F = m\,g$
$= 1500 \times 9.8$
$= 1.47 \times 10^4\ N$
(b) $W = Fs$
$= 1.47 \times 10^4 \times 3$
$= 4.4 \times 10^4\ J$

36. $60\ kmh^{-1} = 16.7\ ms^{-1}$
(a) $E_K = \frac{1}{2} mv^2$
$= (\frac{1}{2})(1500)(16.7)^2$
$= 2.1 \times 10^5\ J$
(b) $v^2 = u^2 + 2as$
$0 = (16.7)^2 + (2)(a)(120)$
$240\ a = -278.9$
$a = -1.16\ ms^{-2}$
$F = ma$
$= (1500)(-1.16)$
$= 1.74 \times 10^3\ N$
∴ *Stopping force* = 1.74×10^3 N, *in the opposite direction to which the car was travelling.*
(c) $v = u + at$
$0 = 16.7 + (-1.16)t$
$\therefore\ 1.16t = 16.7$
$\therefore\ t = 14.4\ s$
∴ *Time taken to stop* = 14.4 s
(d) *Work done to stop = loss in kinetic energy*
$= 2.1 \times 10^5\ J$
OR $W = Fs$
$= 1.74 \times 10^3 \times 120$
$= 2.1 \times 10^5\ J$

37. $100\ kmh^{-1} = 27.8\ ms^{-1}$
E_K *of car* $= \frac{1}{2} mv^2$
$= (\frac{1}{2})(1600)(27.8)^2$
$= 6.17 \times 10^5\ J$

E_K *of truck* = E_K *of car* $= \frac{1}{2} mv^2$
$\therefore\ 6.17 \times 10^5 = (\frac{1}{2})(8000)v^2$
$\therefore v^2 = 154.3$
$\therefore v = 12.4\ ms^{-1}$
∴ *Velocity of truck* = $12.4\ ms^{-1}$ $(44.6\ kmh^{-1})$

38. E_K *of car* = E_p *of spring*
$\frac{1}{2} mv^2 = 2$
$(\frac{1}{2})(0.1)v^2 = 2$
$v^2 = 40$
$v = 6.3\ ms^{-1}$

39. E_K *lost by dart* = E_p *of block + dart*
$\frac{1}{2} m_d v^2 = (m_b + m_d)\,gh$
$(\frac{1}{2})(0.05)\ v^2 = (0.50+0.05)(9.8)(0.040)$
∴ *velocity of block and dart after impact*
$= 2.94\ ms^{-1}$
Also P_i *(dart)* = P_f *(dart + block)*
$(0.050)(v) = (0.50+0.05)(2.94)$
∴ *Initial vel dart* = $32.3\ ms^{-1}$

40.
(a) *Alan falls through a height of 30 cm – 15 cm = 15 cm*
∴ *Alan's energy before impact*
= *loss in potential energy*
$= m\,g\,h$
$= (45)(9.8)(0.15)$
$= 66.2\ J$
(b) E_K *gained* = E_p *lost*
$\frac{1}{2} mv^2 = m\,g\,h$
$(\frac{1}{2})(45)v^2 = 66.2$
$v^2 = 2.942$
$\therefore v = 1.72\ ms^{-1}$
Alan's velocity just before impact = $1.72\ ms^{-1}$ *downwards*
(c) *Momentum before = Momentum after*
$(mu)_{Alan} + (mu)_{peg} = (mv)_{Alan} + (mv)_{peg}$
$(45)(1.72)+(0.20)(0) = 45v + 0.2v$
where $v = v_{Alan} = v_{peg}$

$77.4 = 45.2\,v$

$v = 1.71\ ms^{-1}$

$\therefore$ velocity of the peg after impact = $1.71\ ms^{-1}$

(d) Energy before impact = 66.2 J

Energy after impact

$= E_{K\,Alan} + E_{K\,peg}$

$= ½\,mv^2 + ½\,mv^2$

$= (½)(45)(1.71)^2 + (½)(0.2)(1.71)^2$

$= 65.8 + 0.29$

$= 66.1\ J$

$\therefore$ Energy loss due to impact = 0.1 J

(e) Work done = E lost

E lost = Initial E_k of Alan – E_k of Alan on peg that is 0.6 cm high

$= 66.2 - m\,g\,h$

$= 66.2 - 45 \times 9.8 \times 0.06$

E lost = 39.7 J = Work done

$$F = \frac{W}{s} = \frac{39.7}{0.09} = 442\ N$$

41.

(a) Vertical height climbed by Shirley

$= 30 \times 0.25$

$= 7.5\ m$

Shirley's weight = $m\,g$

$= 50 \times 9.8$

$= 490\ N$

$\therefore$ Work done by Shirley = force (to lift her weight) × distance (vertical height)

$= 490 \times 7.5$

$= 3.68 \times 10^3\ J$

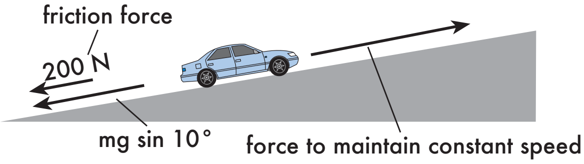
(b) Power output $= \dfrac{\text{work done}}{\text{time taken}}$

$$= \frac{3.68 \times 10^3}{10}$$

$= 3.68 \times 10^2\ W$

$\therefore$ Shirley's power output = $3.68 \times 10^2\ W$

42.



$$P = \frac{W}{t} = F \times \frac{s}{t} = Fv$$

Force to maintain constant speed = Force to overcome gravity along the slope + Force to overcome friction

$= m\,g \sin 10 + 200$

$= 1500 \times 9.8 \times \sin 10 + 200$

$= 2.75 \times 10^3\ N$

Power developed = $F \times v$

$= 2.75 \times 10^3 \times 15$

$= 4.13 \times 10^4\ W$ (41.3 kW)

43.

(a) Work done = area under the graph

$= (5{\times}0.5)+[(5{\times}0.25)+½\ (5{\times}0.25)]+(10{\times}0.75)$

$= 2.5 + 1.88 + 7.5$

$= 11.9\ J$

(b) Average power exerted $= \dfrac{\text{work done}}{\text{time}}$

$$= \frac{11.9}{10} = 1.19\ W$$

CHP 5: WAVES

5. Chapter Questions

5.1 (a) 4.0 m
(b) 10 cm
(c) I
(d) E or M
(e) C, G, K
(f) E
(g) 0.250 s
(h) T = 0.50 s

5.2

(a) $\lambda = \dfrac{v}{f} = \dfrac{1.53 \times 10^3}{450} = 3.40\ m$

(b) $t = \dfrac{s}{v} = \dfrac{1000}{1.53 \times 10^3} = 0.653\ s$

5.3

24 ripples in 4.0 s

$$\therefore f = \frac{24}{4.0} = 6.00\ Hz$$

$$\text{Also } \lambda = \frac{2.0}{24} = 8.33 \times 10^{-2}\ m$$

and $v = \lambda f$

$= (8.33 \times 10^{-2})(6.0)$

$= 0.50\ ms^{-1}$

5.4

(a) Total acoustical power.

$P = I\,A$

$P = (0.150)\ (4\,\pi\,.\,(200)^2)$

$= 7.54 \times 10^4\ W$

(b) Intensity at 150 m distance

$$I \propto \frac{1}{d^2} \therefore\ I\,d^2 = \text{constant}$$

Hence $I_2\,d_2^{\,2} = I_1\,d_1^{\,2}$

$I_2 \times (150)^2 = (0.150) \times (200)^2$

$I_2 = 0.267\ Wm^{-2}$

(c) Distance for I to be $0.01\ Wm^{-2}$

$I_2\,d_2^{\,2} = I_1\,d_1^{\,2}$

$(0.01) \times (d_2)^2 = (0.150) \times (200)^2$

$d_2 = 775\ m$

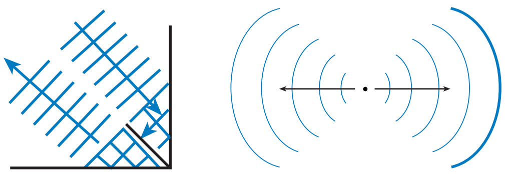
5.5 Same as before, extra distance is 30 m.

$$\Delta\,t = \frac{30}{340} = 0.088\ s\ \therefore \text{ no echo.}$$

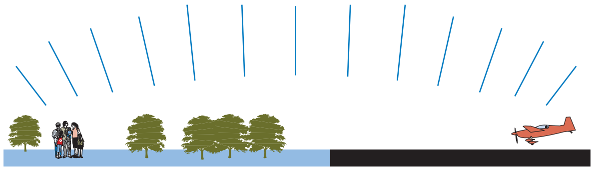
5.6 $s = vt = (1.53 \times 10^3)(0.125) = 191\ m$

$\therefore$ Depth = 191/2 = 95.6 m

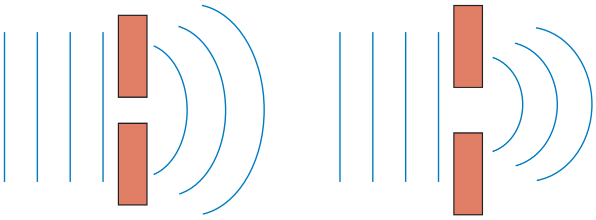
5.7



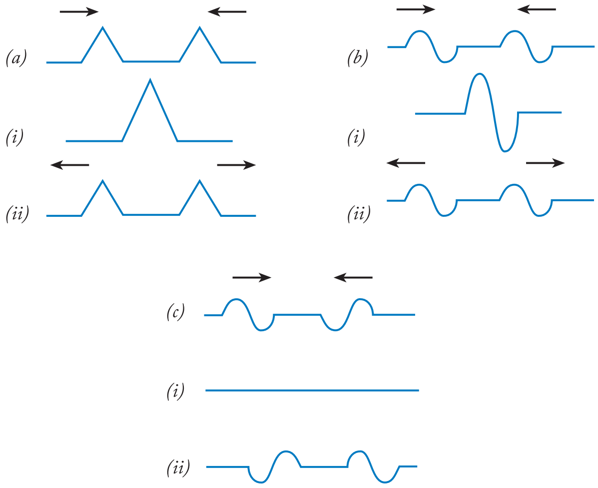
5.8



5.9



5.10



5.11

(a) A→B, loud sound gradually getting softer. On an antinodal line (maximum) but getting further away from the sound source.

(b) P→Q, alternate loud and soft sound as you walk past antinodes and nodes.

(c) A→B, loud sound which is loudest between speakers (i.e. in the middle of AB). You are walking along an antinodal line (maximum) between speakers.

5.12

(a) Alternating loud and soft (zero) sound.

(b) The same but sound loudness/softness would occur twice as often.

5.13

(a)
- fundamental occurs at $\lambda = 2\,l$
- every harmonic occurs

(b)
- antinodes occur at the open end
- node occur only in the pipe.

5.14

(a) λ = ?
l = 2.5×10^{-2} m
v = 3.46×10^{2} m
for closed pipe fundamental
λ = $4\,l$
= $(4)\,(2.5 \times 10^{-2}$ m$)$
= 0.10 m
since $v = \lambda f$
$$f = \frac{v}{\lambda} = \frac{346}{0.10} = 3460 \text{ Hz}$$

(b) The next two harmonics will be $3f_1$ and $5f_1$ 10.38 kHz and 17.3 kHz.

5. Review Questions

5.1 Nature of Waves

1.

(a) False. True statement: The velocity of a wave can be calculated from its wavelength and frequency.

(b) True.

(c) False. True statement: Compressions and rarefactions in a sound wave are 180° out of phase.

(d) True.

(e) True.

2.

(a) $v = \lambda f \qquad \therefore \lambda = \frac{v}{f} = \frac{340}{500}$
$\therefore \lambda = 0.680$ m

(b) 0.113 m

(c) 1.29 m

(d) 2.27×10^{-2} m

(e) 9.71×10^{-5} m

3.

(a) $\lambda = 20$ m
(i) f = 12 waves/min = 0.20 Hz
(ii) $T = \frac{1}{f} = 5.0^\circ$ s
(iii) $v = \lambda f = 4$ ms^{-1}

(b) $t = \frac{s}{v} = \frac{200}{4} = 50$ s

4.

(a) $\lambda = 10.0$ cm

(b) amplitude = 1.0 cm

(c) $v = \lambda f = (0.10)(3.25) = 0.325$ ms^{-1}

5.

(a) $f = \frac{18 \text{ ripples}}{6.5 \text{ s}} = 2.77$ Hz

$\therefore t = \frac{1}{f} = 0.361$ s

(b) $\lambda = \frac{2.40}{18} = 0.133$ m

(c) $v = \frac{2.40}{6.5} = 0.369$ m^{-1}

6.

(a) The time lapse between the gun going off and the sound reaching Paula will cause an error. Paula will start the stopwatch a little after the race has actually begun.

(b) $t = \frac{s}{v} = \frac{100}{344} = 0.291\ s$

"Real" time of race $= 14.2 + 0.291$
$= 14.5\ ms^{-1}$

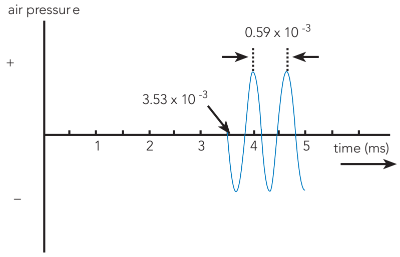
7.
(a) C
(b) B, D, H
(c) A, E, F
(d) A, F

8.
(a) $T = 4.0 \times 10^{-3}\ s$
$\therefore f = \frac{1}{T} = 250\ Hz$
(b) $\lambda = 1.40\ m \therefore v = \lambda f = 350\ ms^{-1}$
(c) amplitude $4 \times 10^{-7}\ m$
(d) $t = 2, 4, 6\ ms$

9.
(a) $\lambda = 0.20\ m$
$v = 340\ ms^{-1}$
$\therefore f = 1700\ Hz$
(b) John is 1.20 m away

$$\therefore t = \frac{s}{v} = \frac{1.20}{340} = 3.53 \times 10^{-3}\ s$$

(c)



$$t = \frac{1}{f} = \frac{1}{1700} = 0.589 \times 10^{-3}\ s$$

10.
(a) Since $v = \frac{s}{t}$ we have $t = \frac{s}{v}$

P wave $t = \frac{s}{v} = \frac{1.2 \times 10^6}{5.2 \times 10^3}$

$= 231\ s$

S wave $t = s/v = \frac{1.2 \times 10^6}{3.3 \times 10^3}$

$= 364\ s$

$\Delta t = 133\ s$

(b) Conversion value given = (9.0 km /s) (Δt between P and S arrival).
Hence distance $s = (9.0)(133) = 1197\ km$
Distances are the same for this example. The conversion value is regularly used as apart from being a more convenient method it is more reliable since it is based on measurements of many previous events.

(c) To locate the earthquake the seismic recordings from at least three different recording stations are required. The distances to the earthquake from these three points can be plotted to scale as circles. The common point of intersection of the circles gives the location of the seismic event.

11. Using the inverse square law.

$$I \propto \frac{1}{d^2} \therefore\ I\, d^2 = constant$$

Hence $I_2\, d_2^{\,2} = I_1\, d_1^{\,2}$

(a) At a distance of 10.0 m from the bell

$$I_2 \times (10.0)^2 = (2.85 \times 10^{-2}) \times (5.0)^2$$
$$I_2 = 7.1 \times 10^{-3}\ Wm^{-2}$$

(b) At a distance of 20.0 m from the bell

$$I_2 \times (20.0)^2 = (2.85 \times 10^{-2}) \times (5.0)^2$$
$$I_2 = 1.8 \times 10^{-3}\ Wm^{-2}$$

12. Intensity at 12.0 m from an operating jackhammer is $1.0 \times 10^{-3}\ Wm^{-2}$. The earmuffs reduce the intensity by a factor of 100. Hence reduced intensity is $1.0 \times 10^{-5}\ Wm^{-2}$.
The distance from the source that would result in this reduced intensity, without earmuffs, can be determined using the inverse square law.

Since $I \propto \frac{1}{d^2}$ we have $I_2\, d_2^{\,2} = I_1\, d_1^{\,2}$

At the required distance x from the jackhammer

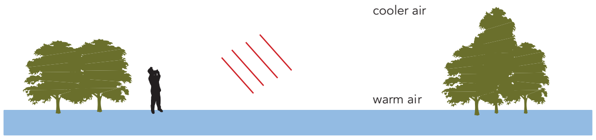
$$(1.0 \times 10^{-5}) \times (x)^2 = (1.0 \times 10^{-3}) \times (12.0)^2$$
$$(x)^2 = 144 \times 100$$
$$x = 120\ m$$

5.2 Reflection, Refraction, Diffraction

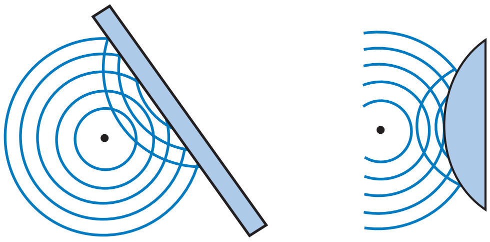
13.
(a) False. True statement: When waves enter a medium of different density their velocity and wavelength will change.
(b) True.
(c) True.
(d) False. True statement: Longer wavelengths are more noticeably diffracted than smaller ones.
(e) True.

14. Frequency is determined by the source of the sound and cannot be affected by the media the sound travels through.

15. Sound refracts towards the normal (and hence upwards).



16.



(a) (b)

17. *Sound wave travels from air to water*

(i) *speed – increases*

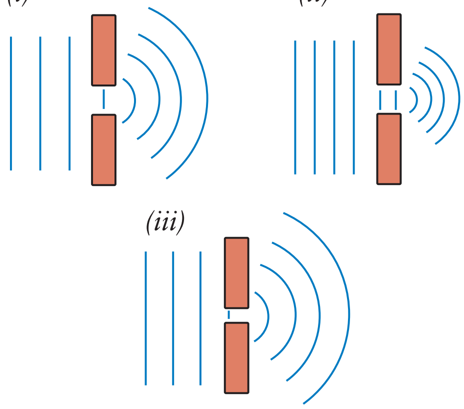
(ii) *wavelength – increases*

(iii) *frequency – no change*

(iv) *direction – may refract if entering obliquely*

(v) *intensity – highly reduced, most sound reflects.*

18.



(i) (ii) (iii)

19. *High frequency sounds (small wavelength) do not diffract well (e.g. 13(ii) above) and hence are best heard in front of a source and not to the side.*

20.

(a) $\lambda = \frac{c}{f} = \frac{1530}{150 \times 10^3} = 1.02 \times 10^{-2}\ m$

(b) *High frequency sounds do not diffract too greatly and are more directional. This means greater sensitivity (or range) since there is less loss of energy and better directional sense.*

(c) *Objects about 10 cm or greater would be most easily located.*

21.

(a) *Light waves are very small* ($\approx 10^{-7}$ *m*) *and hence do not diffract sufficiently for them to be noticeable around corners. Sounds diffract well.*

(b) *Low frequency sounds are more noticeable as they diffract best through doorways, etc.*

22. *Wavelengths of 15 cm or above will diffract best. Hence frequencies smaller than ≈ 2300 Hz (340/0.15) will diffract best.*

23.

(a) *Ultrasonic sounds are more directional (less diffraction).*

(b) *Cannot focus through windows. Object of interest may be very small or sound absorbing.*

(c) $t = \frac{s}{v} = \frac{20}{340} = 0.059\ s$

5.3 Wave Interaction

24.

(a) *False. True statement: Two similar waves travelling in the same medium will destructively combine if they are 180° out of phase.*

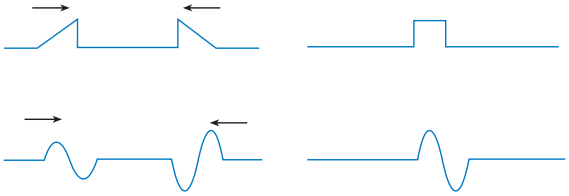
(b) *True.*

(c) *False. True statement: Standing waves are are produced by two waves of the same frequency travelling in opposite directions. Beats are produced by two waves of slightly different frequencies.*

(d) *True.*

(e) *False. True statement: The length of a fixed string vibrating at its fundamental frequency is equal to one half of a wavelength.*

25.



26. $f_x = 440$ Hz $\qquad f_y = 445$ Hz

$z + x, f_b = 2$ Hz $\qquad \therefore z = 442$ or 438

$z + y, f_b = 3$ Hz $\qquad \therefore z = 442$ or 448

Hence $f_z = 442$ Hz

27.

Similarities of the two waves

- *they have the same velocity*
- *they travel in the same medium*
- *they are the same type.*

Differences of the two waves

- *they travel in the same direction for beats but in opposite directions for standing waves*
- *they have slightly different frequencies for beats but the same frequency for standing waves.*

28.

(a) $A = 1.40\ m \qquad \lambda_B = 1.50\ m$

$\Delta\lambda = 1.10\ m$

$\therefore$ *Need 14, 1.5 m waves for in phase position (i.e. 21 m).*

(b) $f_A = \frac{340}{1.40} = 243$ Hz

$f_B = \frac{340}{1.5} = 227$ Hz

$\therefore f_{beat} = (243\text{-}227) = 16$ Hz

$\therefore T = \frac{1}{f} = \frac{1}{16} = 0.0625\ s$

Hence time difference between maximum intensities is 0.0625 s.

29.

(a) *The sound intensity will fluctuate between loud and very soft or no sound.*

(b) *Standing waves exist between A and B.*

(c) (i) *minimum intensity = node*

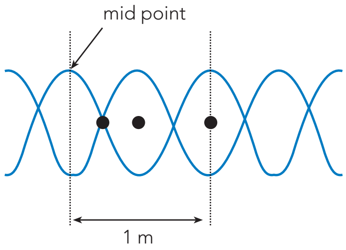
(ii) *maximum intensity = antinode*

(d) *This distance is* $\lambda/2$.

30.

(a) *He will hear a sound of maximum intensity at this point. He is equally distant from both speakers hence the sounds will be in phase.*

(b)

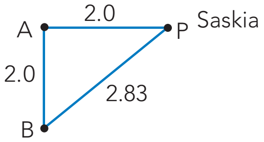


Since Simon has walked 1 full wavelength $\lambda = 1.0$ *m.*

31.

(a) *Hannah is walking away from a maximum loudness point. She will encounter a series of loud and quiet spots. This is due to constructive and destructive interference from the two speakers.*

(b)



$AP = 2.00$ *m*
$BP = 2.83$ *m*
$\therefore \Delta d = 0.83$ *m*

i.e. for out of phase

$$\frac{\lambda}{2} = 0.83 \quad \therefore \lambda = 1.66 \text{ m}$$

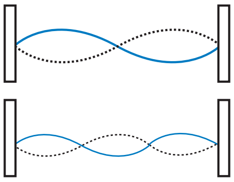
$$\therefore \text{Min frequency} = \frac{340}{1.66}$$

$= 205$ *Hz*

32.

(a) *Standing wave pattern*

(b)



(c) *Max wavelength* $\frac{\lambda}{2} = l$

$\therefore \lambda = 2l = 2.50$ *m*

33.

(a) *Nodes are* $\lambda/2$ *apart.*
$\therefore \lambda = (2)(0.40) = 0.80$ *m*

(b) $v = \lambda f = (0.80)(440) = 352 \text{ ms}^{-1}$

(c) *They used an open pipe since the next antinode would occur at the other end of the pipe.*

SOLUTIONS TO TRIAL TESTS

TT 1: Heating Processes

Section One

1. Heat refers to the energy which is transferred from one body to another due to a difference in temperature. Temperature indicates the degree of hotness. It is related to the average kinetic energy of the particles in a body.

[2]

2.

(a) The woollen jumper insulated Alan's upper body and reduced the heat produced by his body from escaping. The jumper traps air between its fibres and reduces heat loss because air and wool are poor conductors of heat.

[1.5]

(b) Metals are much better conductors than wood, hence the metal handle feels colder as it conducts heat away from your warm hand quickly.

[1.5]

3.

(a) The breeze will cause the moisture from the part of your finger facing the wind to evaporate more quickly than usual. This has a cooling effect on that part of your finger.

[1]

(b) A water mass such as the ocean heats up and cools more slowly than a large land mass. During the day land heats up quickly, warm air above it rises and cool air from the ocean moves inland to replace it. The opposite occurs in the evening.

[1]

(c) A refrigerator cools the contents on the inside by transferring the heat (through the condenser unit) to the outside. Essentially it is pumping heat out. You will notice that the back of a refrigerator is always warm.

[1]

4.

(a) R, it changes phase over a longer period of time (i.e. it absorbs more heat).

[2]

(b) R, for the same rate of heating, temperature of R rises more slowly

[2]

5.

(a) Ceramic tiles are better conductors of heat than carpet. Since both the carpet and tiles are at the same temperature it is the rapid conduction of heat away from your feet which give the sensation of coolness.

[1]

(b) Heat is conducted away from your body by the tiles because on a cool day they are at a lower temperature than your body. At body temperature, 37°C, this effect will no longer occur.

[2]

6.

$Q = 754\ J$

$m = 0.0250\ kg$

$c = ?$

$T_1 = 15.0°C$

$T_2 = 60.0°C$

$Q = mc\,\Delta T$

$754 = 0.0250 \times c \times (60.0 - 15.0)$

$$c = \frac{754}{0.025 \times 45}$$

$= 670.2$

∴ Specific heat of glass $= 6.70 \times 10^2\ J\ kg^{-1°}C^{-1}$

[3]

Section Two

7.

(a) Step A caused the greatest increase in potential energy (change of phase). During step B only temperature and KE of the particles changes.

[2]

(b) Melting ice

$Q = mL \quad = (1.0)(3.34 \times 10^5)$

$\quad = 3.34 \times 10^5\ J$

Heating water to 100°C

$Q = mc\,\Delta T \quad = (1.0)(4180)(100)$

$\quad = 4.18 \times 10^5\ J$

∴ Heating water required more energy.

[4]

(c) Power of heat source $= \frac{\text{energy}}{\text{time}}$

$$= \frac{(3.34 \times 10^5) + (4.18 \times 10^5)}{(20)(60)}$$

$= 6.26 \times 10^2\ W$

Heat required to evaporate all water

$= mL = (1.0)(2.26 \times 10^6) = 2.26 \times 10^6\ J$

∴ Since $P = \frac{E}{t}$

$$t = \frac{E}{P} = \frac{2.26 \times 10^6}{6.26 \times 10^2} = 3.61 \times 10^3\ s$$

Extra time needed = 60.2 min [4]

8.

(a) Heat gained by ice to heat up, melt and reach 5.0°C

$= m\,c\,\Delta T_i \quad m\,L_i + m\,c\,\Delta T_{i/w}$

$= (0.050)(2100)(5.00) + (0.050)(3.34 \times 10^5)$
$+ (0.050)(4180)(5.00)$

$= 525 + 16700 + 1045$

$= 18270\ J$

[6]

(b) Heat lost by soft drink = Heat gained by ice

$(0.02)c(20) = 18270$

$\therefore\ c = 4568$

∴ Specific heat of the soft drink

$= 4.57 \times 10^3\ J\ kg^{-1}{}^\circ C^{-1}$

[4]

9.

(a) Sweat is able to remove heat from the body as it evaporates. Evaporation has a cooling effect. The body can also lose heat by radiation although this depends on the temperature difference with the surroundings. Convection of warm air away from the body also helps to remove excess heat.

[2]

(b) $m = 65.0\ kg$ $\qquad Q = P \times t$

$P = 1500\ Js^{-1}$ $\qquad = (1500)(600)$

$t = 600\ s$ $\qquad = 9.0 \times 10^5\ J$

$Q = ?$

$\Delta T = ?$

$c = 3500\ J\ kg^{-1}K^{-1}$

$$Q = mc\,\Delta T$$

$$\therefore\ T = \frac{Q}{mc} = \frac{9.0 \times 10^5}{(65.0)(3500)}$$

$$= 3.96^\circ C$$

[4]

(c) $Q = mL_v$

$$\therefore\ (\frac{70}{100})(9.0 \times 10^5) = (m)(2.40 \times 10^6)$$

$m = 0.262\ kg$

i.e. 262 mL of sweat (water)

[4]

Section Three

10.

(a) Heat transfer can occur by conduction, convection and radiation. [3]

(b) (i) U value is a measure of the ability to conduct heat.

(ii) Aluminium frame.

(iii) Timber frame with double 3 mm glass.

[3]

(c) Convective heat transfer can be minimised by reducing air movement near windows. Curtains and pelmets can help on the inside while walls, screens and plants help on the outside. [2]

(d) Total transfer is 86%. This is made up of 83% transmitted and 3% which is radiated by the glass. The glass initially absorbed 9% of the solar radiation of which 6% is radiated outside and 3% inside.

[4]

TT 2: Ionic Radiation & Nuclear Reactions

Section One

1.

(a)	(i) 6	(ii) 8	[1]
(b)	(i) 17	(ii) 18	[1]
(c)	(i) 84	(ii) 128	[1]

2.

	ALPHA PARTICLE	BETA PARTICLE	GAMMA RADIATION
What it is	helium nucleus	fast moving electron	electromagnetic radiation
Symbol	$^4_2$He or α	e^- or β	γ
Charge	$^+$ve(2)	$^-$ve	0
Can be deflected	yes	yes	no
Stopped by	thick sheet of paper	thin aluminium sheet	thick sheet of lead (but not all γ radiation)

[5]

3.

(a) beta particle [1]

(b) alpha particle [1]

(c) (i) alpha particle (ii) beta particle [1]

4.

(a) 3.0 seconds [1]

(b) 12% [1]

5. Alpha particles from the dust are absorbed by cells in the respiratory system. The cells may be damaged or destroyed by this ionising radiation. Over a period of time respiratory problems develop.

[2]

6.

(a) $^{1}_{0}n + {}^{235}_{92}u \rightarrow {}^{236}_{92}u$ [1]

(b) $^{236}_{92}u \rightarrow {}^{141}_{56}Ba + {}^{92}_{36}Kr + 3\,{}^{1}_{0}n$ [1]

(c) The neutrons can cause further fission reactions and possibly a chain reaction.

[1]

Section Two

7.

(a) The sum of the masses of the components has the greatest mass. [2]

(b) Atomic mass of lead-208 = 207.97665 u

mass of protons = 82 × 1.00728 u

= 82.59696 u

mass of neutrons = 126 × 1.00866 u

= 127.09116 u

mass of electrons = 82 × 0.00055 u

= 0.0451 u

Total mass = 209.73322 u

[6]

(c) *The mass difference is due to the creation of binding energy when a nucleus is formed from its constituent nucleons.*

[2]

8. *Mass defect* $= 209.73322\,u - 207.97665\,u$

$= 1.75657\,u$

Convert u to kg

$\therefore 1.75657\,u = 1.75657 \times 1.6605 \times 10^{-27}$ kg

$= 2.91678 \times 10^{-27}$ kg

$E = mc^2$

$= 2.91678 \times 10^{-27} \times (3.0 \times 10^{8})^2$

$\therefore$ *Binding energy* $= 2.625 \times 10^{-10}$ J

$\therefore$ *Binding energy/nucleon*

$= 2.625 \times 10^{-10} \div 208$

$= 1.262 \times 10^{-12}$ J

[10]

9.

(a) $^{14}_{7}\mathrm{N} + {}^{1}_{0}n \rightarrow {}^{14}_{6}\mathrm{C} + {}^{1}_{1}H$ [2]

(b) *Mass difference*

$= (mN + mn) - (mC + mH)$

$= (14.00307 + 1.00866) - (14.00324 + 1.00728)$

$= 15.01173 - 15.01052$

$= 1.21 \times 10^{-3}\,u$

$= 1.21 \times 10^{-3} \times 1.6605 \times 10^{-27}$ kg

$= 2.00921 \times 10^{-30}$ kg

$\therefore$ *Energy released* $= mc^2$

$= 2.00921 \times 10^{-30} \times (3.0 \times 10^{8})^2$

$= 1.808 \times 10^{-13}$ J

$= 1.808 \times 10^{-13} \div 1.6 \times 10^{-19}$

$= 1.13 \times 10^{6}$ eV

$= 1.13$ MeV

[8]

Section Three

10.

(a) *A radiopharmaceutical is a compound formed by chemically attaching a radioisotope to it.*

[2]

(b) *PET, positron emission topography; SPECT, single photon emission computed tomography.*

[2]

(c)

(i) *A positron is a positively charged electron particle.*

[1]

(ii) $^{0}_{+1}e + {}^{0}_{-1}e \rightarrow 2\gamma$ [1]

(iii) *The interaction of the two particles releases energy in the form of two gamma rays. These gamma rays strike crystals in detectors located around the patient. Computers are then able to use this information to form an image. The image can then be used to diagnose the patient.*

[2]

(d) (i) *fluorine 18, thallium 201*

(ii) *gallium 67*

(e) *A short half life means that the patient is not exposed to radiation for a long time and the procedure is safer. Rapid decay of the tracer also means high activity and easy detection.*

[2]

TT 3: Electrical Circuits

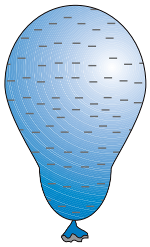
Section One

1.

(a)

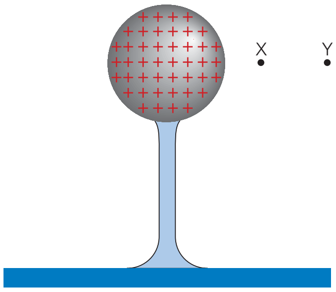
[1]

(b)



[1]

(c)



[1]

2.

	UNIT	SYMBOL
size of an electric current	ampere	I
electric charge	coulomb	q
time	second	t

[3]

3.

(a) *Potential difference is equal to the work done per unit charge (by an external force) to move an electric charge from one point to another in an electric field.*

[1]

(b) $W = Vq$

$= 3.00 \times 10^{3} \times 1.60 \times 10^{-19}$

$= 4.80 \times 10^{-16}$ J

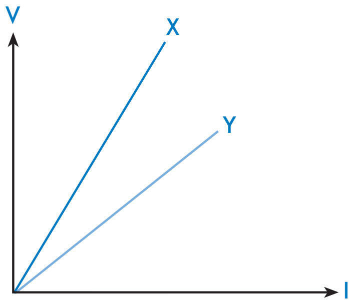
[2]

4.

(a) *The current through a conductor is proportional to the potential difference across it provided its temperature remains constant.*

[1]

(b)



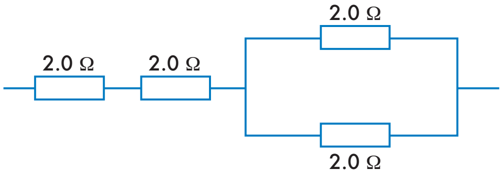
[2]

5.

(a)

[1]

(b)



[2]

6.

(a) $P = VI$

$100 = 240\,I$

$\therefore I = 0.42\text{ A}$ *[1]*

(b) $P = I^2R$

$100 = (0.42)^2 \times R$

$R = 5.76 \times 10^2\ \Omega$

[1]

(c) *The cold filament will have a much lower resistance. At high temperature the resistance to current flow is greater.*

[1]

Section Two

7.

(a) *Position X will correctly measure the current going through the 4.0 Ω resistor. Position Y is in parallel with the 4.0 Ω resistor and can only be used to measure voltage.*

[2]

(b) R_T *for whole circuit* $= 2.0 + 4.0 + 6.0$

$= 12.0\ \Omega$

$$\therefore I = \frac{V}{R} = \frac{6.0}{12.0} = 0.50\text{ A}$$

[2]

(c) $V = IR$

$= (0.50)(4.0)$

$= 2.0\text{ V}$ *[2]*

(d) $P = VI = (6)(0.50)$

$= 3.0\text{ W}$

or $P = I^2R = (0.50)^2(12.0)$

$= 3.0\text{ W}$ *[2]*

8.

(a) *R parallel section:*

$$\frac{1}{R_p} = \frac{1}{8} + \frac{1}{24}$$

$$= \frac{3+1}{24}$$

$$\therefore R_p = \frac{24}{4} = 6.0\ \Omega$$

$\therefore$ *Total resistance of the circuit*

$= 6.0\ \Omega + 4.0\ \Omega = 10.0\ \Omega$

[3]

(b) *(i)* *Current through 4.0 Ω resistor:*

$V_T = I\,R_T$

$6.0 = I \times 10.0$

$\therefore I = 0.60\text{ A}$

$\therefore$ *Current through 4.0 Ω resistor*

$= 0.60\text{ A}$

[2]

(ii) *Voltage across parallel section:*

$V = I\,R_p$

$= 0.60 \times 6.0$

$= 3.6\text{ V}$

$\therefore$ *Current through 24.0 Ω resistor:*

$V = I\,R$

$3.6 = I \times 24.0$

$\therefore I = 0.15\text{ A}$

[2]

(iii) *Current through 8.0 Ω resistor:*

$V = I\,R$

$3.6 = I \times 8$

$\therefore I = 0.45\text{ A}$

[2]

(c) *Power dissipated at the 8.0 Ω resistor:*

$P = I^2R$

$= (0.45)^2 \times 8.0$

$= 1.6\text{ W}$

[3]

9.

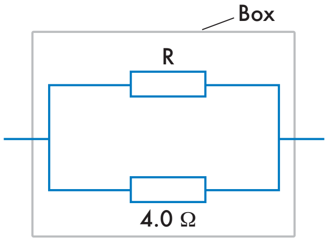
(a) *Since the box is in series with the ammeter and power supply its total resistance can be determined.*

i.e. $V = I\,R_T$ OR

$6.0 = 2.0\,R_T$ $\quad 9.0 = 3.0\,R_T$

$R_T = 3.0\ \Omega$ $\quad R_T = 3.0\ \Omega$

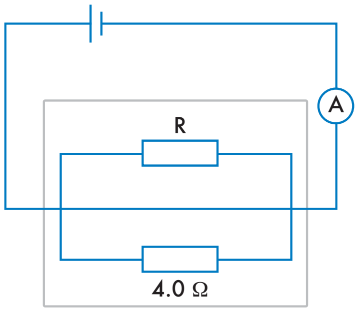
$\therefore$ *The two resistors in the box must be connected in parallel since one of the resistors is known to have a resistance of 4.0 Ω.*



The sum of the resistances of two resistors in series would otherwise have a value greater than either of the two resistors.

[4]

(b)



For $V = 6.0$ V *and* $I = 2.0$ A , $R_T = 3.0\ \Omega$

$$\therefore \frac{1}{R_T} = \frac{1}{4.0} + \frac{1}{R}$$

$$\frac{1}{3.0} = \frac{1}{4.0} + \frac{1}{R}$$

$$\frac{1}{R} = \frac{1}{3.0} - \frac{1}{4.0}$$

$$= \frac{4.0 - 3.0}{12}$$

$$= \frac{1.0}{12}$$

$$\therefore R = 12.0\ \Omega$$

∴ *Value of the unknown resistor* = 12.0 Ω

[6]

Section Three

10.

(a) Sticking a knife into a wall socket is like sticking an electrical conductor into a source of electrical energy and causing it to flow through you to the ground – resulting in electric shock or electrocution. The kite was being held by Franklin in a source of electrical energy (electrons/clouds in the sky) which could be earthed through the string and him – resulting in possible electric shock or electrocution.

[2]

(b) The string is a conductor whilst the silk is an insulator. The string was used to conduct electrical energy to the key and the silk was used to prevent the flow of electrical energy to Franklin and causing an electric shock.

[2]

(c) A potential difference between the kite and the key enabled a flow of electrons to the key from the kite. The build up of electric charge on the key became so high that it was able to produce a discharge to earth via Franklin by sparking through the air. The charge did not flow through the silk because it was an insulator.

[2]

(d) The size of the current depends on the potential difference across the ends of the string and the resistance of the string. A high potential difference (enough to cause lightning) and a metal rod (e.g. aluminium) would cause an extremely large current – this is why the Swedish physicist was electrocuted.

[3]

(e) The Swedish physicist should not have held the rod or at least separated himself from the rod by a very good insulator. He could also have used a rod which was not such a good conductor of electricity – although lightning is severe on even the weakest of conductors.

[3]

TT 4: Linear Motion and Force

Section One

1.

(a)

(i) constant velocity (ii) zero velocity [1]

(b)

(i) A → B *velocity = gradient* = $\frac{4}{3}$ = 1.33 ms^{-1}

(ii) E → F *velocity* = 0 [1]

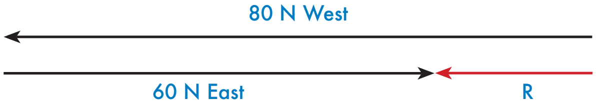
(c) average velocity = $\frac{\text{total displacement}}{\text{total time}}$

$$= \frac{14}{12}$$

= 1.17 ms^{-1} [2]

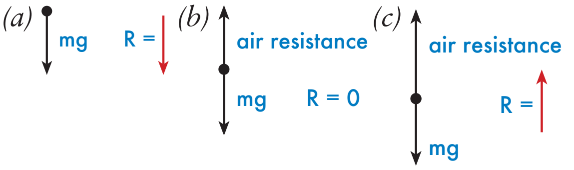
2. *Vectors – acceleration, weight, velocity*
Scalars – speed, mass, area, energy, temperature. [2]

3.



∴ *Resultant* = 20 N *West* [3]

4.



[3]

5.

(a) $v^2 = u^2 + 2as$

$o = u^2 + 2(-9.8)(25)$

$u = 22.1\ ms^{-1}$ [1]

(b) Find total height from which the ball fell.

$v^2 = u^2 + 2as$

$(22.8)^2 = 0 + 2(-9.8)(s)$

$\therefore s = 26.52\ m$

∴ *ball originally thrown from height of 1.65 m*

[3]

6. Work done by Chelsea = force × distance

$$= (55.0 \times 9.8)(24 \times 3.00)$$

$$= 3.88 \times 10^4 \text{ J}$$

$$\text{Power output} = \frac{\text{work done}}{\text{time taken}}$$

$$425 = \frac{3.88 \times 10^4}{t}$$

$$t = \frac{3.88 \times 10^4}{425}$$

$$= 91.3 \text{ s}$$

$\therefore$ Time taken = 91.3 s

[2]

Section Two

7.

(a)

(i) constant acceleration

(ii) constant acceleration (negative)

(b)

(i) disp = area under graph

$$= \frac{1}{2}(2 \times 1) + (2)(1) = 3.0 \text{ m}$$ [2]

(ii) during fourth second i.e. between $t = 3$ and $t = 4$

$s = (1.0)(1.0) = 1.0$ m [3]

(c)

(i) a is maximum (negative) between $t = 16$ to $t = 20$ (greatest slope)

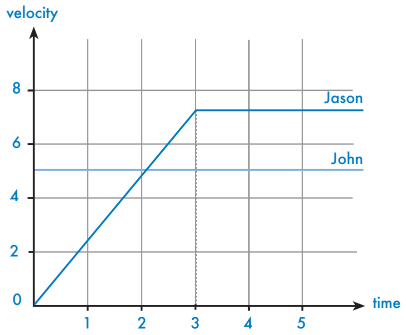
(ii) at $t = 10$

$$a = \text{gradient} = \frac{3.0 - 1.0}{14 - 4}$$

$$= 0.20 \text{ ms}^{-2}$$

[3]

8. A simple v/t graph will help clarify this question.



(a) Jason does catch John as he reaches a higher velocity

$$18.0 \text{ kmh}^{-1} = \frac{18}{3.6} = 5.0 \text{ ms}^{-1}$$

This is faster than John. [5]

(b) John $s = vt = (5.0)(t)$ ①

Jason $s = (1/2)(3.0)(7.2) + (7.2)(t - 3)$ ②

① = ②

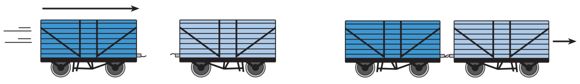
$\therefore$ $5.0\,t = 10.8 + 7.2\,t - 21.6$

$t = 4.91$ s (to catch John)

$\therefore$ $s = (5.0)(4.91) = 24.6$ m

[5]

9. (a) Before After



Momentum before collision = Momentum after collision

$m_1v_1 + m_2v_2 = (m_1 + m_2)\, v$

$(5.0 \times 10^4)(4.0) + (2.5 \times 10^4)0 = (5.0 \times 10^4 + 2.5 \times 10^4)\, v$

$20.0 \times 10^4 + 0 = 7.5 \times 10^4\, v$

$7.5 \times 10^4\, v = 20.0 \times 10^4$

$v = 2.7 \text{ ms}^{-1}$

$\therefore$ The carriages moved off at 2.7 ms^{-1} in the initial direction of the larger carriage.

[4]

(b) EK before $= 1/2\, mv^2$

$= (1/2)(5.0 \times 10^4)(4.0)^2$

$= 4.0 \times 10^5$ J

EK after $= 1/2\,(m^1 + m^2)v^2$

$= (1/2)(5.0 \times 10^4 + 2.5 \times 10^4)(2.7)^2$

$= (1/2)(7.5 \times 10^4)(7.29)$

$= 2.7 \times 10^5$ J

$\therefore$ After coupling kinetic energy is $\dfrac{2.7 \times 10^5}{4.0 \times 10^5}$ or 0.68 of the kinetic energy before the coupling. [4]

(c) The principle has been obeyed. Energy would have been dissipated overcoming the frictional resistance of the stationary carriage (e.g. heat), absorbed (vibrational) by the carriages, released as sound on impact and used to move coupling devices into position.

[4]

Section Three

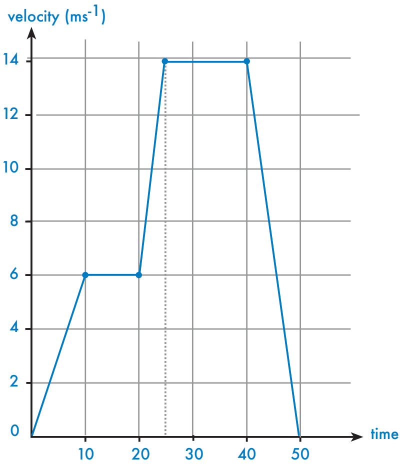
10.

(a)

TIME (s)	0	10	20	25	40	50
VELOCITY (m)	0	6	6	14	14	0

[2]

(b)



[3]

(c) *acceleration between 20 s and 25 s equals the gradient*

$$\therefore \text{acceleration} = \frac{14 - 6}{25 - 20} = \frac{8}{5} = 1.6\ ms^{-2}$$

$\therefore$ *acceleration* = $1.6\ ms^{-2}$ [2]

(d) *deceleration equals the gradient between 40 s and 50 s*

$$\text{deceleration} = \frac{0 - 14}{50 - 40} = \frac{-14}{10} = 1.4\ ms^{-2}$$

$\therefore$ *deceleration* = $1.4\ ms^{-2}$

[2]

(e) *distance travelled equals the area under the graph*

$$\therefore \text{distance} = \frac{1}{2}\ (6 \times 10) + (6 \times 10) + (6 \times 5)$$

$$+ \frac{1}{2}\ (8 \times 5) + (14 \times 15) + 1/2(14 \times 10)$$

$$= 30 + 60 + 30 + 20 + 210 + 70$$
$$= 420\ m$$

[3]

TT 5: Waves

Section One

1.

(a) *Sound A is louder and lower in pitch (frequency) than sound B.* [1]

(b) *Sound C would have a better quality than sound B due to the presence of overtones.*

[1]

2. *When we are listening to music for instance, we can hear all the different frequency sounds together, even if the source of the music is some distance away. This means that all the different frequency sounds come towards us at the same speed.* [2]

3.

(a) *Velocity – will increase.*

(b) *Direction – may change (for oblique entry).*

(c) *Wavelength – will increase.*

(d) *Frequency – no change.* [4]

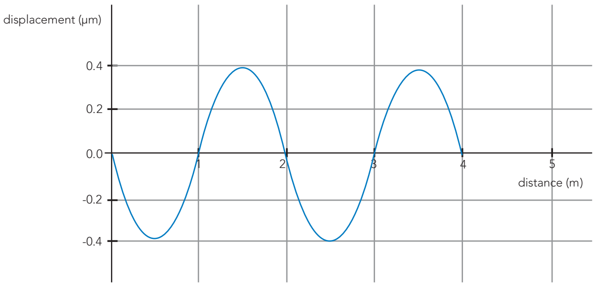
4.

(a) (i) *0.4 mm* (iv) *BE*

(ii) *2.0 m* (v) *C*

(iii) *A and G* (vi) *D, F* [3]

(b)



[3]

5.

(a) *Since the velocity of sound in water is known, the time delay between sending a signal and receiving an echo can be used to calculate depth.* [1]

(b) *High frequency sounds do not diffract too much and are much more directional and accurate.* [1]

(c) $s = v\,t = (1.53 \times 10^3)(110 \times 10^{-3})$

$= 168\ m$

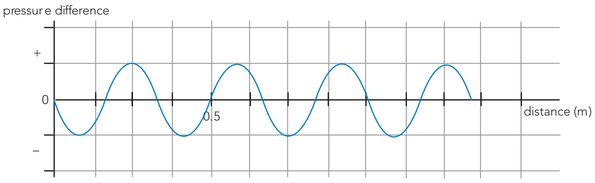
$\therefore$ *depth* $= 84\ m$ [2]

Section Two

6.

(a) $\lambda = \frac{v}{f} = \frac{340}{1000} = 0.340\ m$ [1]

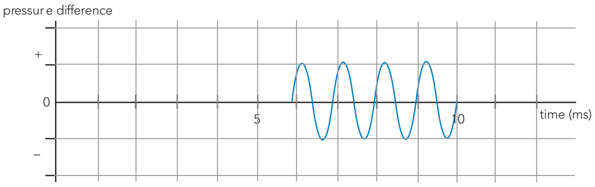
(b)



[4]

(c) $t = \frac{s}{v} = \frac{2.0}{340} = 5.88 \times 10^{-3}\ s$ [1]

(d)



[4]

7.

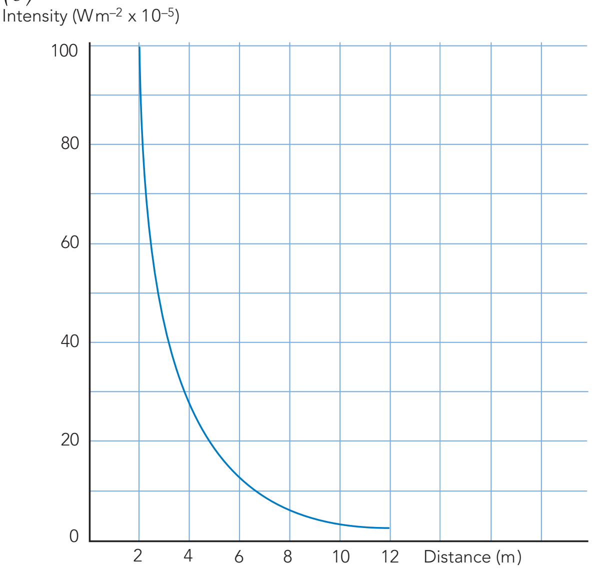
(a) (i) *from 2 m → 4 m*

$$\text{Intensity ratio}\ \frac{1.0 \times 10^{-3}}{2.5 \times 10^{-4}} = 4.0$$

(ii) *from 4 m → 8 m*

Intensity ratio = 4.0 [3]

(b)



[4]

(c) *From the answers in (b) or by graphing* *intensity versus distance we can see that*

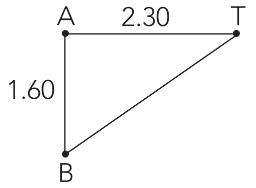
$$Intensity\ \alpha\ \frac{1}{d^2}$$ [3]

8.

(a) *Constructive and destructive interference cause loud and quiet spots.*

[2]

(b)



$(BT)^2 = (1.60)^2 + (2.30)^2$

$BT\ = 2.80\ m$

[3]

(c) *Since point T is a maximum then B T > A T by one wavelength.*

$\therefore\ v = \lambda f = (0.50)(685)$

$= 342\ ms^{-1}$

[3]

(d) *There will be loud and quiet spots as before but closer together (i.e. twice as many).*

[2]

Section Three

9.

(a) *P waves are the fastest and first to arrive after a seismic event.*
Hence they are called primary waves or P waves.

[2]

(b) *P waves are longitudinal waves like sound. When they reach the earths surface they travel through the air as sound waves and can be heard. S waves are transverse waves and can only travel through solids.*

[2]

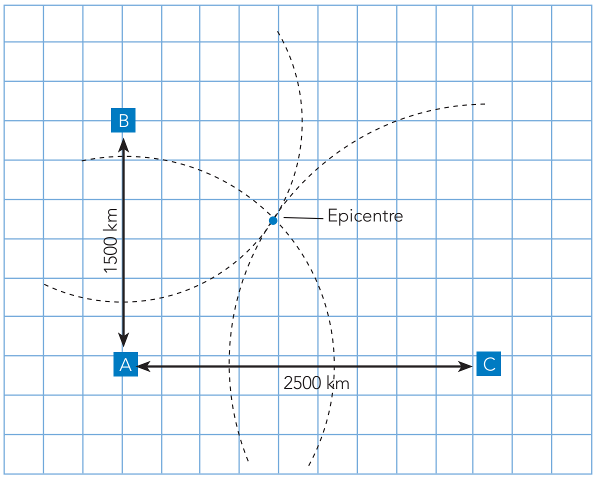
(c) *Time difference = 2.5 minutes (150 s)*

[2]

(d) *Conversion value given =(9.0 km/sec)(Δt S-P)*
$= (9.0)(150) = 13500\ km$ [2]

(e) *The distances of the 3 recording stations A, B, C are 13500 km, 1200 km and 1750 km respectively from the earthquake. The circles plotted represent these. The point of intersection is the epicentre.*

[4]



APPENDIX 1 – Metric Units and Symbols

SI Base Units

Quantity	Unit	Symbol
length	metre	m
mass	kilogram	kg
time	second	s
electric current	ampere	A
temperature	kelvin	K
luminous intensity	candela	cd
amount of substance	mole	mol

SI Derived Units With Special Names (Common Examples)

Quantity	Unit	Symbol	Expressed in Other SI Units
charge	coulomb	C	A s
dose equivalent	sievert	Sv	J kg^{-1}
electric potential	volt	V	W A^{-1}, JC^{-1}
electromotive force	volt	V	W A^{-1}, JC^{-1}
force	newton	N	kg m s^{-2}
frequency	hertz	Hz	s^{-1}
potential difference	volt	V	W A^{-1}, JC^{-1}
power	watt	W	J s^{-1}
pressure	pascal	Pa	N m^{-2}
quantity of electricity	coulomb	C	A s
radiation activity	becquerel	B q	s^{-1}
radiation dose	gray	G y	J kg^{-1}
resistance	ohm	Ω	V A^{-1}
work, energy, quantity of heat	joule	J	N m

Other SI Derived Units (Selected Examples)

Quantity	Unit	Expressed in Other SI Units
acceleration	metre per second squared	m s^{-2}
area	square metre	m^{2}
density	kilogram per cubic metre	kg m^{-3}
impulse	newton second	kg m s^{-1}
latent heat capacity	joules per kilogram	J kg^{-1}
momentum	kilogram metre per second	kg m s^{-1}
specific heat capacity	joules per kilogram per degree celsius	J kg^{-1} °C^{-1}
thermal conductivity	watt per metre per degree celsius	W m^{-1} °C $^{-1}$
velocity	metre per second	m s^{-1}
volume	cubic metre	m^{3}

Table of Common Prefixes

Prefix	Symbol	Factor	Prefix	Symbol	Factor
tera	T	10^{12}	milli	m	10^{-3}
giga	G	10^{9}	micro	μ	10^{-6}
mega	M	10^{6}	nano	n	10^{-9}
kilo	k	10^{3}	pico	p	10^{-12}

APPENDIX 2 – Physical Constants and Data

Physical Constants	
Speed of light in air	c = 3.00×10^{8} m s^{-1}
Electron charge	e = -1.60×10^{-19} C
Mass of an electron	m_e = 9.11×10^{-31} kg
Mass of a proton	m_p = 1.67×10^{-27} kg
Mass of a neutron	m_n = 1.68×10^{-27} kg
Mass of an alpha particle	m_α = 6.64×10^{-27} kg
Absolute zero	0K = –273°C

Conversion Factors	
1 atomic mass unit	u = 1.6605×10^{-27} kg
mass-energy equivalent	= 931.5 M eV
1 electron volt	eV = 1.602×10^{-19} J
1 light year	= 9.460×10^{15} m
1 tonne	= 10^{3} kg = 10^{6} g
1 m s^{-1}	= 3.6 km h^{-1}

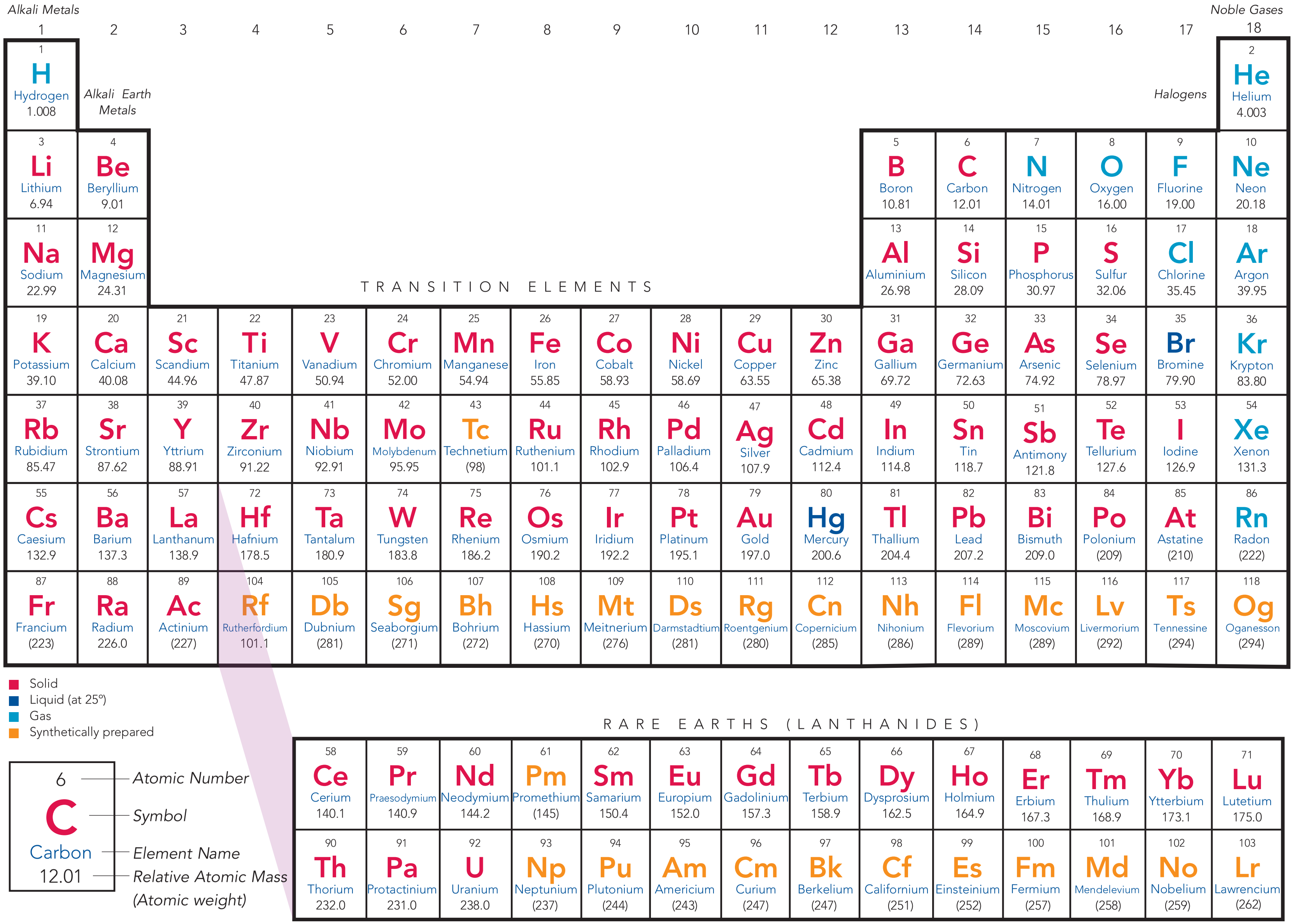
Selected Physical Data			
Acceleration due to gravity (mean)	9.80 m s^{-2}		
Specific Heat Capacities	Air	1.01×10^{3}	
(J kg^{-1} °C $^{-1}$)	Alcohol	2.44×10^{3}	
	Aluminium	8.80×10^{2}	
	Copper	3.85×10^{2}	
	Glass	8.40×10^{2}	
	Human body (average)	3.50×10^{3}	
	Ice	2.10×10^{3}	
	Iron	4.50×10^{2}	
	Mercury	1.40×10^{2}	
	Steam	2.00×10^{3}	
	Water	4.18×10^{3}	
Latent heat of fusion	Water	3.34×10^{5}	
(J kg^{-1})	Lead	2.51×10^{4}	
	Alcohol	1.65×10^{5}	
Latent heat of vaporisation (J kg^{-1})	Water	2.26×10^{6}	
Speed of sound (ms^{-1}) at 25°C	Air	3.46×10^{2}	
	Water	1.50×10^{3}	
	Water (salt)	1.53×10^{3}	
Selected atomic masses (u) and (kg)	electron	0.000549	9.11×10^{-31}
	proton	1.00728	1.6726×10^{-27}
	neutron	1.00866	1.6750×10^{-27}
	deuterium	2.01410	3.3445×10^{-27}
	helium-4	4.00260	6.6466×10^{-27}
	carbon-12	12.00000	1.99267×10^{-26}
	thorium-234	234.04360	3.88643×10^{-25}
	uranium-238	238.05079	3.95298×10^{-25}

APPENDIX 3 – List of the Elements

For elements beyond 103 and relative atomic masses please see periodic table next page.

Element	Symbol	Atomic Number	Mass Number (most common isotope)
Hydrogen	H	1	1
Helium	He	2	4
Lithium	Li	3	7
Beryllium	Be	4	9
Boron	B	5	11
Carbon	C	6	12
Nitrogen	N	7	14
Oxygen	O	8	16
Fluorine	F	9	19
Neon	Ne	10	20
Sodium	Na	11	23
Magnesium	Mg	12	24
Aluminium	Al	13	27
Silicon	Si	14	28
Phosphorus	P	15	31
Sulfur	S	16	32
Chlorine	Cl	17	35
Argon	Ar	18	40
Potassium	K	19	39
Calcium	Ca	20	40
Scandium	Sc	21	45
Titanium	Ti	22	48
Vanadium	V	23	51
Chromium	Cr	24	52
Manganese	Mn	25	55
Iron	Fe	26	56
Cobalt	Co	27	59
Nickel	Ni	28	58
Copper	Cu	29	63
Zinc	Zn	30	64
Gallium	Ga	31	69
Germanium	Ge	32	74
Arsenic	As	33	75
Selenium	Se	34	80
Bromine	Br	35	79
Krypton	Kr	36	84
Rubidium	Rb	37	85
Strontium	Sr	38	88
Yttrium	Y	39	89
Zirconium	Zr	40	90
Niobium	Nb	41	93
Molybdenum	Mo	42	98
Technetium	Tc	43	99
Ruthenium	Ru	44	102
Rhodium	Rh	45	103
Palladium	Pd	46	106
Silver	Ag	47	107
Cadmium	Cd	48	114
Indium	In	49	115
Tin	Sn	50	120
Antimony	Sb	51	121
Tellurium	Te	52	130
Iodine	I	53	127
Xenon	Xe	54	132
Caesium	Cs	55	133
Barium	Ba	56	138
Lanthanum	La	57	139
Cerium	Ce	58	140
Praseodymium	Pr	59	141
Neodymium	Nd	60	142
Promethium	Pm	61	145
Samarium	Sm	62	152
Europium	Eu	63	153
Gadolinium	Gd	64	158
Terbium	Tb	65	159
Dysprosium	Dy	66	164
Holmium	Ho	67	165
Erbium	Er	68	166
Thulium	Tm	69	169
Ytterbium	Yb	70	174
Lutetium	Lu	71	175
Hafnium	Hf	72	180
Tantalum	Ta	73	181
Tungsten	W	74	184
Rhenium	Re	75	187
Osmium	Os	76	192
Iridium	Ir	77	193
Platinum	Pt	78	195
Gold	Au	79	197
Mercury	Hg	80	202
Thallium	Tl	81	205
Lead	Pb	82	208
Bismuth	Bi	83	209
Polonium	Po	84	210
Astatine	At	85	210
Radon	Rn	86	222
Francium	Fr	87	233
Radium	Ra	88	226
Actinium	Ac	89	227
Thorium	Th	90	232
Protactinium	Pa	91	231
Uranium	U	92	238
Neptunium	Np	93	237
Plutonium	Pu	94	244
Americium	Am	95	243
Curium	Cm	96	247
Berkelium	Bk	97	247
Californium	Cf	98	251
Einsteinium	Es	99	254
Fermium	Fm	100	257
Mendelevium	Md	101	256
Nobelium	No	102	259
Lawrencium	Lr	103	257

APPENDIX 4 – Periodic Table of the Elements



Alkali Metals (1) · *Alkali Earth Metals* (2) · TRANSITION ELEMENTS · *Halogens* (17) · *Noble Gases* (18)

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1 H Hydrogen 1.008																	2 He Helium 4.003
3 Li Lithium 6.94	4 Be Beryllium 9.01											5 B Boron 10.81	6 C Carbon 12.01	7 N Nitrogen 14.01	8 O Oxygen 16.00	9 F Fluorine 19.00	10 Ne Neon 20.18
11 Na Sodium 22.99	12 Mg Magnesium 24.31											13 Al Aluminium 26.98	14 Si Silicon 28.09	15 P Phosphorus 30.97	16 S Sulfur 32.06	17 Cl Chlorine 35.45	18 Ar Argon 39.95
19 K Potassium 39.10	20 Ca Calcium 40.08	21 Sc Scandium 44.96	22 Ti Titanium 47.87	23 V Vanadium 50.94	24 Cr Chromium 52.00	25 Mn Manganese 54.94	26 Fe Iron 55.85	27 Co Cobalt 58.93	28 Ni Nickel 58.69	29 Cu Copper 63.55	30 Zn Zinc 65.38	31 Ga Gallium 69.72	32 Ge Germanium 72.63	33 As Arsenic 74.92	34 Se Selenium 78.97	35 Br Bromine 79.90	36 Kr Krypton 83.80
37 Rb Rubidium 85.47	38 Sr Strontium 87.62	39 Y Yttrium 88.91	40 Zr Zirconium 91.22	41 Nb Niobium 92.91	42 Mo Molybdenum 95.95	43 Tc Technetium (98)	44 Ru Ruthenium 101.1	45 Rh Rhodium 102.9	46 Pd Palladium 106.4	47 Ag Silver 107.9	48 Cd Cadmium 112.4	49 In Indium 114.8	50 Sn Tin 118.7	51 Sb Antimony 121.8	52 Te Tellurium 127.6	53 I Iodine 126.9	54 Xe Xenon 131.3
55 Cs Caesium 132.9	56 Ba Barium 137.3	57 La Lanthanum 138.9	72 Hf Hafnium 178.5	73 Ta Tantalum 180.9	74 W Tungsten 183.8	75 Re Rhenium 186.2	76 Os Osmium 190.2	77 Ir Iridium 192.2	78 Pt Platinum 195.1	79 Au Gold 197.0	80 Hg Mercury 200.6	81 Tl Thallium 204.4	82 Pb Lead 207.2	83 Bi Bismuth 209.0	84 Po Polonium (209)	85 At Astatine (210)	86 Rn Radon (222)
87 Fr Francium (223)	88 Ra Radium 226.0	89 Ac Actinium (227)	104 Rf Rutherfordium 101.1	105 Db Dubnium (281)	106 Sg Seaborgium (271)	107 Bh Bohrium (272)	108 Hs Hassium (270)	109 Mt Meitnerium (276)	110 Ds Darmstadtium (281)	111 Rg Roentgenium (280)	112 Cn Copernicium (285)	113 Nh Nihonium (286)	114 Fl Flevorium (289)	115 Mc Moscovium (289)	116 Lv Livermorium (292)	117 Ts Tennessine (294)	118 Og Oganesson (294)

🟥 Solid
🟦 Liquid (at 25°)
🟦 Gas
🟧 Synthetically prepared

6 — *Atomic Number*
C — *Symbol*
Carbon — *Element Name*
12.01 — *Relative Atomic Mass (Atomic weight)*

RARE EARTHS (LANTHANIDES)

58 Ce Cerium 140.1	59 Pr Praesodymium 140.9	60 Nd Neodymium 144.2	61 Pm Promethium (145)	62 Sm Samarium 150.4	63 Eu Europium 152.0	64 Gd Gadolinium 157.3	65 Tb Terbium 158.9	66 Dy Dysprosium 162.5	67 Ho Holmium 164.9	68 Er Erbium 167.3	69 Tm Thulium 168.9	70 Yb Ytterbium 173.1	71 Lu Lutetium 175.0
90 Th Thorium 232.0	91 Pa Protactinium 231.0	92 U Uranium 238.0	93 Np Neptunium (237)	94 Pu Plutonium (244)	95 Am Americium (243)	96 Cm Curium (247)	97 Bk Berkelium (247)	98 Cf Californium (251)	99 Es Einsteinium (252)	100 Fm Fermium (257)	101 Md Mendelevium (258)	102 No Nobelium (259)	103 Lr Lawrencium (262)

ACTINIDES

( ) = mass number of the isotope with the longest half life

Atomic weights from data published by IUPAC Commission on Atomic Weights 2018

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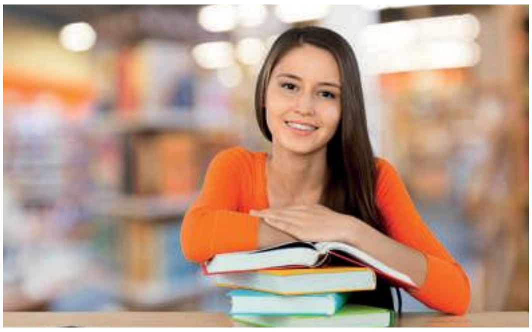

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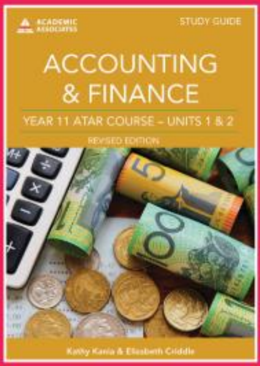

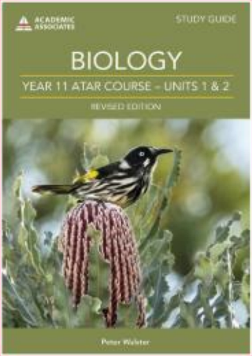

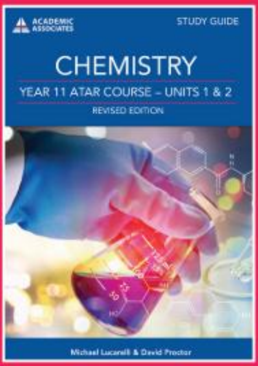

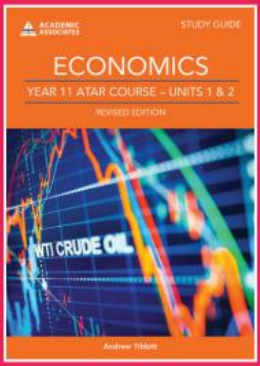

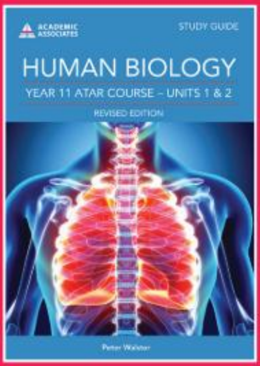

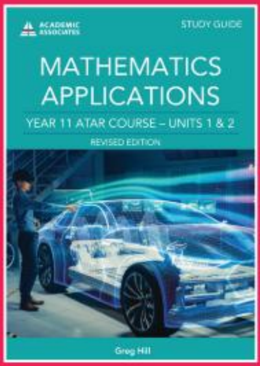

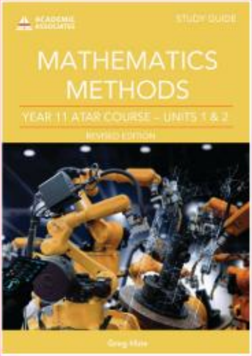

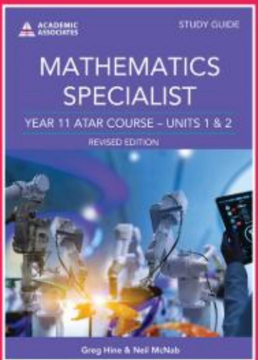

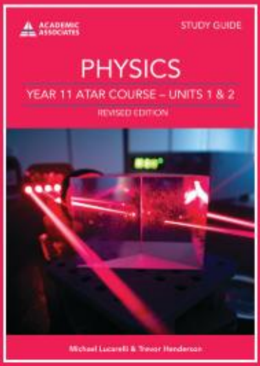

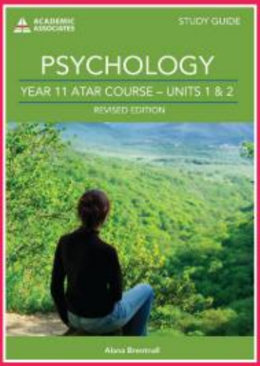

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