YEAR 11 ATAR COURSE REVISED EDITION

ACADEMIC TASK FORCE

REVISION SERIES

PHYSICS

UNITS 1 & 2

ROY SKINNER

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PHYSICS

YEAR 11 ATAR COURSE
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FIRST EDITION

ROY SKINNER

ACADEMIC GROUP
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First published 2014
Reprinted 2015, 2020, 2021, 2022, 2024

National Library of Australia ISBN 978-1-74098-173-6

Printed in Western Australia on paper supporting responsible forestry.

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Acknowledgements
- W.A. School Curriculum and Standards Authority – with permission to use extracts from the Physics syllabus and Physics Data Sheet.
- Images by CanStockPhoto and iStock

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UNIT 1 – THERMAL, NUCLEAR AND ELECTRICAL PHYSICS

UNIT 2 – LINEAR MOTION AND WAVES

How to Use this Revision Series

This book is meant to be used in conjunction with a class text book; the aim is to simply reinforce the most important principles and understandings. Contained are the basic essentials needed for students to teach themselves by absorbing the bare facts and concepts, then working through the many example questions and quizzes. This book is meant to be written in as a Work Book to produce progressive learning in a student-friendly manner.

An active learning style is promulgated through the use of simple pictures and diagrams within the text, making full understanding cognitively simpler.

Tests are supplied at the end of each topic and trial papers that would typify those used in National Curriculum examinations.

One of the main thrusts in this new system is the importance of experimental design and analysis, where specific thinking skills and a focus on practical work has become more prominent (e.g. control of variables, data analysis, graphing and evaluation skills). This book is unique in this aspect as it has a whole chapter devoted to Investigations, where the separate, discrete skills are each targeted, from "How to design experiments" to "Evaluation and improvement of techniques".

This new ATAR Year 11 physics book follows on from the very successful Physics 2AB book Dr Skinner produced previously.

Dr Roy Skinner

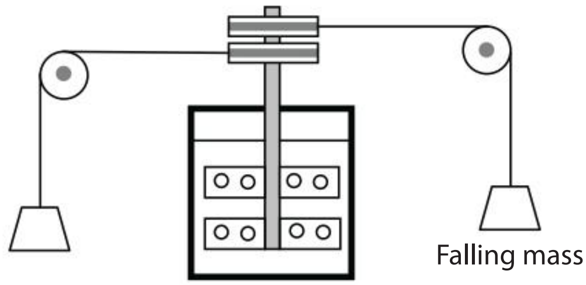
HEATING AND COOLING

Chapter
1

1.1 Ideas of Heat

Early ideas were that heat was an invisible fluid called "caloric" which flowed out of a hot object and into a cold one. This notion remained until an Englishman called Count Rumford noticed that cannons that were being bored out with a drill became very hot. This could not be explained by the Caloric Theory and so a new idea emerged that heat was a form of **energy**: The mechanical energy used to drill out the cannon was being converted into heat, according to Count Rumford. It was argued that one form of energy could be converted to another.

Later James Joule set up an experiment to measure the equivalence between mechanical energy and absorbed heat. Weights on strings were allowed to fall, lose their potential energy and stir up the water. The temperature rise of the water was measured and linked to the amount of potential energy lost by the weights. In those days heat was measured on calories and potential energy measured in foot-pounds.

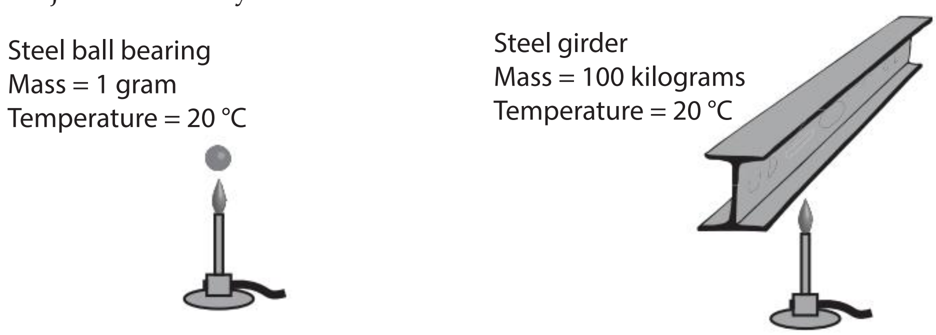


The unit of heat is now the **joule**, which is the same for all forms of energy.

1.2 Temperature

What is the difference between heat and temperature?

To answer this, consider the same lighted Bunsen burner being placed underneath each of these two objects for exactly 1 minute:



At the end of 1 minute, which object possesses the **most heat**?

Which object has the highest temperature?

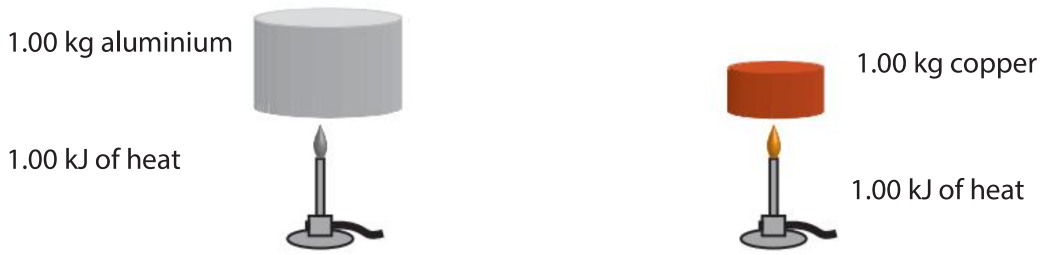
Answers:

- They both must have had the same amount of heat added as the same bunsen burner was used for the same amount of time.
- The steel ball-bearing will have the highest temperature because there is less of it to heat up (a smaller mass)

Temperature change, then, is a measure of the **concentration of heat** i.e. how much heat has been added to each kilogram of material.
Temperature change ΔT is proportional to the heat per kilogram, H/m (H in joules, m in kg)

Mathematically: $\Delta T \propto H/m$ or rearranging, $H \propto m \times \Delta T$ ($\propto$ means "proportional")

Consider the following two objects of the same mass being supplied with the same quantity of heat. Will they both have the same temperature rise?



Because the objects are made of different materials, this will also affect the temperature rise - so allowance must be made in the formula for the **type of substance** being heated. The amount of heat needed to raise the temperature of one kilogram of any material by 1 degree Celsius (or 1 Kelvin degree) is called its **Specific Heat Capacity** (symbol c)

So the final formula for heating an object is $H = mc\,\Delta T$

H = heat supplied (joules)

m = mass of object (kg)

ΔT = temperature change ($T_2 - T_1$) in celsius or kelvins

As $c = H/(m\Delta T)$, the units of SHC are J Kg^{-1} K^{-1}

For water, the SHC is 4180 J Kg^{-1} K^{-1}

The SHC of water is extremely high – the only substance significantly higher is hydrogen whose SHC is 14.3 kJ kg^{-1} K^{-1}.

Example 1

A girl runs 150 litres of hot water at 40°C into a bath. If this water was heated from 20°C by the heater, what quantity of heat has been absorbed by the water?

Solution 1

m = 150 kg	$H = mc\Delta T$
c = 4180 J Kg^{-1} K^{-1}	$H = 150 \times 4180 \times (40 - 20) = 12,540,000$ J
$\Delta T = (40 - 20)$	H = 12.54 MJ or 1.254×10^7 J

There is also a quantity called Heat Capacity (C_H) which does not take into account the mass of a substance.

$H = C_H \times \Delta T$ So to raise 2 kg of water through 5 °C would need $2 \times 4180 \times 5$ joules = 4.181×10^3 J.

Hence the Heat Capacity of this mass of water is 4.181 kJ K^{-1} (note the units).

1.3 Mechanical Energy Conversion

As Joule showed, potential energy and kinetic energy can be converted into heat energy and cause a temperature rise in another object. For instance, if a brick is dropped from the top of a roof it would become warmer when it hits the ground as the potential energy of the brick on the roof gets converted, firstly to kinetic energy as it speeds up, and finally into heat as it hits the ground.

Potential energy (PE), due to the position of an object above the ground is given by the equation

PE = mgh (mass × gravitational field strength × height)

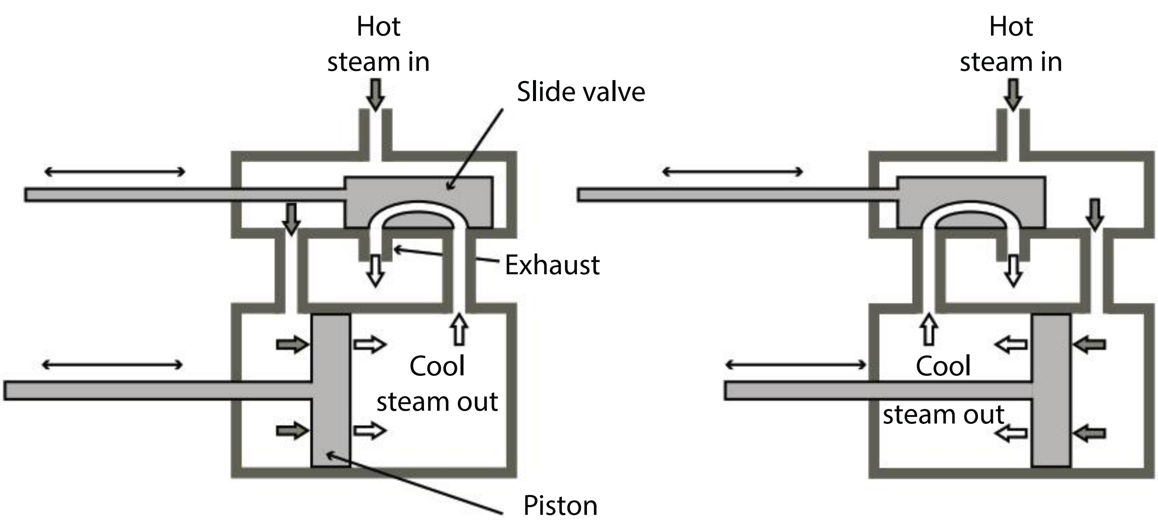
Kinetic energy (KE), due to the motion of an object is given by the equation

$KE = \frac{1}{2} mv^2$ (½ × mass × velocity squared)

Electrical energy is regarded as the highest form of energy as it can easily be converted into other forms: heat, light, mechanical, etc. Heat is said to be the lowest form of energy as it is the most difficult to convert into other forms of energy. For instance, the sea has vast amounts of heat energy but this heat is not concentrated enough to be useful because the temperature of the sea is low.

However, when the temperature of water is high its heat energy can be easily converted to other forms, such as occurs in a steam engine. When water boils, it expands by about 1600 times and can drive a piston forwards, producing mechanical energy. The workings of any engine rely on the 1st Law of Thermodynamics.

The Steam Engine



As the steam pushes the piston to the right the piston pushes the previous mass of steam out through the exhaust valve. The slide valve then moves to the left allowing steam to push the piston back again.

1st law of Thermodynamics

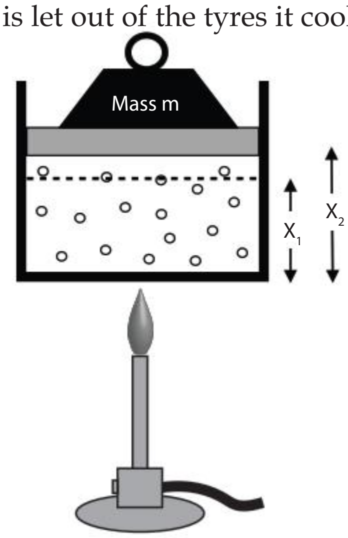
This is really a statement based on the Law of Conservation of Energy and says that for any closed system the total energy content of the matter inside is the sum of heat energy (kinetic) plus mechanical work (potential).

As an equation: $\Delta U = Q + W$

So if energy is added to the system (ΔU) this will result in an increase in the heat content (Q) of the matter plus an increase in its potential energy W i.e. work is done on the system.

An example of how this works is shown when a cyclist pumps up his tyres and work is done on the system (air inside the tyre). Where work is done on a system then W is a positive value so the formula shows $\Delta U = Q + W$ so for total energy U to be conserved, Q must increase i.e. the temperature of the air in the tyre increases. Conversely, if air is let out of the tyres it cools down.

In the steam engine, heat is being added to make the gas heat up and expand and in expanding, kinetic energy is being converted to potential energy and work is done by the gas. So, as W increases the temperature of the gas must decrease.



Work done by gas W = force × distance moved

Pressure P exerted by the mass is given by:

P = force/area so $mg = P \times A$

Therefore $W = P \times A \times (x_2 - x_1) = P \times \Delta V$

Work done by a gas = Pressure × volume change.

Example 2(a)

A bicycle pump contains 2.50×10^{-1} g of air at a temperature of 22.0 °C. In pumping up the tyre an average force of 3.75 N was exerted on the handle and it was moved through a distance of 35.0 cm. Calculate the final temperature of the air in the tyre. (SHC of air = 1.00×10^3 J kg^{-1} K^{-1})

Solution 2(a)

Work done on the air = Fs = 3.75 ×0.35 = 1.3125 J
1st Law of thermodynamics: $1.3125 = 2.5 \times 10^{-4} \times 1000 \times \Delta T$
$\Delta T = 5.25$ K

So final temperature = 27.3 °C.

Example 2(b)

A 2.5 kg brick (SHC = 1100 J Kg^{-1} K^{-1}) is dropped from the roof of a building 30 m above the ground.

Find a) the PE of the brick, b) the KE that the brick has as it hits the ground c) the temperature rise of the brick.

Solution 2(b)

a) PE = mgh = 2.5 × 9.8 × 30 = 745 J
b) KE gained at bottom = PE lost in falling = 745 J
c) KE converted to heat = $mc\Delta T$ so 745 = 2.5 × 1100 × ΔT

ΔT = 745/2750 = 0.0267°C

1.4 Power

Power is the **rate** at which heat is supplied. So a heater with a power of 5 watts gives out heat at a rate of 5 joules per second. In 20 seconds this heater would give out 100 J (5×20) so the heat given out is given by the formula: Heat = power×time.

Example 3

A family arrives home from holiday and switches on their 3.5 kW water heater, which contains 150 litres of water at 20°C. How long will it be before the family can have a shower if the water needs to be at a temperature of 40°C?

Solution 3

Heat needed to heat the water = 150 × 4180 × (40 – 20) = 1.254×10^7 J
Heat supplied = Pt = 3500t = 1.254×10^7
t = 1.254×10^7/3500 = 3583 s = 59.7 min (almost an hour)

Example 4(a)

A heavy box is being dragged along the floor with a frictional force of 12 kN. The distance the box is dragged is 8 metres. a) How much heat would have been generated from friction? b) If the box has a mass of 8 kg and a SHC of 720 J kg^{-1} K^{-1}, calculate the temperature rise of the box after dragging it.

Solution 4(a)

a) Work done against friction = F × d = 12,000 × 8 = 96,000 J
b) Heat supplied = 96,000 = 8 × 720 × ΔT So ΔT = 16.7°C

Example 4(b)

A heavy box is being dragged along the floor against a frictional force of 12 kN. The distance the box is dragged is 8 metres. a) How much heat would have been generated from friction? b) If the box has a heat capacity of 5760 J K^{-1}, calculate the temperature rise of the box after dragging it.

Solution 4(b)

a) Work done against friction = F × d = 12,000 × 8 = 96,000 J
b) H = $C_H \times \Delta T$, so Heat supplied = 96,000 = 5760 × ΔT ΔT = 16.7°C

Specific Heat Capacity Quiz

(Reminder: PE = mgh; g = 9.8 m s^{-2}; KE = ½mv^2; H = Pt.)

1. A 400 g block of lead (SHC = 130 J kg^{-1} K^{-1}) is being heated up from 20°C to its melting point of 327°C. How much heat was absorbed in the process?

2. A solar heating panel on a roof is used to heat 40 kg of water initially at 22°C, using the sun, which absorbs 750 joules per second. What would the temperature of this water be after 1 hour?

3. A 450 g block of metal is supplied with 11 kJ of heat and its temperature rises by 41°C. What is the SHC of the metal?

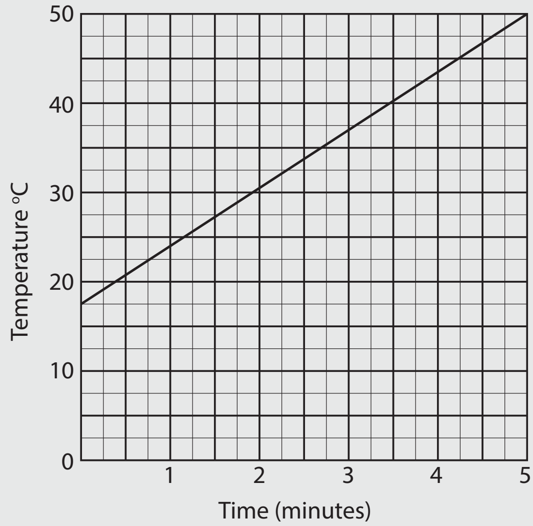
4. A 90 watt heater used to heat a 0.52 kg block of a material for 1½ minutes, during which time its temperature rises from 20°C to 100°C. Find the SHC of the metal.

5. A kettle contains 1.8 kg of water at 25°C. If the element is rated at 2100 W, how long will it be before the water boils?

6. A Bunsen burner is used to heat 250 g of water at 15°C for 4 min. If the Bunsen burner is rated at 200 watts, find the final temperature of the water.

7. A 60 kg athlete takes in 9 MJ of energy from her food per day. If this energy were converted into heat, what would be the theoretical temperature rise of her body if its SHC is 3.49 kJ kg^{-1} K^{-1}?

8. 12 kg of a liquid is heated, using a 900 W heater. The temperature of the liquid is recorded every minute as shown. Use the graph to estimate the SHC of the liquid.



9. A paddle wheel is used to stir 0.5 L of water in a beaker. The wheel is turned by a weight of mass 9.5 kg falling through a height of 2.0 m. After the weight has fallen 50 times the temperature of the water rose by 4.0 °C. Calculate the SHC of water from these data.

10 A 1.8 tonne 4WD travelling at 90 km h^{-1} is stopped by 4 iron disc brakes (SHC = 440 J kg^{-1} K^{-1}), each of mass 500 g. Assuming all the kinetic energy is changed to heat, calculate the temperature rise of each brake with no air cooling.

11. Estimate the difference in temperature of the water at the top and bottom of Niagara Falls (height = 60 m).

12. A building's air-conditioning system recirculates 200 kg of air in one minute with a SHC of 995 J kg^{-1} K^{-1}. If the air comes in at 30°C and is cooled to 18°C calculate the heat removed from the air each minute.

13. A candle of mass 12.65 g initially is used to heat 100 g of water at 21°C. When the water temperature has risen to 29°C it was found that the candle mass was now 12.39 g. Calculate the energy contained in 1 gram of the candle wax.

14. In an experiment to find the SHC of lead shot, 100 g was placed in a 50 cm, closed tube and inverted 20 times. Originally the lead's temperature was 18.4°C and its final temperature was 19.1°C. Calculate a value for the SHC of lead.

15. A bullet of mass 9.50 g was fired at a velocity of 250 m s^{-1} at a brick with a mass of 3.0 kg. Estimate the temperature rise of the brick after the bullet had stopped (SHC of brick = 800 J kg^{-1} K^{-1}.)

16. 300 g of water was placed on an electric heater for 2 minutes and its temperature rose by 44°C. What would be the temperature rise of 500 g of cooking oil (SHC = 2800 J kg^{-1} K^{-1}) placed on the same heater for 1 minute?

17. A gas heater was used to heat a room of air measuring 3 × 4 × 5 metres. After 5 minutes the temperature of the air (SHC = 995 J kg^{-1} K^{-1}) had risen by 15°C. If 1 m^3 of air has a mass of 1.20 kg, find the rate at which the heater is supplying heat, in joules per second.

18. A man making an iron gate in a forge hammered a 750 g piece of iron, which was at 650°C and placed it into a 5 litre bucket of water at 22°C. Estimate the final temperature of the water, assuming that all the heat from the iron (SHC = 440 J kg^{-1} K^{-1}) was transferred to the water without any boiling (See section 1.8).

19. A 1.78 kg square piece of copper, measuring 20×20 cm and painted black is placed in the sun for 12.0 minutes where its temperature was found to rise from 18.0 °C to a final temperature T. The copper was then quickly transferred to a bucket of water containing 2.00 kg of water at 20.0 °C. After stirring, the final temperature of the water was found to be 21.6 °C.

a) Calculate the amount of heat transferred from the copper to the water.

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b) Calculate a value for T, the temperature of the hot copper, when transferred to the water.

c) Estimate the amount of heat energy falling on the Earth per square metre per second.
(Take the SHC of copper to be 390 J kg^{-1} K^{-1})

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20. An electric kettle has a heating element which uses 2.20 kW of power. The kettle has a mass of 1.65 kg and is made of a metal with a SHC of 410 J kg^{-1} K^{-1} and contains 0.55 kg of water at 10°C. If the kettle is left on for 3.00 minutes, what will the temperature of the water be, assuming no energy losses?

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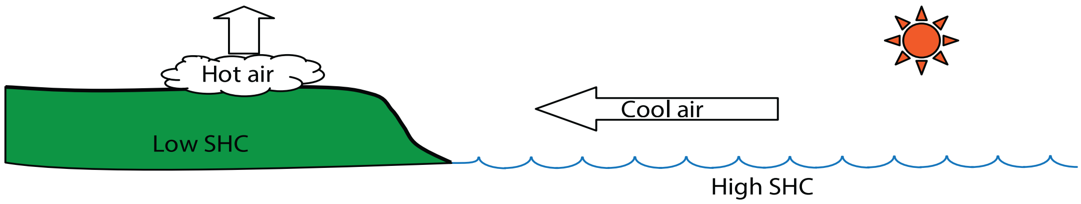
1.5 Climate considerations

The difference between the SHC of land and water is the cause of breezes on the coast and is responsible for the wind flow patterns around the Earth.

Imagine the land and sea being heated in the early morning

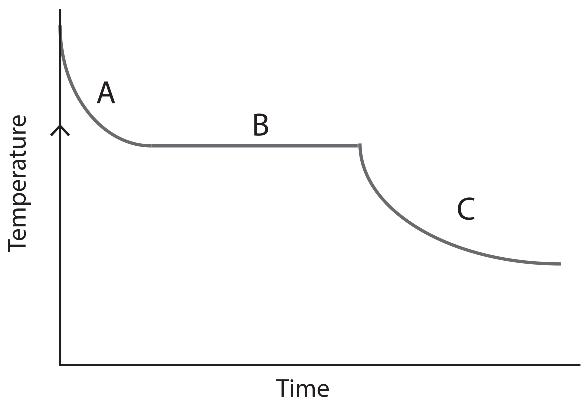


Land has a low SHC and water has a very high value, which means that during the day the land will get hot whilst the sea's temperature will stay virtually the same. Hot air will rise above the land due to convection currents, leaving an area of low pressure (less air). Air will then move in from the sea where the pressure is higher and cause a **sea breeze**. When the hot air from the land rises to the upper atmosphere it cools and falls down out at sea, creating a cycle of moving air. All winds over the surface of the Earth are produced in this way. At night the air flow reverses (land breeze) because the sea is now warmer than the land.

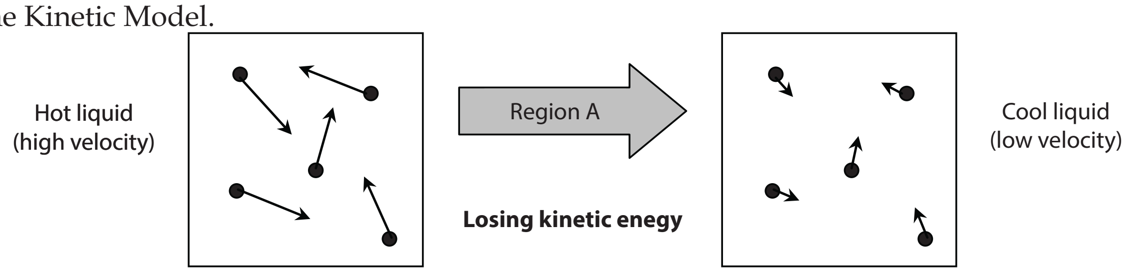
1.6 Latent heat

If a beaker of water is heated continuously with a Bunsen burner its temperature continues to rise until it gets to 100°C. If heat is still being supplied, why does the temperature not rise any further? The heat energy is obviously being used to do something else but not for changing the temperature. This hidden (latent) heat is being used to **change the state** of the water from liquid to vapour.

When solids are cooled (e.g. wax) the shape of the cooling graph has 3 main regions, as shown on the right.

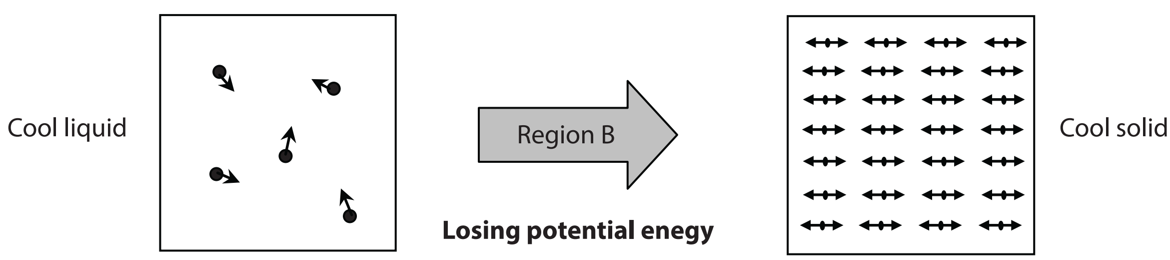


Region A is where the hot liquid wax is cooling and losing temperature, but in region B the wax is hot and not losing temperature. Why? How can a hot object stay at the same temperature? The heat loss seems to be "hidden". The following diagrams illustrate the situation in terms of the Kinetic Model.



High temperatures means that the molecules are moving with a high average kinetic energy, so cooling involves losing kinetic energy and therefore temperature.

In cooling, the molecules also move **closer** to each other and consequently the intermolecular forces become greater.



At the start of region B energy is given out as the molecules move closer to each other and lose potential energy so some liquid starts to become solid. More and more potential energy is lost as more molecules move closer together but their **temperature stays the same**. The heat given out during cooling is called latent heat (hidden heat).

The heat absorbed when a solid melts is called latent heat of fusion and the heat absorbed when a liquid boils is called the **latent heat** of vaporisation.

Specific latent heat of fusion (SLHF, L_f) of a substance is the heat needed to melt 1 kilogram of the substance without a change in temperature.

Specific latent heat of vaporisation (SLHV, L_v) of a substance is the heat needed to boil 1 kilogram of the substance without a change in temperature.

Values: SLHF of ice = 3.34×10^5 J kg^{-1} (= L_f)
SLHV of water = 2.25×10^6 J kg^{-1} (= L_v)

Example 5

How much heat is needed to melt 50 g of ice cubes without a temp change?

Solution 5 $H = mL = 0.05 \times 3.34 \times 10^5 = 1.67 \times 10^4$ J

Example 6

A saucepan of water at 100°C is heated on a stove that gives 35 kJ of heat per minute. After 3 minutes:

a) How much heat has been supplied to the saucepan?

b) How much water has boiled off?

Solution 6

a) 35 kJ in 1 minute = 3 × 35000 J in 3 minutes = 1.05×10^5 J

b) $H = mL_v$ so $m = H/L_v = 1.05 \times 10^5/2.25 \times 10^6 = 0.0467$ kg boiled off.

Example 7

An aluminium can of mass 270 g contains 150 g of water at 25 °C. The can of water is heated by a Bunsen burner that supplies 14.6 kJ of heat. Calculate the final temperature of the aluminium can of water (SHC of aluminium = 880 J Kg^{-1} K^{-1})

Solution 7

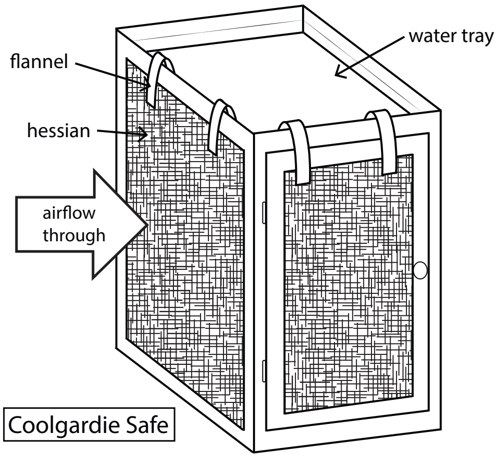
The heat supplied is shared between the can and the water so they both have the same change of temperature.

$$H = (m_{Al} \times c_{Al} \times \Delta T) + (m_w \times c_w \times \Delta T)$$
$$1.46\times10^4 = (0.27 \times 880 \times \Delta T) + (0.15 \times 4200 \times \Delta T)$$
$$= 237.6\Delta T + 630\Delta T = 867.6\Delta T$$
$$\text{So } \Delta T = 1.46\times10^4/867.6 = 16.8^\circ C$$

1.7 Refrigeration

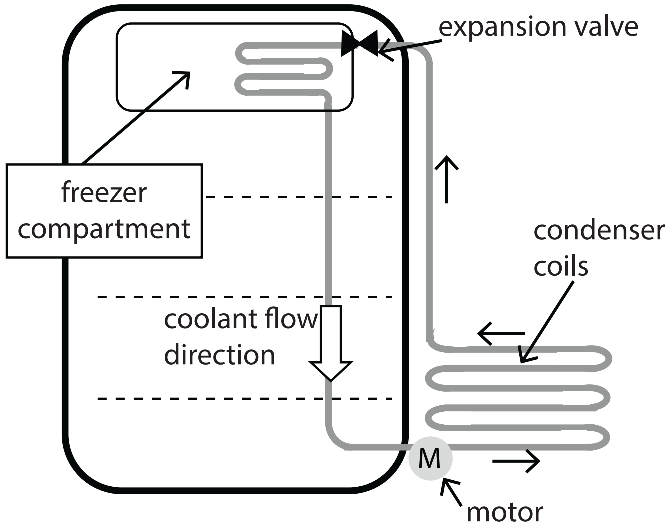
A very simple form of food cooler was used by the old gold miners out in the bush from a box and some wet cloth supplied with water from a reservoir on top.

This device relied on natural airflow and was called the Coolgardie safe. As the breeze flows through the wet hessian sacking it forces the water molecules apart to gain PE. This PE is obtained from the KE of the water. The KE of the water reduces and hence its temperature drops, cooling the air and the food inside the safe. This is still the principle used today for evaporative air conditioners.



Coolgardie Safe

The Refrigerator



Instead of water, a gas is now used which has a much lower boiling point (volatile) and can be compressed easily into a liquid, using a pump.

This volatile liquid is used as a refrigerant inside the tubes. This liquid is allowed to boil by passing into a low pressure area through the expansion valve.

The latent heat needed to boil the refrigerant is extracted from the air in the freezing compartment, so the air cools. The gaseous refrigerant then moves down and is compressed into a liquid once again outside the fridge.

Latent heat is given out in the process, which is released in the condenser coils. These have a large area and are painted black to transfer heat efficiently because they get hot.

Evaporative air conditioners work in the same way as the Coolgardie safe and refrigerative air conditioners work as the refrigerator does with air constantly flowing through what is the freezing compartment area. The advantage of refrigerative air conditioners is that they will still work in humid climates, whereas with evaporative air conditioners the water cannot easily evaporate into air if it is already saturated with vapour.

1.8 Interconversion of energy

Energy can neither be created nor destroyed. It can only be converted from one form to another.

Forms of energy are: **Potential, Kinetic, Heat, Light, Sound, Electrical, Magnetic, Nuclear.**

e.g The energy conversions of a car going up a hill:

LIGHT → CHEMICAL → HEAT → KINETIC → POTENTIAL
Sun petrol heat movement up-hill

The sun made plants grow in the past and these decayed over millions of years to become oil. This was burnt in the engine to produce heat (hot air), which expanded to move the wheels (KE). As the car went up the hill, KE was converted to PE.

Interconversion calculations

Example 8

A car of mass 1000 kg, moving at 30 m s^{-1} is stopped by 4 disc brakes, each made of iron and of mass 3.0 kg. If the SHC of iron is 440 J kg^{-1} K^{-1}, find the temperature rise in the brakes after braking.

Solution 8

Kinetic energy of car = $\frac{1}{2}mv^2 = 0.5 \times 1000 \times 30^2 = 450$ kJ

If temp rise is ΔT then $450000 = 4 \times 3 \times 440 \times \Delta T$ so $\Delta T = 85.2°C$

Example 9

A 2 kg block of lead is dropped from a helicopter to the ground 500 m below. Find the temperature rise if the SHC of lead block = 130 J kg^{-1} K^{-1}.

Solution 9

PE of the block = mgh ($g = 9.8$ m/s^2) = 2×9.8×500 = 9800 J

If temp rise is ΔT then: $9800 = 2 \times 130 \times \Delta T$ so $\Delta T = 37.7°C$

1.9 Mixing Hot and Cold Objects

When a hot object comes into contact with a cold object heat becomes transferred from one to the other until they both reach the same temperature. The principle involved with solving the mixing problems involves the Law of Conservation of Energy:

Heat given out by the hot object = Heat taken in by the cold object

Example 10

A 50 g block of copper (SHC = 390 J kg^{-1} K^{-1}) is heated to 200°C and transferred to a beaker containing 200 g of water at 20 °C. What is the final temperature after mixing?

Solution 10

Let the final temperature of the water and metal = T °C

Heat lost by the hot copper = $mc\Delta T = 0.05 \times 390 \times (200 - T) \rightarrow 3900 - 19.5T$

Heat gained by the water = $0.2 \times 4180 \times (T - 20) \rightarrow 836T - 16720$

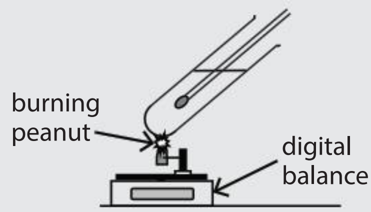
$$20620 = 855.5T \qquad \text{so } T = 24.1°C$$

Heat Calculations Quiz

1. A burning peanut is suspended on a digital balance in an experiment to find the heat content of peanut oil. It is used to heat up a test-tube full of water whose temperature can be measured with a digital thermometer.

The following experimental results were obtained:

Mass of water used	=	32.2 g
Initial temperature	=	17°C
Final temperature	=	31°C
Time of heating	=	68 s
Initial mass of peanut	=	2.89 g
Mass of peanut after burning	=	2.33 g



a) Find the heat gained by the water

b) Find the energy obtained from each gram of peanut oil

2. 60 g of boiling water is poured into a cup containing 150 g of cold tea at 15°C. What would the approximate temperature of tea be after adding the hot water? (Assume the specific heat capacity of tea to be the same as water = 4200 J kg^{-1} K^{-1}).

3. 30 g of crushed ice at 0°C are dropped into 320 g of water at 70°C.

What would the overall temperature of the mixture be immediately after the ice has melted?

4. A pipe from a Canadian steam boiler breaks so the steam comes out and melts the ice around it. If 25 g of steam emerges from the pipe per second, how much ice would have melted before the pipe was repaired 5 minutes later?

5. 1.85 kg of copper shavings were heated to 400°C and then transferred to 620 g of water at a temperature of 29°C contained in a polystyrene bowl. What mass of water boils away?

6. 55 g of crushed ice at –5 °C are transferred into 160 g of water at 65°C. Calculate the temperature of the mixture after mixing (SHC of ice = 2100 J kg^{-1} K^{-1})

7. A 70.0 kg athlete runs up a mountain path ascending 500 m in a race. Assuming that his body temperature remains the same at 38.1°C, estimate the mass of water evaporated as sweat during the race. (Hint: water must rise in temperature to 100°C then boil)

8. A girl's bath contains 30 litres of water at 60°C but she wants to run cold water into it so the final temperature of the water is 40°C. How much water at a temperature of 15°C must she run in?

9. A refrigerator has a power rating of 250 W and contains a single ice-tray with 200 g of water in it at 20.0°C. How long must the refrigerator run so that all of the water is now frozen? Assume all of the refrigerator energy is used to cool the water.

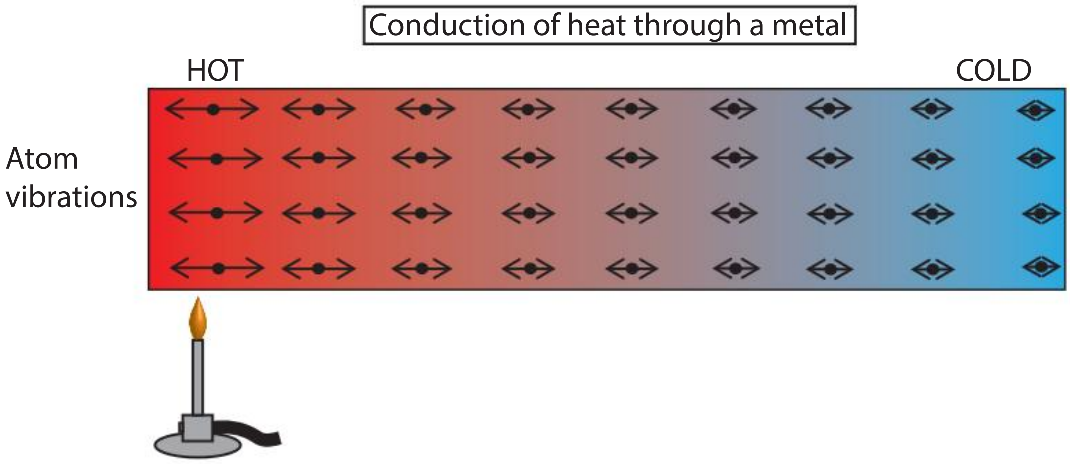
10. A man pours water onto a hot barbecue plate to cool it down. The 10 kg plate is made of iron ($c = 440\ J\ kg^{-1}\ K^{-1}$) and is at 600°C when one litre of water at a temperature of 20°C is poured onto it. If all the water boiled off, what was the temperature of the plate at the end?

1.10 Heat Transfer

There are 3 main methods by which an object loses heat: Conduction, Radiation and Convection

Conduction

The molecules of a hot solid are in constant motion – vibrating back and forth in the crystal lattice with vibrational kinetic energy. Gradually this KE gets passed on to the adjacent atoms so that they also become hot. The atoms also move further away from each other to produce expansion in the length and width of the solid.



Some materials can pass their heat energy on better than others – these are good conductors. Where atoms are widely spaced (e.g. gases) the transfer will be very poor.

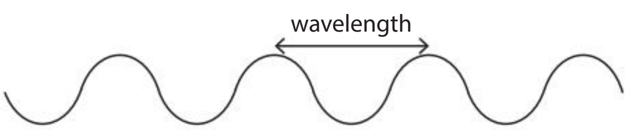
Place the following materials in what you think is the correct order of conduction from Best to Worst:

GLASS STEEL SEAWATER VACUUM COPPER

(Answer: Copper, steel, glass, seawater, vacuum)

Radiation

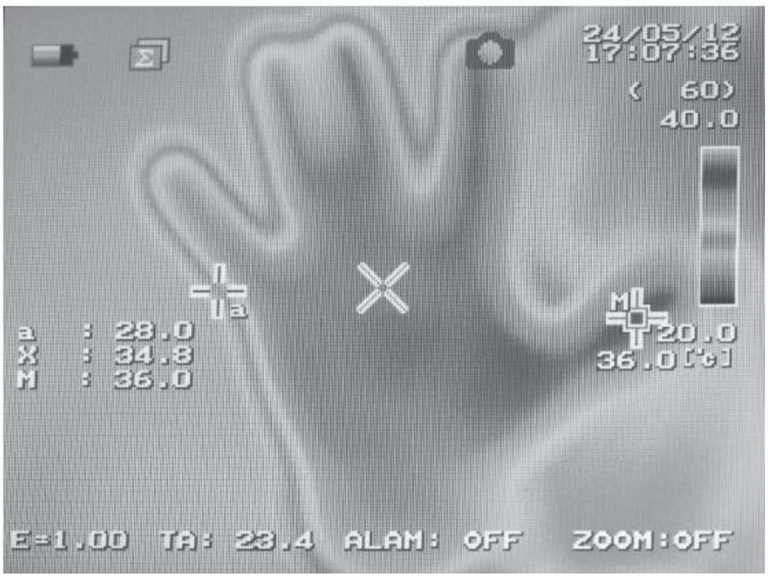
Any object which is hot emits heat rays of varying wavelengths. The lower the temperature the longer the wavelength.



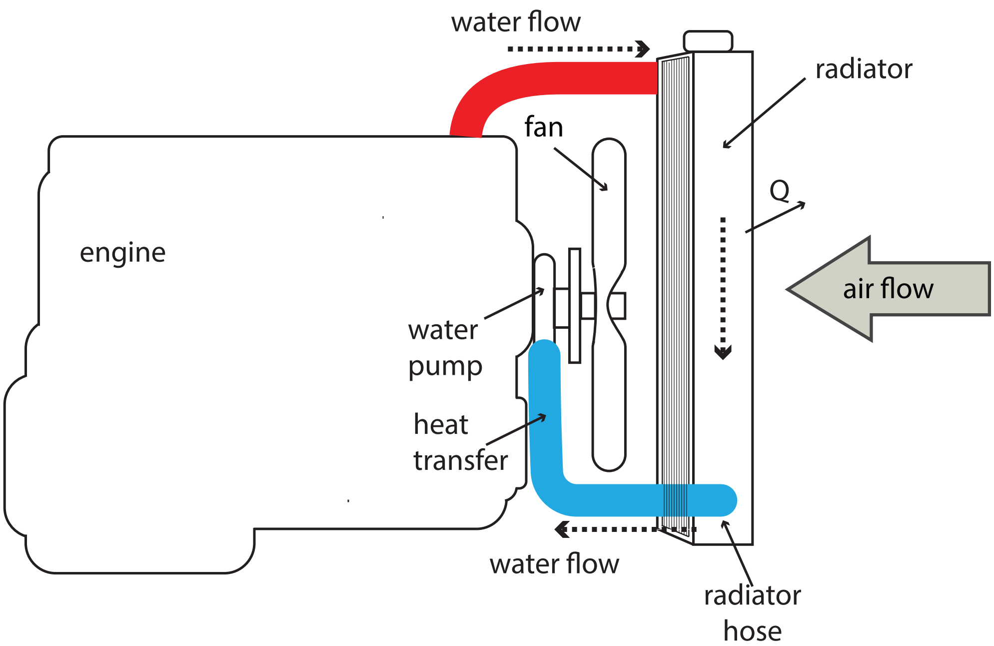
Infrared heat rays are about 1 millionth of a metre long and will make you feel warm if they strike your skin. Hotter objects give out visible light: 800°C will be red hot, while >1000°C will be white hot (more blue light).

Insects like mosquitoes can find animals in the dark by sensing their infrared radiation and ballistic missiles "lock on" to the exhaust IR radiation from a jet engine in order to follow and hit it.

This photograph was taken with an infrared camera which displays the difference in temperature at different parts of the hand. The thumb and forefinger are at a higher temperature than the palm.



Car Cooling System



The large amount of heat generated in a car engine has to be removed otherwise the engine would overheat and seize up (the pistons become melted into the cylinders).

Heat is transferred from the engine to the water surrounding it and pumped to the radiator at the front where fast-moving air can flow through it as the car moves forwards. Hot water is fed from the engine block to the radiator and the car heating system by means of rubber hoses, which allow for movement of the engine whilst it is running.

Air still needs to circulate even when the car is stationary, so a rotating fan pulls the air through the radiator constantly. The heat in the hot water jacket can be used in the winter to heat the interior of the car, using a heat-exchanger.

Conduction occurs in the radiator as it is made of thin copper tubes that allow heat to pass easily through to the outside where the air rushes past these tubes.

Convection carries some of the heat away as the hot air next to the radiator rises.

Radiation from the radiator, in the form of infrared rays, also removes radiant heat and so the radiator is painted black to make this transfer more efficient.

Radiation experiment

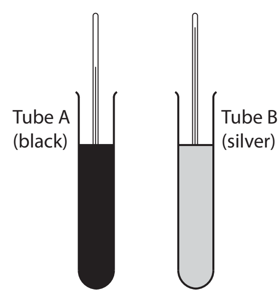
Some colours make a hot object cool down faster than others by allowing more radiation to occur. This experiment is designed to compare the cooling rates of a black test tube with a silvered one.

The **independent variables** that are controlled are:

same temperature;

same volume of water; same surface area of tube;

same position in the room for airflow.



The Independent Variable changed is the surface colour and the **dependent variable** measured is the final temperature of the tubes.

Procedure

Pour the same amount of boiling water into each tube

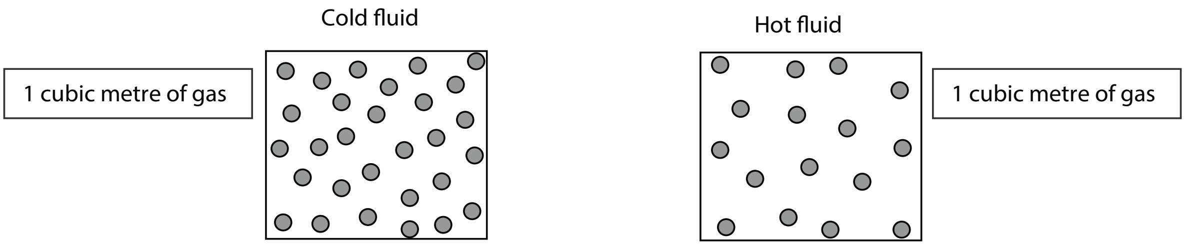
Take readings of each tube for 10 minutes and record the final temperatures of each tube.

Results: The black tube had a final temperature of 81°C and the silver tube was at 92°C.

Conclusion: Heat is radiated at a faster rate from a black hot surface than a silver hot surface.

Convection

As the molecules of a fluid (liquid or gas) get hot they move faster and the average distance apart increases.

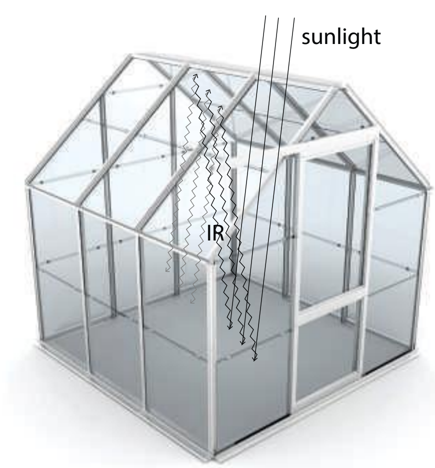


If 1 m^3 of liquid is heated, the liquid expands and so less mass of liquid is contained in the cubic metre. This means that the **density of the liquid will decrease** (D = m/V). Less dense liquids float on more dense ones, so a hot liquid will rise. This is the cause of currents in the sea and wind systems around the Earth.

The same thing happens with gases, so a hot gas will rise and float above a cold gas. Hot air balloons work in this way – the large amount of hot air causes the balloon to float above the cooler air. The cruising height of the balloon can be adjusted by weights attached to the balloon and by heating the air more with a burner to rise more.

1.11 The Greenhouse

A greenhouse is used to grow plants quicker, particularly in colder countries. Sunlight comes in through the glass and strikes the floor. This energy is absorbed and heats up the ground, which will then emit heat rays (infrared or IR). When these IR waves strike the glass walls they cannot go through as glass is not transparent to IR, which means the heat rays are trapped in the interior. Even when the outside temperature is low, it can become quite warm inside a greenhouse if the sun is shining.



Global Warming

The **Greenhouse Effect** is where the Earth seems to act like a greenhouse due to an outer layer of greenhouse gases (CO_2 and methane) that are trapped in the upper atmosphere. The Earth heats up due to the sunlight falling on it and therefore emits IR rays towards the sky. The theory is that this IR becomes absorbed by the upper greenhouse gas or reflected downwards again, keeping the heat in – just like a greenhouse.

If the average temperature of the earth rises by only a few degrees it will cause massive melting of the polar ice caps, so many countries are now trying to limit the greenhouse gas emissions by switching more of their energy generation to renewable systems, such as solar panels, hydroelectric generators, wind and wave turbines and geothermal heating plants.

Solar panels

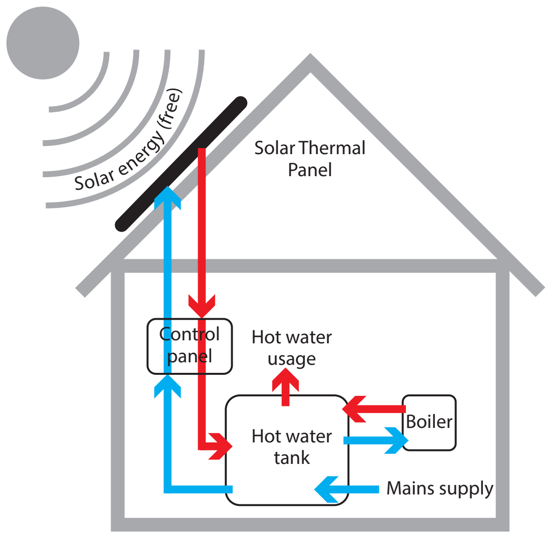
These are of two types:

a) ones that absorb the sun's energy to heat water for domestic use and

b) ones that generate electricity from sunlight using solar cells.

a) Solar Thermal Panels

These are installed on the roof and use a radiation collector housed in a mini greenhouse on the roof to trap the sun's rays. The collector pipes are painted black and made of copper to conduct the heat to a stream of water running through them.



b) Photoelectric cells.

Many houses today can be seen with solar panels on their roofs as these can generate electricity directly from sunlight and save power usage. Photovoltaic cells are made of semiconducting silicon sheets. When light strikes the cell, the absorbed light is transferred to the semiconductor atoms where the energy causes electrons to be released and generate a current.

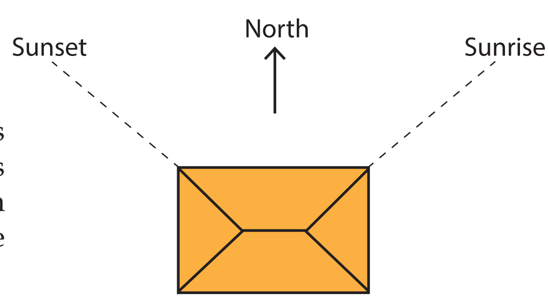
Passive solar design of buildings

With the current concern over making house designs more 'Green" all new houses built must have good insulation and use other new techniques for conserving energy. Traditionally we have used heating systems in the winter and cooling systems in the summer, just so the temperature inside a house remains fairly constant but well-designed homes can get much closer to achieving these energy saving ideals.

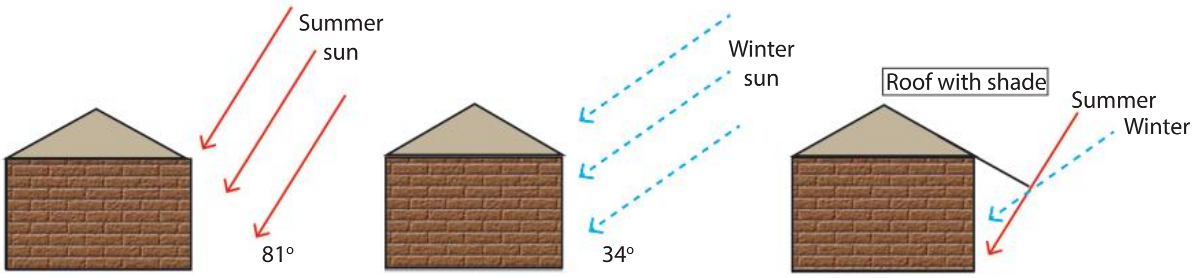
The 5 principles for passive solar design houses are:

- Orientation
- Shading
- Ventilation
- Thermal mass
- Insulation

The **orientation** of a house should be with its rear facing north so as to allow the main glass area to receive the most sunlight. In Perth sunlight delivers 600 W power on each square metre of ground in mid-summer.



Sunlight can help heat the house in the winter without electricity, and also correct **shading** can prevent the house from heating up excessively during summer.

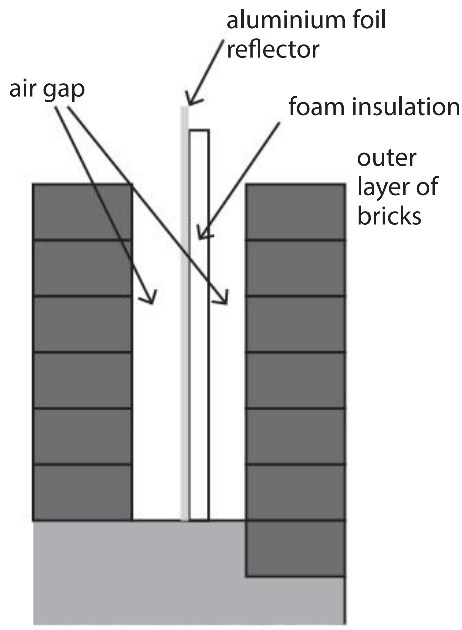


When a shade is attached to the back of a house with the correct amount of overhang then in the summer the rays cannot reach the house but in the winter they can, meaning that the house can be heated by the sun's rays when it is cold in the winter months.

It is essential that the windows in a house are hinged from the top so rain cannot get in when they are open but natural breezes can still **ventilate** the house.

If a house has a large **thermal mass** (large heat capacity) then it can absorb a large amount of heat without its temperature rising very much. Also, when this mass becomes warm it would take a long time for it to cool down and hence the internal temperature of such a house would be very resistant to changes in temperature. In some newly designed "green" houses they have a large mass of concrete (usually as rubble) as the core of the house which "holds" the heat absorbed during the day in winter and retains its low temperature mass in summer when the outside conditions are hot.

These days new houses are, by law, well insulated by means of double glazed windows, insulated ceilings and double brick (cavity) walls. These methods cut down heat transfer from conduction, convection and radiation effectively.



Modern cavity wall design

Heat Transfer Conceptual Quiz 1

1. Steam pipes from boilers always have "U"-shaped bends in them every 10 m or so. This is because the pipes become very hot. Explain why these bends are necessary.

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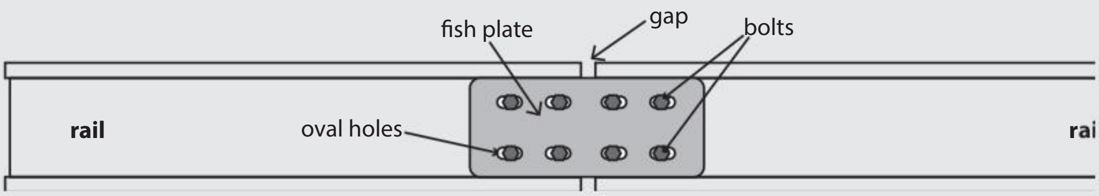
2. Railway lines are joined using "fish plates" shown below. Comment on this method of joining (as opposed to welding) and why it is necessary.



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3. Bimetallic strips are used in fire alarms — when the temperature gets high an electrical circuit is turned on to sound a bell. Draw a diagram to show how the bimetallic strip is arranged to make the alarm sound.

4. On a cold day, if you touch a brass doorhandle it feels cold, whereas the wooden door doesn't. Explain this.

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5. Tramps in London sleep out under bridges when the temperature is below zero. You find that they wear as many layers of clothes as possible and stuff their trousers with newspaper. Explain the physics principles here.

6. When long-distance runners have finished their race they are covered with a silver space-blanket. Explain the principles of this blanket and how it helps athletes and people suffering from exposure.

7. Racing motorcycles have their engines painted black. Explain the logic of this.

8. People who live in the tropics often wear white clothing. Explain why this is so.

9. Explain the design features that allow vacuum flasks to keep liquids hot.

10. The smaller an animal is, the faster it radiates heat compared with larger animals. Do a calculation using a simple shape, such as a cube; to show that the smaller it is the larger its surface area is relative to its volume.

Heat Transfer Conceptual Quiz 2

Conduction

1. When a student touches the metal tap in the lab he remarks that it feels colder than the bench top. Discuss this phenomenon.

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2. Surfers use wet-suits in the winter. How do these work?

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3. Eskimos dress using lots of layers of woolly or furry underclothes. Explain how these keep them warm.

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4. House roof spaces have layers of Pink Batts laid above the ceiling. Explain the use of these.

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Convection

5. Why is the freezing compartment of a refrigerator (ice box) often at the top of the fridge cabinet?

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6. In summer, the Fremantle Doctor breeze always comes in about 11 am which helps to cool Perth down. Explain how this breeze is generated.

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7. In summer a girl notices that when she swims in the pool on a hot day that the water is always warmer on the surface. Explain why this is so.

8. A wood fire in a house, when alight, always draws in air from the room and the smoke outside is seen to rise up vertically. Explain these observations.

Radiation

9. In hot countries, such as Africa, many houses are painted white.

   Why is this?

10. A boy walking on the road in bare feet notices that his feet are burning hot when standing on the tar but cooler when on the concrete pavement.

    Explain this.

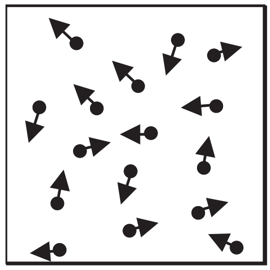
11. Solar panels on a roof heat up water for use in the house hot water system. Explain why they are always black and facing North on the roof.

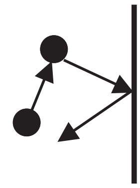
1.12 The Kinetic Theory of Gases

The Kinetic Theory is used to explain how moving particles of gas produce a pressure and thereby provides an explanation of the gas laws.

In the Kinetic Theory all gas particles are extremely small compared to the volume they occupy and are each moving at high speed in constant, random motion.

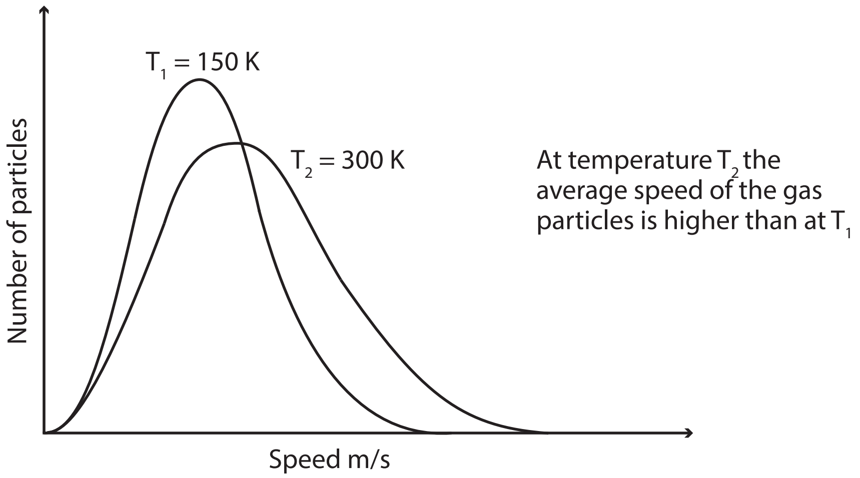
As they move, they are constantly colliding with other particles and the walls of the container.





Atom moving at random and colliding with the wall to create a force and hence presure.

The distribution of particle speeds follows the graph shown below.



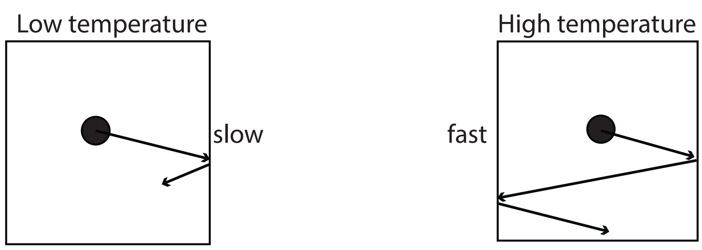
The number of gas particles colliding with the container walls per second is what creates the force on the walls and hence the pressure of the gas.

Temperature link to Pressure (Volume remaining the same)

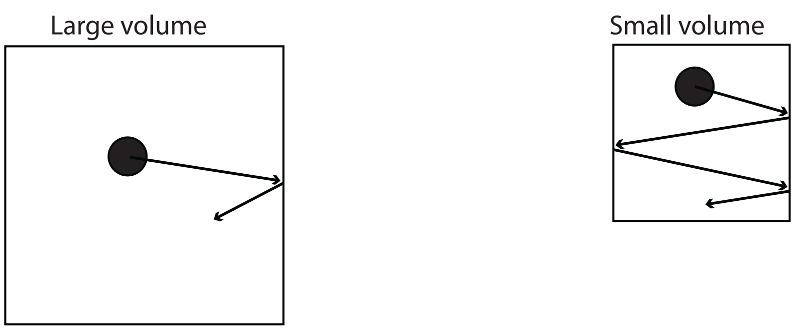
If the temperature of the gas in the box rises, the average speed of the particles rises and therefore the number of collisions per second will increase.

Volume and Pressure (Temperature remains constant)

If the size of the box is reduced (volume is less) then, travelling at the same speed, the particles will collide with the walls more frequently as there is less distance to travel.

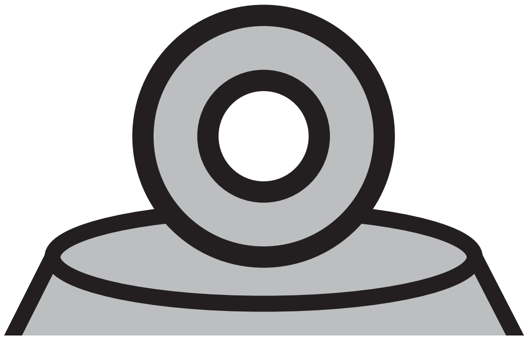


Pressure Law: P is proportional to T



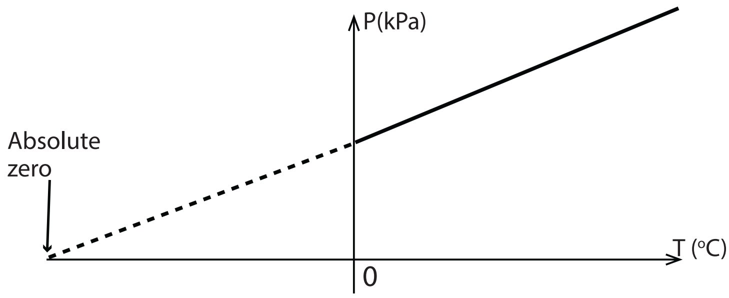
Boyle's Law: Pressure is inversely proportional to volume (V↑ P↓)

Temperature link to Volume (Pressure remains constant)



Absolute Zero

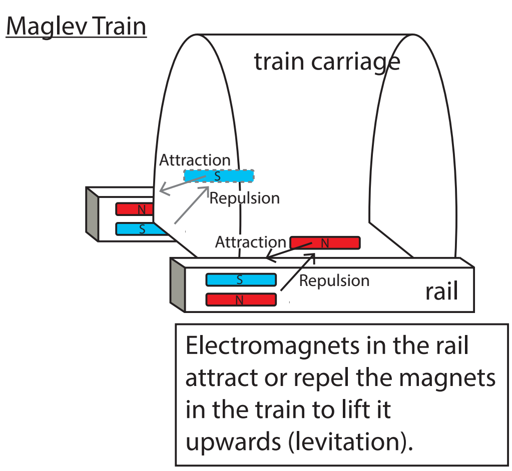
If we measure the gas volume in the cylinder at different temperatures we will obtain a graph like this:

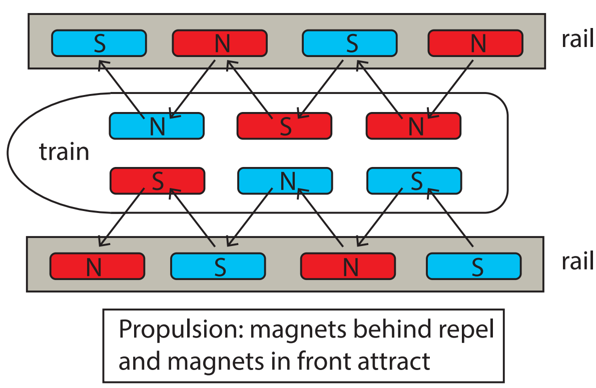


When T = 0°C the gas still has volume but if we trace the graph back to where V = zero the point on the T axis is -273°C. This is called **Absolute zero**, where no gas can have a volume because none of the particles in the box are moving.

This lack of movement of particles at absolute zero is made use of in superconducting substances. These metalloids have a zero resistance below about 90 K and hence can carry very large currents without getting warm. Superconducting magnets are used in MRI machines, magnetic levitation trains and the Large Hadron Collider.

In the Maglev Train, two magnets raise the train above the rails and another set moves the





train along by magnetic attraction.

Zero Celsius is not a true zero — it is only the melting point of ice. If we measure temperatures starting from the true zero (-273°C) then we have the Kelvin Scale of Temperature and V will be directly proportional to the temperature, measured in kelvins. 0°C = 273 kelvins (273 K).

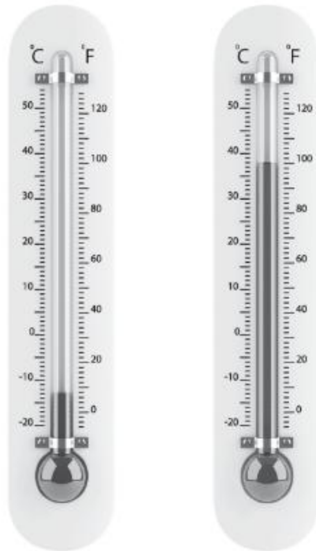
Temperature in kelvins = Temperature in Celsius +273

1.13 Thermometers

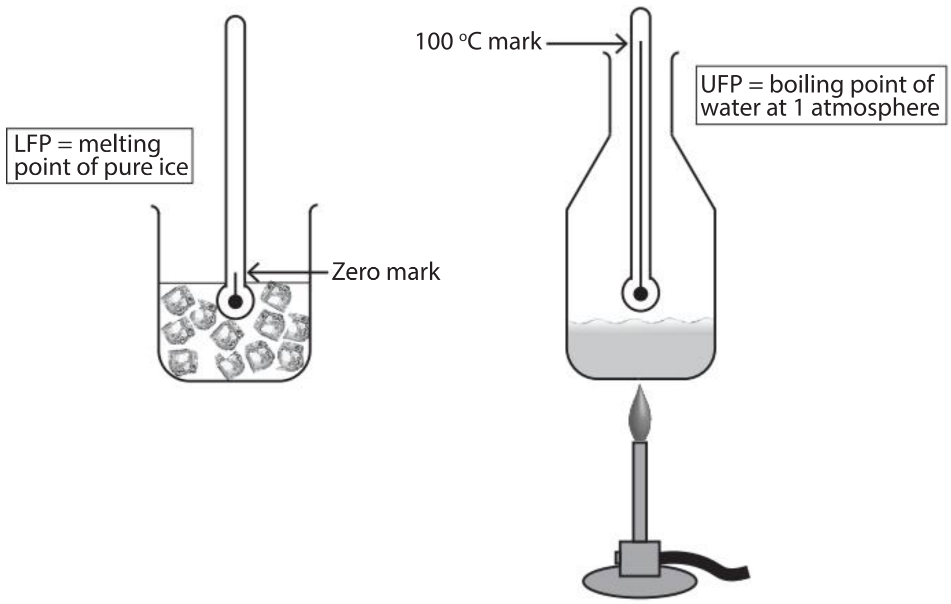
Thermometers use the change in a physical property of a substance to judge temperature e.g. expansion of a liquid, resistance of a conductor.

The thermometers used in schools use the fact that the volume of mercury (or alcohol) increases with temperature to indicate temperatures.

Any thermometer must be **calibrated** (markings put onto it) by referring to defined temperatures. In the Celsius scale the upper and lower fixed points are defined: Upper Fixed Point (UFP) is 100 degrees Celsius – the boiling point of pure water at 1 atmosphere pressure; Lower Fixed Point (LFP) is zero degrees Celsius – the temperature of pure melting ice.



To make **graduations** on the thermometer the distance between the marks for UFP and LFP is divided into 100 parts. Each division is then 1 degree Celsius.



There are other types of thermometers that rely on other properties that change with temperature e.g. change in colour, change in resistance, change in pressure or change in thermocouple voltage. All of these would be calibrated in the same way.

Heating & Cooling Test 1

[40 marks total]

Data on Specific Heat Capacities (J kg^{-1} K^{-1}):

Water = 4180, Copper = 390, Aluminium = 880, Human Body = 3470, ice = 2100

Specific Latent Heat of Fusion of ice = 3.36×10^5 J kg^{-1}

Specific Latent Heat of Vaporisation of steam = 2.25×10^6 J kg^{-1}

PE = mgh   g = 9.8 ms^{-2} KE = ½mv^2

Formulas: H = mcΔT   H = mL   H = Pt

1.a) How much heat is required to heat 150 g piece of copper up from 20 to 45 degrees? [2 marks]

b) If a water heater supplies 36 MJ of heat to 280 litres of water at 22°C what will the final temperature be after heating? [3 marks]

2.a) 225 kJ of heat is absorbed from the stove by an empty aluminium saucepan of mass 1650 g. Calculate what the temperature rise of the saucepan would be [3 marks]

b) If the saucepan had contained 350 g of water before heating, what would the temperature rise have been then? [4 marks]

3.a) A gas burner is placed under a beaker containing 330 g of water at 15°C for 2½ minutes. The temperature of the water rises to 77°C. Calculate the heat given out by the gas burner. [3 marks]

b) Calculate the power of the gas burner (heat per second). [2 marks]

c) How long will it be before the water reaches boiling point from 77°C?

[4 marks]

4.a) A man of mass 72 kg running in a marathon race starts with a normal body temperature of 37.6°C. At the end of Riverside Drive his body has generated 1.05×10^6 joules of heat. What would be the theoretical rise in temperature of his body? [3 marks]

b) If his body compensated for the extra heat by sweating to remain at a constant temperature, how many grams of sweat (water) would his body have lost for this amount of heat? [3 marks]

5. A copper can of mass 230 g contains 210 g of water at a temperature of 86°C. A mass of crushed ice at a temperature of –7°C is added to the water and, after stirring, the temperature of the whole mixture was found to be 38°C. Find the mass of ice that was added. (Hint: Don't forget to allow for the heating of the copper can). [5 marks]

6.a) An ice tray contains 185 g of iced water at 0°C when it is put into the freezer. If the freezer has a power rating of 285 watts (285 joules extracted per second) calculate how long it will be before all the water has frozen (Hint: find the heat that must be extracted from the water) [3 marks]

b) Steam from a boiler is pumped through a pipe for 2 minutes into a bucket of water containing 4.85 kg of water at 20°C. Steam comes through the pipe at a rate of 5.00 g per second. What is the final temperature of the water in the bucket? [5 marks]

Heating & Cooling Test 2

Section A - Multiple Choice **[15 marks]**

1. Which of the following statements are true when a hot object is brought into a cool room?
   1. Heat is being radiated by the room
   2. The room will heat up by conduction, convection and radiation
   3. The rate of radiation of the hot object will remain the same in the first few minutes

   a) 1 & 3 only
   b) 2 & 3 only
   c) 1 & 2 only
   d) all are correct
   e) 1 only is correct

2. Two different objects are given the same amount of heat. Which statement is true?
   a) Each object will always radiate the same amount of heat
   b) Each object will always be at the same temperature
   c) Each object will have the same temperature rise
   d) The molecules of each object will be vibrating at the same speed
   e) The total energy increase is the same for each object

3. A man fans himself and feels cooler. This can be explained by the fact that:
   a) water has a high specific heat capacity
   b) the air is saturated with water vapour and there is no air flow
   c) the air is not saturated with water vapour, he is not sweating and there is no air flow
   d) the air is saturated with water vapour, he is not sweating and there is air flow
   e) the air is not saturated with water vapour, his face is sweating and there is air flow

4. Which of the following is most closely associated with the temperature of a body?
   a) the closeness of the atoms
   b) the mass of the body
   c) the volume of the body
   d) the surface area of the body
   e) the motion of its molecules

5. If the molecules of two different gases have the same average kinetic energy,
   a) the volumes of the gases must be the same
   b) their temperatures are equal on the absolute scale only

c) they exert the same pressure on the walls of the containers

d) the temperature of the gas with the larger molar mass (molecular weight) is lower

e) their temperatures are equal on any scale

The next three questions refer to the following information.

4180 joules of heat energy will cause a rise of 1°C in 1 kilogram of water. In an investigation, a student placed a beaker containing 0.5 kg of water over a Bunsen burner for two minutes. The water temperature rose from 19°C to 33°C.

6. The quantity of heat energy that the water received was about

a) 600 J b) 29300 J c) 840 J d) 1040 J e) 147,000 J

7. If only half the heat produced from the burner had been absorbed by the water, the heat given out by the burner would have been about:

a) 15 kJ per minute b) 86 kJ per minute

c) 29 kJ per minute d) 118 kJ per minute

e) 57 kJ per minute

8. The beaker is replaced by an identical one containing 2.5 kg of water at 20°C, and is left on the burner for 10 minutes. The final temperature of the water will be closest to:

a) 14 °C b) 34 °C c) 20 °C d) 48 °C e) 100 °C

9. When both are supplied with the same amount of heat, 100g of copper takes less time than 100g of water for an increase in temperature of 5°C. The best explanation for this is:

a) the volume of the copper is less than the volume of the water

b) the copper is a solid and the water is a liquid

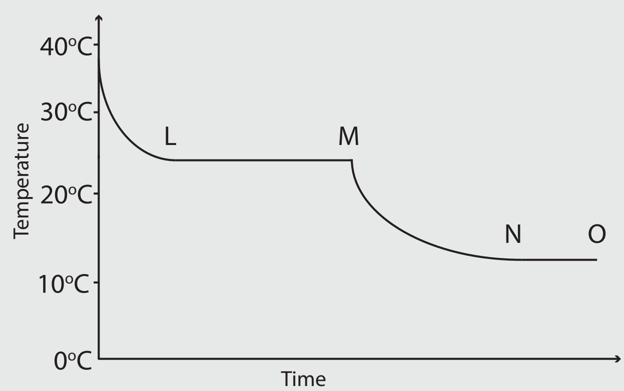
c) copper has a specific heat capacity that is lower than that of water

d) copper has used up less heat than water

e) copper is a metal

The next three questions refer to the following information:

A solid X was heated in a test tube until it melted. As it cooled in air, a thermometer was used to stir it slowly and the temperature was recorded every minute. The results were recorded on a graph, as shown below.



10. The melting point of substance X is:
    a) 15 °C
    b) 40 °C
    c) between 25 °C and 15 °C
    d) between 20 °C and 30 °C
    e) below 15 °C

11. The temperature remained constant between L and M because:
    a) room temperature had been reached
    b) heat energy was absorbed by substance X from the environment
    c) no heat was being lost
    d) substance X was changing from a liquid to a solid
    e) substance X was changing from a gas to a liquid

12. The temperature remained constant between N and O because:
    a) substance X was changing from a liquid to a solid
    b) heat energy was absorbed by substance X from the environment
    c) stirring generated enough heat to keep the temperature constant
    d) room temperature had been reached
    e) substance X was getting colder, but it was already in a frozen state

13. The rate of evaporation of a liquid depends upon
    1 humidity of the atmosphere
    2 boiling point of the liquid
    3 temperature of the liquid
    4 temperature of the surroundings
    5 the density of the liquid

    a) all of 1 - 5
    b) all except number 2
    c) all except number 5
    d) Only 1,2 and 3
    e) Only 2, 3 and 4

14. Advantages of a thermometer containing mercury over one containing alcohol are:
    1 mercury is a liquid
    2 mercury is a better conductor
    3 mercury is denser
    4 mercury is opaque
    5 mercury has a lower freezing point

    a) all of 1 - 5
    b) all except number 2
    c) all except number 5
    d) Only 1, 2 and 3
    e) Only 2 and 4

15. An energy efficient house has Pink Batts (fibreglass) above the ceiling with silver foil just below the tiles under the roof. A shiny aluminium foil covered material is often used under the roof of a house because it

a) decreases the amount of convection of heat inside the house

b) helps conduct heat away from the roof

c) decreases the amount of heat transfer through the roof of the house

d) absorbs heat from outside and inside and conducts it away

e) makes the roof waterproof

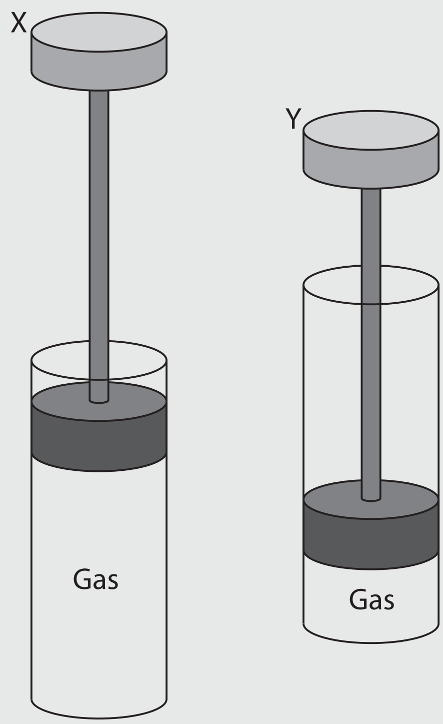
SECTION B (35 marks total)

Formulae and data:

Kinetic energy = ½ mv^2 Potential energy = mgh $H = mc\Delta T$

$g = 9.8\ m\ s^{-2}$ $c_w = 4.18 \times 10^3\ J\ kg^{-1}\ K^{-1}$ $L_v = 2.25 \times 10^6\ J\ kg^{-1}$ $L_f = 3.36 \times 10^5\ J\ kg^{-1}$

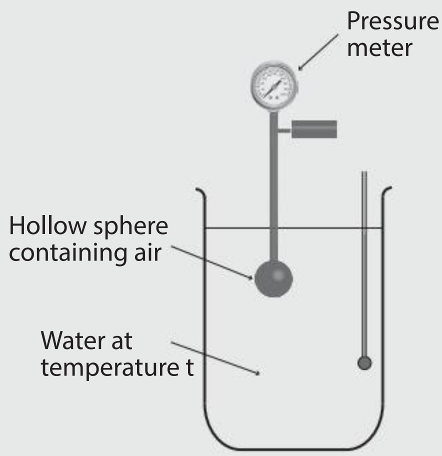
1.a) A syringe containing air at 1 atmosphere pressure (X) is pushed in until it is 1/3 of the original volume (Y). State what differences occur in the gas pressure and explain why [3 marks]



2. An experiment was used to investigate the variation of pressure of a gas with its absolute temperature (T in kelvins = t + 273).

The experimental results of temperature against pressure (kilopascals) are shown below:

t°C	7	27	47	77
P(kPa)	93	100	107	117



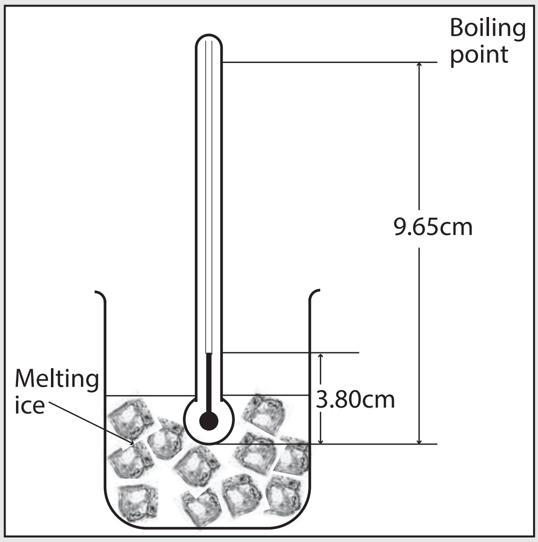
a) What link do these results show between the two variables? [1 mark]

b) Use the ideas of the kinetic theory of gases to explain the results in the table [2 marks]

3.a) Why do ordinary ovens have their heating elements placed at the bottom? [3 marks]

b) Directions for escaping from a burning house are to drop to the floor so you can breathe better. Explain why this could save your life. [3 marks]

4.



An uncalibrated thermometer filled with a black thermometric liquid is shown above while it is at the Lower Fixed Point and attached to a ruler.

a) Explain the terms:

i) Calibrated ________________

ii) Thermometric ______________

iii) Lower Fixed Point __________ [3 marks]

When the thermometer bulb is placed in Lower Fixed Point conditions the liquid reaches a mark of 3.80 cm on the ruler.

When the thermometer bulb is placed in Upper Fixed Point conditions the liquid reaches a mark of 9.65 cm on the ruler

b) (i) What will be the distance between each 1°C mark of the thermometer when calibrated? [3 marks]

___

___

___

___

(ii) What temperature is indicated when the liquid reaches a point 6.68 cm along the ruler? [3 marks]

___

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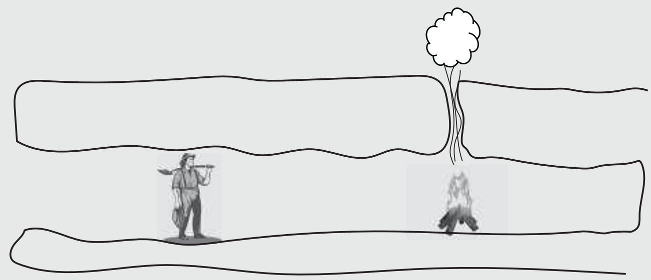
5. In the 18th Century mines were ventilated with air by drilling a small extra shaft and lighting a fire beneath it.



Explain how the fire helps to ventilate the mine. [3 marks]

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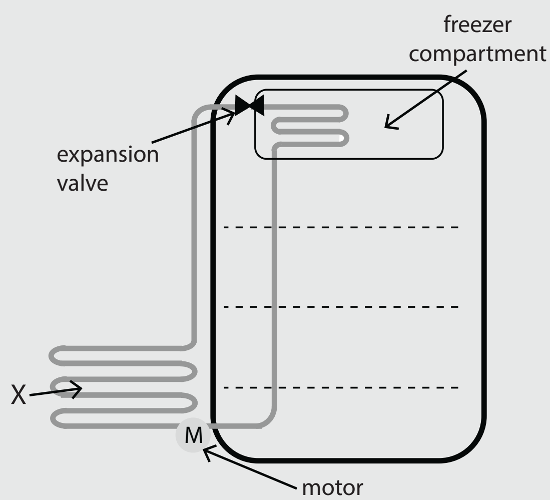
6. Below is a simplified diagram of a refrigerator system.



a) Draw in arrows to show the direction of flow of refrigerant [1 mark]

b) Name and explain the design of structure X [2 marks]

____

____

____

____

c) Explain how the refrigeration system works, mentioning the function of the motor and the expansion valve. [4 marks]

____

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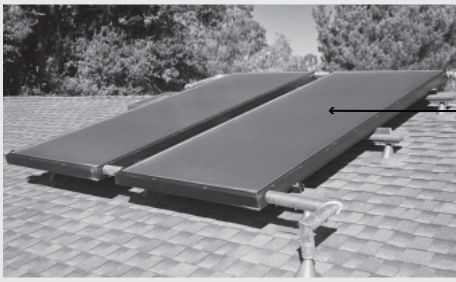
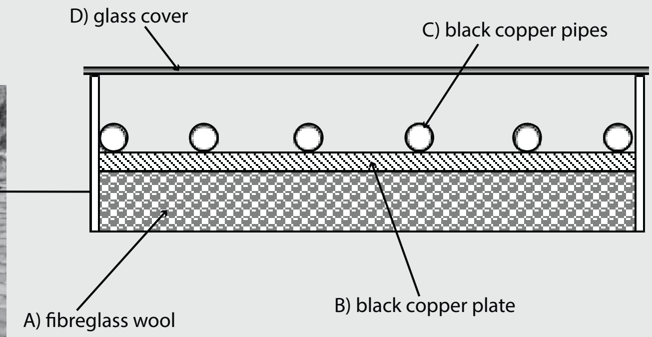
7. Shown below is a solar pool heater that uses the sun's light to produce warm water for a swimming pool. A cutaway section of the solar panel is shown on the right.





For each of the four labelled components indicated with arrows (A, B, C, D) state their purpose and how they contribute to the efficiency of the heat transfer process [8 marks]

A ____

____

____

____

____

B ____

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C ____

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____

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D ____

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NUCLEAR PHYSICS

Chapter
2

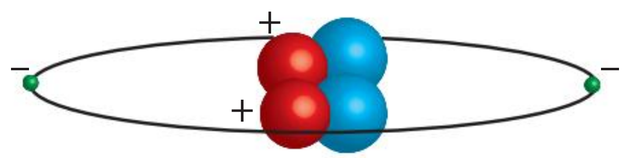
2.1 Atomic Models

The Greeks were the first to find that atoms have positive and negatively charged parts from their experiments with amber (the Greek name for amber was "Electros").

J.J. Thomson's model of the atom, developed in the 1890s, had the atom as a big spherical positive charge with electrons stuck in it like plums. This was known as the "Plum-pudding model" of the atom.

Ernest Rutherford developed the current "solar system" model through his experiments where he fired positively charged ions at thin gold sheets. The results of the deflection of these + ions showed that the + and – charges had to be widely separated and that the atom behaved as if the electrons had no effect in deflecting these ions. This could only be explained if an atom consisted of a large central + charged particle (nucleus) surrounded by tiny, remote, negatively – charged particles in orbit – so far away that they showed no attractive force (electrons had been discovered in 1897 by Thomson).

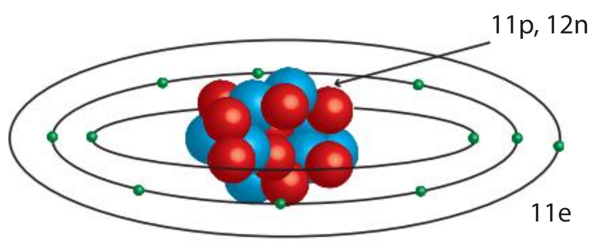
Rutherford discovered the proton in 1919 and the neutron was discovered in 1933 to complete the picture. (Neutrons seem to help in the stability of the nucleus to overcome the repulsive force between the protons.)



So now the atomic model had + protons in the nucleus together with about the same number of neutrons surrounded by electrons which orbit the nucleus in "shells". Diagrams in books give a false impression of the distances of the electrons from the nucleus: If the nucleus were a soccer ball then the nearest electron to it would be the size of a pea about 1 kilometre away.

The atomic number (symbol Z) of any atom is the number of protons in the nucleus, which is also the number of electrons orbiting for a neutral atom. The periodic table organises all the elements present in the Universe in order of atomic number from 1 (hydrogen) to 92 (uranium). Other elements with Z greater than 92 have been artificially made in particle accelerators. The **mass number** (A) of an element is the sum of the number of nucleons (protons + neutrons) in the nucleus, so the number of neutrons in a nucleus is A – Z.

An **isotope** is an atom with a particular value of A and Z, for instance sodium-23 is the 11th element in the periodic table and would have the structure: 11p, 12n, 11e in the following shell structure:

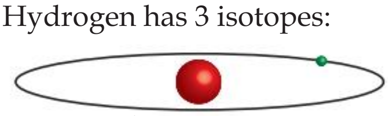


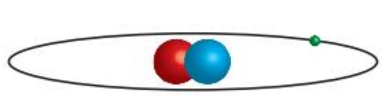
Using atomic symbols sodium-23 is written $^{23}_{11}\text{Na}$

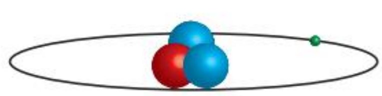
Any element may have a number of different isotopes. For instance, there exists sodium-22 and sodium-24 which each contain a different number of neutrons: $^{22}_{11}\text{Na}$, $^{24}_{11}\text{Na}$

All these isotopes have identical chemical properties but their physical properties are not the same, like melting points, densities, etc. Unstable isotopes will emit matter and energy in an attempt to become stable. These isotopes are called "radioisotopes".

Hydrogen has 3 isotopes:


Protium $^{1}_{1}\text{H}$


Deuterium $^{2}_{1}\text{H}$


Tritium $^{3}_{1}\text{H}$

Tritium is radioactive and is a radioisotope.

Weighted Averages

You will notice, if you look at the Periodic Table, that most of the elements shown have mass numbers that are not whole numbers e.g. Lithium is given as 6.94 atomic mass units. This does not mean that the nucleus contains fractions of a proton or neutron, but is indicating a weighted average of all its isotopes that naturally exist on earth. When chemists obtain a sample of an element, they need to know how many isotopes are present and in what ratio. This is calculated by multiplying each isotope by its relative abundance and then adding these values.

For example, Lithium has one isotope Li-6 with 6% abundance and another, Li-7, with an abundance of 94%.

To calculate the weighted average this is the calculation:

$$6 \times 0.06 + 7 \times 0.94 = 6.94.$$

Some elements have many isotopes, so the calculation of the weighted average would involve multiplying each by its abundance and adding. e.g Xenon has 36 isotopes but only 9 of these are stable — the others undergo radioactive decay.

Strong Nuclear force

How is it that several protons can co-exist within a nucleus? This is the question that the scientists of the early 20th century asked, as two positively charged particles that are very close to each other would exert a massive repulsive force. They realised that there had to be another type of force responsible within the nucleus which is so strong that it can overcome this large repulsive force and which must "switch on" at very small distances – less than 10^{-15} m. This is called the Strong Nuclear force.

Quarks

The latest theory related to the nucleus is called the Standard Model, where protons and neutrons are actually composed of smaller particles, called quarks, held together in bundles by the Strong Nuclear Force. Quarks have either ⅓ or ⅔ of an electronic charge and come in threes to make up protons and neutrons.

Atomic Structure Quiz

1. An element A has an atomic structure of: 66 electrons, 96 neutrons and 66 protons.

   Write the correct symbol for the element showing its atomic number and mass number.

   ____

2. The table below shows the structure of elements A to E.

Element	Proton number	Neutron number	Electron number
A	15	15	18
B	17	18	18
C	16	16	16
D	17	17	17
E	15	16	16

   a) Which pairs of elements in the table are isotopes?

   ____

   b) Write the nuclear symbols for the pairs of isotopes

   ____

3. Calculate the percentage by mass that the electrons have in a phosphorus-30 atom.

   ($m_e = 9.109 \times 10^{-31}$ kg, $m_p = 1.673 \times 10^{-27}$ kg, $m_n = 1.675 \times 10^{-27}$ kg.)

   ____

   ____

   ____

4. Identify these isotopes:

   (i) ${}^{14}_{6}X$ ______________

   (ii) ${}^{23}_{11}X$ ______________

   (iii) ${}^{66}_{30}X$ ______________

5. All chlorine gas is composed of chlorine-35 atoms and chlorine-37 atoms. If the percentages of these are fixed at 77.5% Cℓ-35 and 22.5% Cℓ-37, calculate the weighted-average atomic mass for chlorine.

   ____

   ____

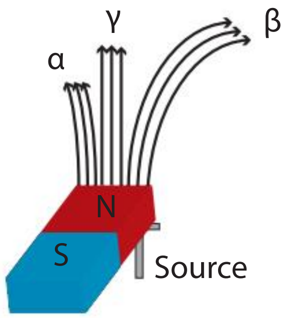
   ____

   ____

2.2 Radioactivity

In the 1890s Henri Becquerel discovered radioactive materials whilst experimenting with fluorescent minerals. He found that "invisible rays" were coming from a uranium ore (pitchblende) which he at first thought were X-rays. Marie Curie did some further investigations and discovered the previously unknown radioactive isotope, Radium. Since then, many more radioactive isotopes of elements have been discovered and some are now manufactured for devices, such as smoke detectors.

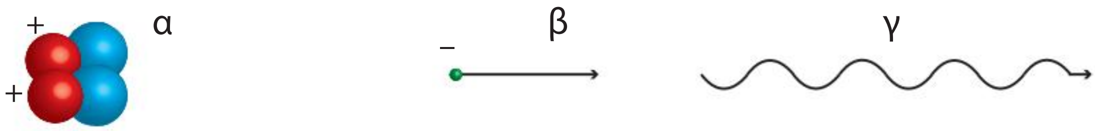
Ernest Rutherford tried deflecting the invisible rays coming from a radioisotope and discovered something interesting: A magnet could deflect some of the rays to the left, some the right and some were not affected by the magnetic field at all.



Rutherford concluded from this that there were 3 types of rays, which he called alpha (α), beta (β) and gamma (γ) rays.

From electrical and magnetic principles it was apparent that α-rays had a positive charge and were heavy whereas β-rays had a negative charge and were light. γ-rays had no charge and were hence not deflected.

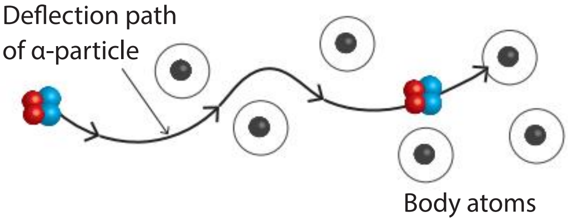
Later scientific research showed that α-rays are particles made up of helium nuclei with 2+ charges, β-rays are simply fast-moving electrons or anti-electrons and γ-rays are very short wavelength electromagnetic waves.



2.3 Hazards of radioactive decay

If any of these 3 rays strike the body, damage can occur due to ionised electrons striking atoms in the skin, which impairs the cells and stops them functioning properly. Ultimately this can destroy the DNA in a cell and cause tumours. The amount of cellular damage caused will depend on how much ionisation a particle can cause.

α-particles have a double charge and are large, and so are much more likely to interact with outer electrons of atoms. Thus they are very ionising particles.

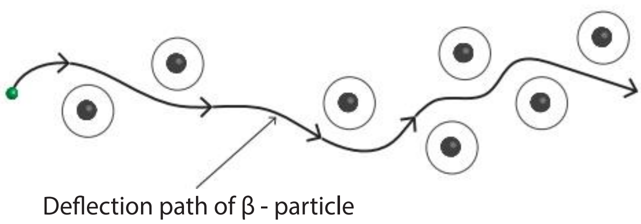


Because they are so highly charged α–particles can interact with atoms, lose their kinetic energy and, hence, be stopped by just a few cm of air or tissue paper, etc.

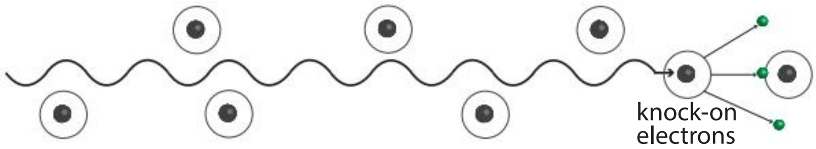
Alpha rays have a low risk outside of the body (apart from when they hit the cornea of the eye) because the dead layer of skin covering the body protects us.

However, Alpha emitters cause most damage to body cells inside the body (lungs, stomach etc). This is because inside the body, fine blood vessels (capillaries) are only one cell thick and can easily be damaged.

β–particles are far less ionising (small and singly charged) and so they will cause far less cellular damage than alphas but will penetrate matter deeper (past the dead skin layer and into body tissue.)



γ-rays are the least ionising (no charge) and can penetrate deep into the body before they collide with an atom causing "knock-on" electrons. It is these that cause cellular damage.



2.4 Health Physics

The number of decays per second, or Activity, of an isotope is measured in becquerels (Bq), with each particle's kinetic energy being converted to heat in an absorbing material or doing work on an atom by ionising it. 1 Bq = 1 decay per second.

The Absorbed Dose of radiation is defined as the heat energy absorbed per kilogram of material.e.g. If a 2 kBq source transfers 3×10^{-5} joules of heat to 2.5 kg of material then:

The absorbed dose = E/m = $3 \times 10^{-5}/2.5 = 1.2 \times 10^{-5}$ J kg^{-1} or 12 micrograys. (1 joule of energy absorbed per kilogram = 1 gray, the correct unit for absorbed dose)

Each radiation of the same dose has a different effect on the body due to the different amounts of ionisation caused by the different types of ray (α being the most ionising)

The Dose Equivalent is a measure of radiation which allows for the different amounts of damage caused by different rays. Dose Equivalent values give a more realistic measure of the danger to the body.

> Dose Equivalent = Absorbed dose × Quality factor (QF) – measured in sieverts (SV). The Quality factor is a dimensionless number that compares the biological damage that each ray can do to a human.

The QF of β–rays and γ–rays is 1, of neutrons is between 1 and 10 and the QF of α–rays is the largest at 20 i.e. α–rays cause 20 times more cell damage than β–rays.

> For α –rays, an absorbed dose of 12 μGy would yield an effective dose of
> $12 \times 10^{-6} \times 20 = 2.4 \times 10^{-4}$ sieverts, or 0.24 mSv (the Sievert is the unit of effective dose)

Absorbed dose amounts are cumulative, which means that over your lifetime all the effective doses received add up. The effect on the body of 1 sievert is fairly minor — it may cause a drop in white blood cell count, but is not fatal.

We all receive an average 1.3 mSv per year just from the Earth, our food and rocks around us. Over a 100 year life-span, a safe level for humans would be about 10 mSv per year (a total of 1 Sv). However, an immediate dose of 4 Sv would prove fatal for about 50% of the total population.

2.5 Decay products

(i) α-decay

When a nucleus X ejects an α-particle it will lose 2 units of atomic number and 4 units of mass number.

In general: ${}^{A}_{Z}X \rightarrow {}^{A-4}_{Z-2}Y + {}^{4}_{2}\alpha$

Example: Radium α-decay to radon: ${}^{226}_{88}Ra \rightarrow {}^{222}_{86}Rn + {}^{4}_{2}He$

(ii) β-decay (–)

If a nucleus has too many neutrons for stability it can convert a neutron to a proton plus an electron in the nucleus The extra electron is ejected as a β –particle.

i.e. ${}^{1}_{0}n \rightarrow {}^{1}_{1}p + {}^{0}_{-1}e + {}^{0}_{0}\bar{v}$

This means that for a β –emitting isotope, Z increases by 1 and A stays the same.

Example: Thorium decay: ${}^{234}_{90}Th \rightarrow {}^{234}_{91}Pa + {}^{0}_{-1}e + {}^{0}_{0}\bar{v}$

The $\bar{v}$ at the end of the equation represents an antineutrino, an antiparticle which was only found to exist in the 1960s. It has a very low mass, 500 thousand times lighter than an electron.

(iii) β-decay (+)

If a nucleus has too many protons for stability it can convert a proton to a neutron plus an anti-electron (known as a positron) in the nucleus. The positron is ejected as a β+ particle.

i.e. ${}^{1}_{0}p \rightarrow {}^{1}_{0}n + {}^{0}_{1}e + {}^{0}_{0}v$

This means that for a β+ emitting isotope, Z decreases by 1 and A stays the same.

Example: ${}^{23}_{12}Mg \rightarrow {}^{23}_{11}Na + {}^{0}_{1}e + {}^{0}_{0}v$

The ${}^{0}_{0}v$ at the end of the equation represents a neutrino the anti-equivalent of the anti-neutrino which was discovered in the 1950s.

Properties of particles

Particle	Mass (kg)	Mass (amu)	Charge (e)	Energy (MeV)	Emission Speed	Ionisation ability	Penetration in air
alpha	6.64×10^{-27}	4.001	+2	~ 5	~ 0.1 c	High	~ 2 cm
beta	9.11×10^{-31}	0.00054	±1	~ 0.1 – 1	~ 0.9 c	Medium	~ 1 m
gamma	none	none	none	~ 0.1	c	Low	~ 1 – 5 m

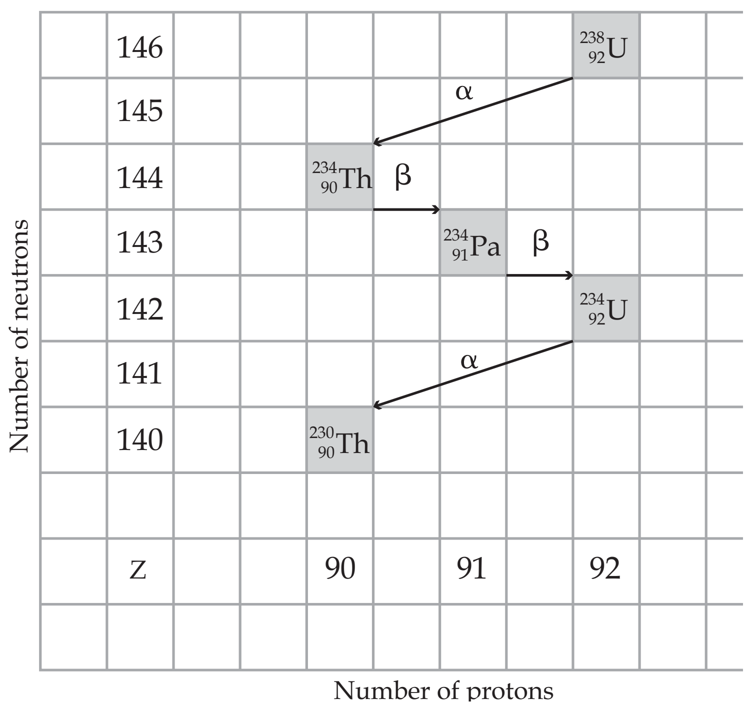
Note: The last 4 columns are approximate as every radioisotope will have its own unique energy of emission, which will dictate its speed and penetration distance in air.

(iv) γ-decay

No change in the nucleus occurs with γ-decay, which often happens in conjunction with alpha or beta decays and is a way in which the excited nucleus with can release its excess energy.

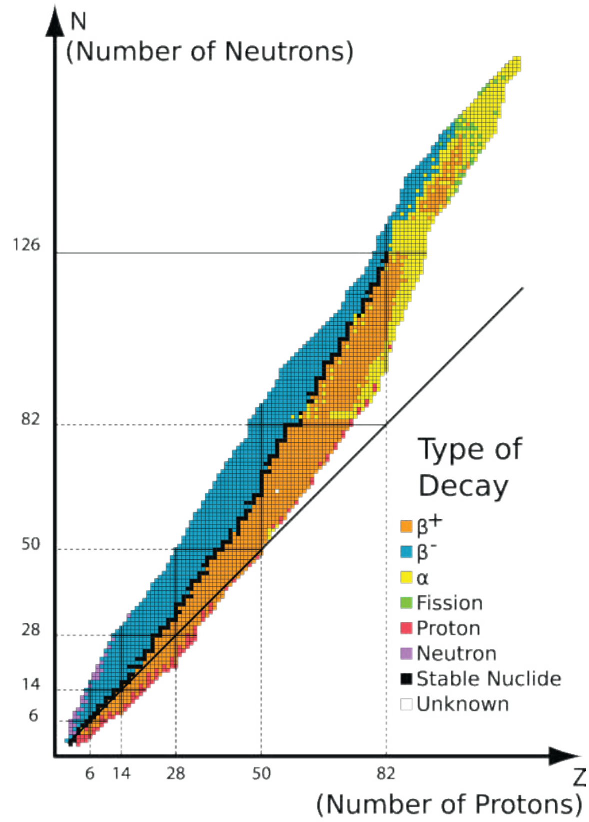
2.6 Decay chains

Often once a radioisotope decays, the daughter particle may also be unstable and also decay. This process, known as a decay chain, will continue until the daughter particle is a stable isotope. Heavy radioisotopes will often have decay chains that eventually finish with the production of a stable isotope of lead-206.



Zone of Stability

For elements up to Z = 20 (Calcium) stable isotopes exist at around a 1:1 ratio of neutrons to protons. Above this, the geometric packing of the protons in the nucleus require more neutrons to bind the nucleus together and keep it stable. The following diagram shows a "Zone of Nuclear Stability" which curves upwards (higher neutron ratio) to ensure stable isotopes.



Above the zone of stability, the nucleus contains too many neutrons and will likely decay via β-.

Below the zone of stability, the nucleus contains too many protons and will likely decay via β+.

2.7 Rate of decay

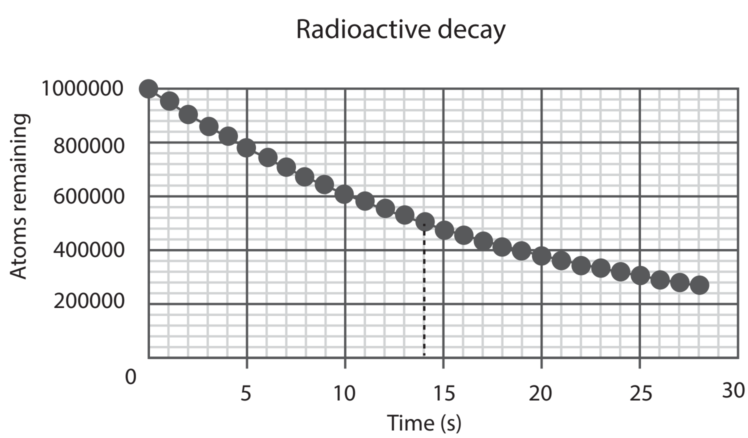
The number of decays per second produced by an isotope is called its activity and is measured in becquerels (symbol Bq) i.e. a sample with 2 kilobecquerels (2 kBq) activity is emitting 2000 particles per second.

Different isotopes decay at different rates, according to a probability law. Because there are large numbers of atoms involved (in the order of 10^{23}–10^{26}) the randomness produces a very constant number of decays per second. For example, when throwing a coin there is a 50% probability of a head with any throw, however Billy tosses a coin ten times and only gets 2 heads. But if Billy were to throw a million coins the fraction of heads will be very close to 50% because of the large number of throws.

Excel simulation

The graph was produced using an Excel Spreadsheet where the initial number of atoms was 1 million and 5% of the previous number decayed every second. This number is placed in the cell below and 5% of that number subtracted, and so on.

The graph plots the number of undecayed atoms left which is an exponential decay curve. This mathematical equation theoretically never reaches zero on the y-axis. In reality we cannot have a fraction of a becquerel, but the mathematical modelling works exceptionally well when there are a large number of atoms present in the sample.



An indication of how fast the isotope is decaying is given by the half-life ($t_{½}$). This is the time for half of the initial amount to decay. In this case, the dotted line on the graph shows the Half-life to be about 14 seconds.

2.8 Half-life Calculations

In the case of the isotope above, its mass and activity halve every 14 seconds:

Activity (kBq)	50	25	12.5	6.25	3.125
Time (s)	0	14	28	42	56

A more generalised equation can be formed by considering that every half-life the activity or mass left equals the initial value multiplied by ½ to the power of n, where n is the number of half-lives, so in 3 half-lives the initial activity would be multiplied by 3 lots of ½. The working formula, therefore, is:

$$A = A_o(½)^n$$

Where A = present activity, A_o = initial activity, n = Number of half-lives = $\frac{t}{t_{½}}$

Example 1

An isotope has a half-life of 129 days and an initial activity of 25.0 kBq. What is its activity after 2.00 years? [3 marks]

Solution 1

Description	Marks
$A = A_o (½)^{\frac{t}{t_{½}}}$	1
$= 25000 (½)^{2 \times 365/129}$	1
= 495 Bq	1
Total	3

Example 2

An isotope with a mass of 1.23 g has a half-life of 9.80 years. After a time only 0.0870 g of the isotope is left. How long has it been decaying? [4 marks]

Solution 2

Description	Marks
$A = A_o(½)^n$	1
$0.087 = 1.23 (½)^n$ $0.0707 = (½)^n$	1
log 0.0707 = n log (½) n = 3.822	1
$t = n \times t_{½}$ = 37.5 years	1
Total	4

(N.B. An alternative way of finding the solution can also be found without using logs by trying out different powers for n on your calculator)

Nuclear Decay Quiz

1. In his exposure to radiation in a nuclear plant it was calculated that 2.00×10^{-3} J of heat had been generated in a man of mass 70.0 kg. Calculate the absorbed dose, in grays, received by the man.

____

____

2. It was estimated that a 0.300 kg rat in a mine had received an absorbed dose of 8.00 milligrays of radiation. How much heat would this have generated in the rat's body?

____

____

3. (i) Calculate the effective dose (in sieverts) the man in Q1 had received if he had been exposed to β radiation.

____

____

(ii) Calculate the effective dose (in sieverts) the rat in Q2 had received if it had been exposed to α-radiation.

____

____

4. An 80.0 kg man receives an absorbed dose of 12.0 micrograys of α radiation a day from the radon gas accumulated in his house. How long will it take before the man has received an effective dose of 1.00 sievert?

____

____

5. a) Identify the following particles:

(i) ${}^{4}_{2}X$ ____________________

(ii) ${}^{1}_{1}X$ ____________________

(iii) ${}^{1}_{0}X$ ____________________

(iv) ${}^{0}_{-1}X$ ____________________

b) Write the decay products for the following emissions, identifying the elements formed:

(i) ${}^{239}_{94}Pu$ emitting an α particle ____________________

(ii) ${}^{14}_{6}C$ emitting a β particle ____________________

(iii) ${}^{32}_{15}P$ emitting an α particle ____________________

(iv) ${}^{214}_{82}Pb$ emitting a β particle ____________________

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6. Particles can collide with an element to form new products. Identify the missing species (X) in the following transformations:

(i) ${}^{14}_{7}N + {}^{1}_{0}n \rightarrow X + {}^{1}_{1}p$ X is ____________________

(ii) ${}^{27}_{12}Mg + {}^{1}_{1}H \rightarrow X + {}^{0}_{-1}e$ X is ____________________

(iii) ${}^{75}_{33}As + {}^{0}_{-1}e \rightarrow X + \gamma$ X is ____________________

(iv) $X + \alpha \rightarrow {}^{17}_{8}O + {}^{1}_{1}n$ X is ____________________

7. A radioisotope with a half-life of 2.00 hours has an activity of 2.40×10^2 Bq at 9:00 am. What will its activity be at 3:00 pm?

8. A radioisotope with an activity of 2.00 hBq is left for 24.0 hours, after which time its activity was measured as 125 kq. Calculate its half-life.

9. A 1.0000 g sample of phosphorus-32 is left in a cupboard for 72.0 days after which time there was found to be only 0.03125 g left. Calculate the half-life of the phosphorus isotope.

10. 30.0 mg of radioactive sodium-24 is injected into a patient as a tracer. How much of the radioactive isotope is left in the patient after 3.00 days if the half-life of the sodium-24 is 15.0 hours?

11. A 1.00 gram piece of living tree emits 2.72 Bq of β-radiation from carbon-14 decay. A 0.350 g sample of an ancient scroll in a laboratory was found to be emitting β-rays at a rate of 1.10 Bq. If the background count in the lab was 0.420 Bq and the half-life of carbon-14 is 5730 years, make an estimate of the age of the scroll.

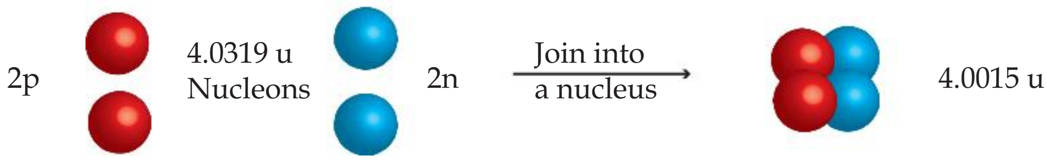
2.9 Binding Energy

The mass of an atomic nucleus is measured in Atomic mass units, a.m.u. or just u.

The definition of 1 unit is $\frac{1}{12}$th of the mass of a carbon-12 nucleus (almost the mass of a single proton). 1u = 1.6605×10^{-27} kg. The proton has a mass of 1.00728 u and a neutron has a mass of 1.00867 u. These accurate atomic masses have been found using a mass spectrometer, which ionises elements, deflects them in a magnetic field into a circle and then measures the charge-to-mass ratio from the radius of the circle.

A helium nucleus has a mass of 4.0015 u, measured with a mass spectrometer but there is something strange about this figure:

Mass of 2 protons + 2 neutrons = 2.01456 + 2.01738 which equals 4.0319 u



As the nucleons are joined they lose mass. The loss of mass is called the mass defect (δ) and is the amount of mass that has been converted to energy used in binding the nucleus together (Binding Energy or B.E.). Note: This topic involves incredibly small masses and incredibly small changes in mass. In the calculations involved in this topic, use as many decimal places as possible and then round your answer to 3 significant figures.

In this case $\delta = 4.0319 - 4.0015 = 0.0304$ u

Einstein first proposed that matter could be converted into energy according to the formula:
$E = mc^2$ where m is the mass in kilograms and c = velocity of light (3×10^8 m s^{-1})
1 u = 1.66×10^{-27} kg so it would equate to a B.E. of $1.66 \times 10^{-27} \times (3 \times 10^8)^2 = 1.495 \times 10^{-10}$ J.

Joules are very large units for nuclei so we always use smaller units called electron-volts (eV).

1 eV = 1.6×10^{-19} J so 1 u = $1.495 \times 10^{-10} / 1.6 \times 10^{-19}$ eV which equals 931 mega electron-volts, or 931 MeV. Therefore the energy used to hold a helium-4 nucleus together = mass defect × 931.

Thus the B.E. = 0.034 × 931 = 28.3 MeV

Beware of what masses are provided. If the **nuclear mass** is provided, then the electrons in the atom **don't** need to be considered. The Mass defect will then be:

Z × m(n) + (A-Z) × m(n) – m(nucleus mass).

If the **atomic mass** is provided, then the electrons in the atom **do** need to be considered. In this case, using the mass of hydrogen-1 will contain the mass of the electrons. The mass defect equation can then be simplified to:

Z × m(H-1) + (A-Z) × m(n) – m(atomic mass).

The following masses are provided:

Neutron: m(n) = 1.00866490 u

Proton: m(p) = 1.00727647 u

Hydrogen-1: m(H-1) = 1.00782517

Electron: m(e) = 0.0005487 u

In summary:

If the mass defect is in kilograms (kg): use $E = \delta \times c^2$. Energy will be in joules.

If the mass defect is in atomic mass units (u): use $E = \delta \times 931$. Energy will be in Mega electron-volts.

Example 3

Calculate the binding energy of a nitrogen-14 nucleus (atomic mass = 14.003074 u). [3 marks]

Solution 3

Description	Marks
$\delta = 7 \times m(H-1) + 7 \times m(n) - 14.003074$ $= 7 \times 1.00782517 + 7 \times 1.00866490 - 14.003074$	1
$= 0.112356$ u	1
$\times 931 = 105$ MeV	1
Total	3

(To change from MeV to joules, multiply by $10^6 \times 1.60 \times 10^{-19}$)

$= 105 \times 10^6 \times 1.60 \times 10^{-19}$

$= 1.68 \times 10^{-11}$ Joules.

Comparison of stability

B.E. of $^4_2$He = 28.3 MeV and B.E. of $^{14}_7$N = 104.7 MeV. But if we want to make a fair comparison of the stability of these two nuclei we need to allow for the fact that nitrogen has more nucleons.

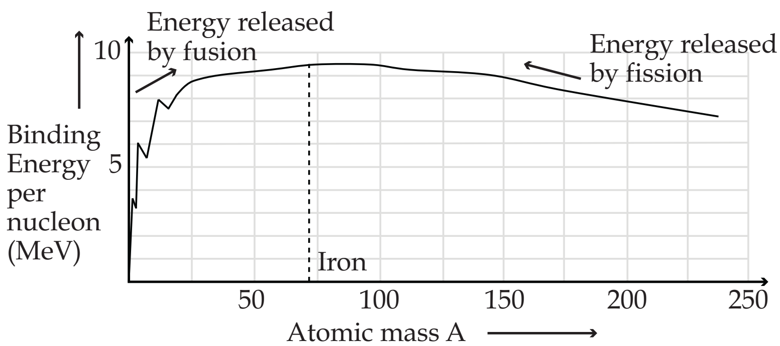
A rigorous comparison of the two nuclei can be made if we calculate the amount of binding energy per nucleon (i.e. divide B.E. by the number of particles in the nucleus).

For $^4_2$He this is 28.3/4 = 7.075 MeV/nuc and for $^{14}_7$N the value is 105/14 = 7.50 MeV/nuc.

Therefore the nitrogen nucleus is more stable as it has more B.E. per nucleon.

2.10 Fission and Fusion

Looking at a graph of B.E. per nucleon for every element in the periodic table we can see a gradual rise in energy up to the element iron-56 (known as the "Iron peak") and then a fall down to Uranium. This means that the nucleons in iron-56 are more tightly bound together (more stable) than any other element.



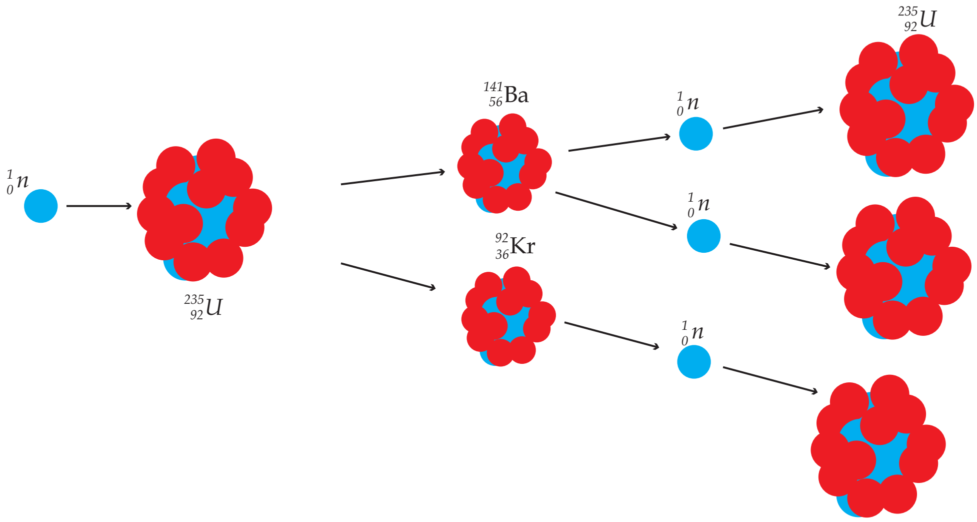
Binding Energies are actually negative in value to give stability just like a golf ball is stable when it is down a hole below the ground where it has negative potential energy.

Because B.E. is negative, if another element were to change into iron it would increase its negative energy and become more stable. The difference in energy would cause heat to be emitted.

In fission, an element to the right of the iron peak splits into 2 products; each product will have less (negative) B.E. and hence more stability. Energy will thus be given out when elements on the right break into other elements with smaller mass number.

In a nuclear reactor Uranium 235 atoms split into 2 smaller pieces after they have captured a neutron. The daughter products are shot out with a very high kinetic energy and three neutrons are produced. Note: 1 neutron in gives 3 neutrons out for every reaction that can each cause the fission of another uranium atom.

$^{1}_{0}n + ^{235}_{92}U \rightarrow ^{141}_{56}Ba + ^{92}_{36}Kr + 3\,^{1}_{0}n$



Atomic masses are: n = 1.00867 u, U-235 = 235.01205 u, Ba-141 = 140.9512 u, Kr-92 = 91.8373 u

Mass defect of reaction = (1.00867 + 235.01205) – (140.9512 + 91.8373 + 3 × 1.00867) δ = 0.2062 u, converted into energy by each fission. E = 0.2062 × 931 = 192 MeV

In 1 kg of uranium-235 the number of atoms present is $(6.02 \times 10^{23})/0.235 = 2.56 \times 10^{24}$ atoms. If each one undergoes fission then the total energy output will be $2.56 \times 10^{24} \times 192$ MeV If this is converted to joules: $4.92 \times 10^{26} \times 1.6 \times 10^{-13} = 7.87 \times 10^{13}$ J

By comparison, when one kilogram of coal is burnt it only releases about 4×10^{6} J which is about 20 million times less!

Fission will only produce 2 large fission fragments and ~2 to 3 neutrons. There are around 40 different fission fragment pairs. A rule of thumb is that one fission event will release approximately 200 MeV.

Items that can undergo fission are said to be "fissile". The two most common fissile isotopes are U-235 and Pu-239. In order for fission to occur in U-235, a "slow neutron" (energy between 1 – 100 keV) must be captured by the nucleus which then immediately undergoes fission. Plutonium can accept fast neutrons (energies above 100 keV). Plutonium was first created in 1941 by neutron bombardment of U-238 (non-fissile):

$$^{238}_{92}U + ^{1}_{0}n \rightarrow ^{239}_{92}U$$

$$^{239}_{93}U \rightarrow ^{239}_{93}Np + ^{0}_{-1}e + ^{0}_{0}\bar{v}$$

$$^{239}_{93}Np \rightarrow ^{239}_{94}Pu + ^{0}_{-1}e + ^{0}_{0}\bar{v}$$

U-235 on average releases ~ 2.37 neutrons in a fission event.

Pu-239 on average releases ~ 2.9 neutrons in a fission event.

Fusion

In a fusion reaction two atoms which are to the left of the graph peak are **joined together** to form a new nucleus. The difference in mass between the reactants and products is converted to kinetic energy of the products which will heat up the surroundings. e.g. the fusion of 2 protons in the Sun to produces a deuteron ($^{2}_{1}H$), a positron (e^{+}) and a neutrino (v):

$$^{1}_{1}H + ^{1}_{1}H \rightarrow ^{2}_{1}H + ^{0}_{+1}e + v + \text{energy}$$

The two protons will repel each other due to the positive charge of the nucleus. Their light mass makes them quick to accelerate and avoid collision. At a temperature of about 800 million degrees they can collide with sufficient energy to overcome the electrostatic force and "switch on" the Strong Nuclear Force.

Mass defect of reaction = $2 \times 1.00728 - (2.0135 + 0.000549) = 5.11 \times 10^{-4}$ u
(NB the neutrino has a mass in the order of 10^{-12} q.m.u. and so, is not significant to these

calculations.)

Energy from 1 g of hydrogen = $5.11 \times 10^{-4} \times 6.02 \times 10^{23} \times 1.6 \times 10^{-13} = 4.91 \times 10^{7}$ J

The Sun is a giant fusion reactor which uses hydrogen as a fuel to produce vast amounts of energy every second. Scientists have been trying for decades to produce a fusion reactor on Earth that would solve all our energy problems but, so far, the problems of containing a plasma at 800 million degrees have not been able to be solved.

Nuclear Reactors

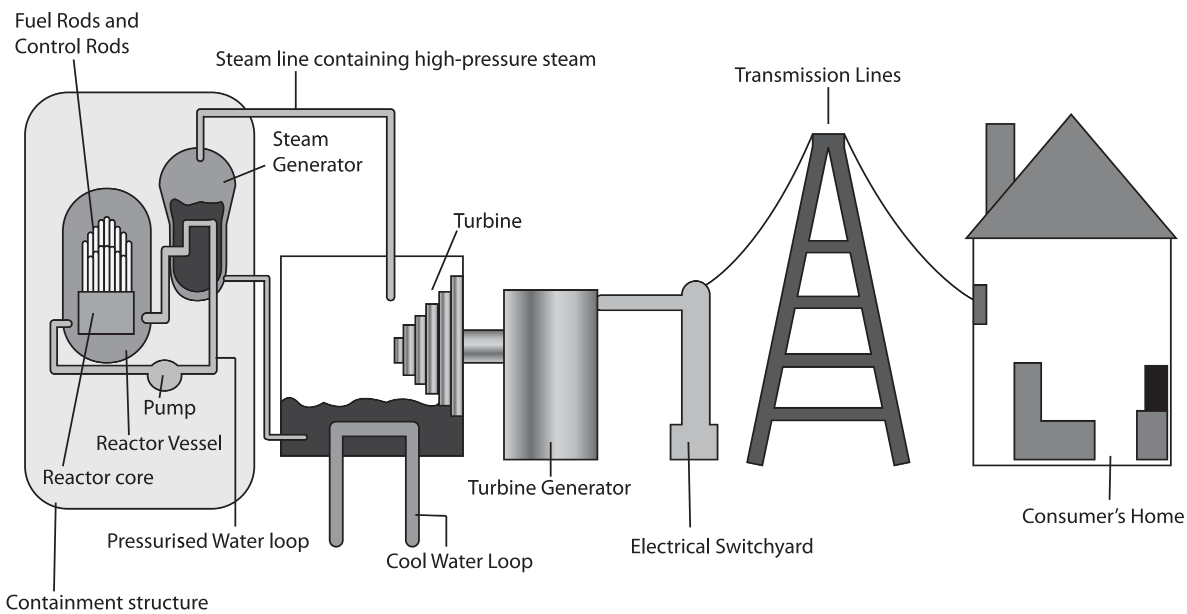
In a thermal reactor, uranium 235 is used as a fuel because it is fissile i.e. nuclei will split apart when struck with a neutron.

Natural uranium extracted from a mine only contains about 0.7% U-235 which is fissile so it has to be "enriched" until that the amount of U-235 is about 3%, otherwise too many of the neutrons are captured by the "non-fissile" U-238 atoms and the reaction would stop.

Enrichment is a difficult process as the 2 isotopes both have the same chemical properties but is achieved using an ultracentrifuge which acts like a giant spin dryer: Uranium hexafluoride gas is spun round at nearly 20,000 km s^{-1} and the heavier isotope is "thrown" to the outside, leaving the U-235 hexafluoride gas in the middle where it is extracted and passed to the next ultracentrifuge. Once enriched, the uranium is made into fuel rods and placed into the moderator in the reactor core where they remain for about a year. The moderator slows the neutrons down so they can react with U-235 as fission can only occur with the slower neutrons.

Moderator material can be graphite or heavy water; water where the hydrogen atom in the molecule is deuterium (H–2). The amount of power generated at any time can be reduced or increased using control rods that are made of boron because this element absorbs neutrons very well; Boron has many isotopes that are stable, meaning light isotopes of boron can capture neutrons without becoming β(–) emitters. These rods are raised or lowered into the core to absorb more or less neutrons. Coolant is circulated through the core to extract the heat generated and passed into a sealed heat exchanger where this heat transfers into a water tank to make it boil. The steam generated is used to drive a turbine and generate electricity. Some thermal reactors use CO_2 or water as a coolant and some even use liquid sodium.

Nuclear Reactor Generating Electricity



Fast reactors use plutonium instead of uranium as a fuel because this element is fissile when hit with fast neutrons. The advantage of a fast reactor is that a moderator is not needed and so it can be made into a much smaller size for use in nuclear submarines, etc.

Breeder reactors use the neutrons from a normal reactor to produce plutonium from uranium-238 which is not normally useful. The reactor core is surrounded with U-238 and the neutrons coming from the core collide with this isotope to produce Pu-239 which can then be used as a fuel for fast reactors.

2.11 Nuclear Transmutations

By bombarding one atom with another particle or ion it is possible to convert one element into another. Production of another element is called transmutation.

E.g. α-particles on nitrogen $^{4}_{2}He + ^{14}_{7}N \rightarrow ^{17}_{8}O + ^{1}_{1}H$

The α-particle needs to have sufficient collision energy to react with the nitrogen and produce oxygen and then the product particles will be produced with a large amount of kinetic energy equal to the mass converted in the reaction ($E = mc^2$).

Calculation of KE

In any particle interaction the "mass-energy equivalence" remains constant. As Einstein said with his equation: $E = mc^2$, energy and mass are different manifestations of the same thing.

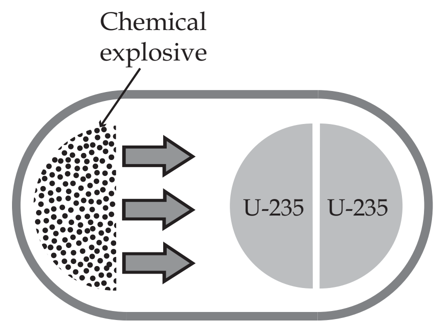
Suppose the α -particle had 4.5 MeV of kinetic energy as it collided in the above reaction;

Mass of reactants = 4.0015 + 13.99923 = 18.00073 u
Converted to energy units E = 18.00073 × 931 = 16,759 MeV plus the 4.5 MeV of kinetic energy that the α gives a total mass/energy value of 16,763 MeV
Total mass/energy of products = (16.99474 + 1.00728) × 931 = 16,760 MeV
Difference in mass/energy of reactants and products = 16,763 - 16,760 = 3 MeV
So 3 MeV must be the KE of the O-17 and H-1 as they fly out from the reaction.

2.12 Nuclear Weapons

Criticality (η)

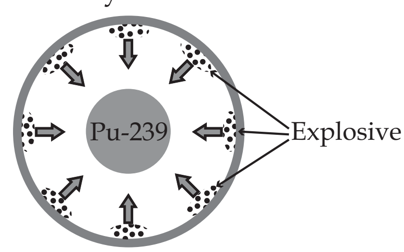
Criticality is a measure of the ratio of the number of neutrons being emitted compared to those being captured. A η < 1 (sub critical) means that less neutrons are emitted to those capture and so a chain reaction does not occur. A η = 1 (critical) means the ratio is equal, this is required for constant power generation in nuclear power). A bomb requires a η > 1 (super critical) where an exponential chain reaction of fission/fusion events rapidly increases the amount of energy released.



Factors affecting Criticality.

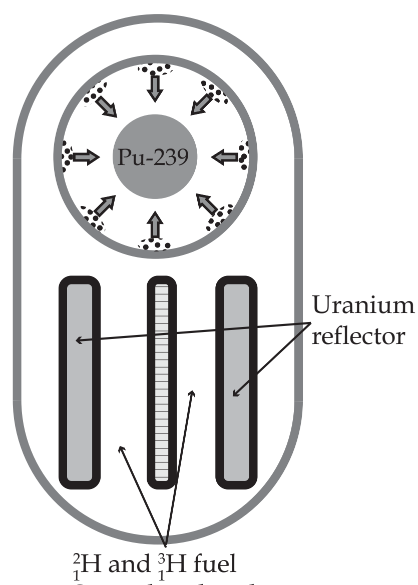
1. Purity of the source. Increases the chance of neutron capture which increase the amount of emitted neutrons.
2. Source of neutrons. Is initially required to 'seed' the chain reaction.
3. Tamper. A substance that can absorb neutrons and re-emit them, allowing them another chance of being captured by a fissile nucleus.
4. Shape. Generally, a sphere has the smallest surface area to volume ratio; reducing the number of neutrons that can escape the fuel source.
5. Pressure/density. Having more fissile nuclei per unit volume increase the chance of neutron capture.

Primary fission bomb



A critical mass is a fuel source where the above factors satisfy the condition that η > 1.

There are two types of nuclear bombs — fission bombs and fusion bombs. The first to be developed during of World War 2 was the fission bomb which used Uranium 235 as a fuel and was dropped on Hiroshima in Japan (named Little Boy).



Secondary bomb

The diagram shows the 'Gun-type" of bomb, where two sub-critical masses of U-235 are compressed together under enormous pressure to produce a critical mass of fuel which will spontaneously explode due to the enormous amount of energy released.

The two pieces must be compressed like this to overcome the electric repulsion of the protons and bring them closer than the 10^{-15} m required to 'switch on' the Strong Nuclear Force.

The second bomb exploded at Nagasaki in 1945 was of a different kind: It used Plutonium as a fuel and used an implosion method of detonation (named Fat Man).

This type of bomb used compression of the central plutonium fuel from all sides by packing explosive around the inside of the outer shell, which was much more efficient.

The maximum explosive force from fission bombs is about 500 kilotons i.e. equivalent to 500,000 tons of conventional TNT explosive.

Thermonuclear weapons have now been developed, which utilise the fusion of light isotopes to produce vastly more energy release. Another name for a fusion bomb is a "hydrogen bomb".

Fusion bombs usually use the two hydrogen isotopes deuterium and tritium as the fuel ($^{2}_{1}H$ and $^{3}_{1}H$), but these will not fuse together unless the compression and temperature is very high (several million degrees).

In order to achieve these conditions a fission bomb is used to initiate the high pressures and temperatures that would cause the fuel to fuse. The explosion occurs within nanoseconds.

Nuclear Physics Quiz

Multiple Choice Questions

Constants to use for this section:

$^{1}_{0}n = 1.008665$ u	$^{1}_{1}H = 1.007276$ u	$1u = 1.6605 \times 10^{-27}$ kg or 931 MeV
$1 \text{ eV} = 1.60 \times 10^{-19}$ J	$c = 3.0 \times 10^{8}$ m s^{-1}	

1. An isotope of sodium has an atomic number of 11 and a mass number of 24. The structure of the atom for this isotope is:

   A. 11 protons, 24 neutrons and 13 electrons

   B. 11 protons, 13 neutrons and 24 electrons

   C. 11 protons, 13 neutrons and 11 electrons

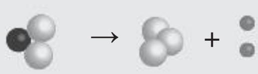
   D. 11 protons, 11 neutrons and 13 electrons

2. The theoretical amount of energy that could be obtained from the complete destruction (annihilation) of 1 kilogram of a substance in a nuclear reaction is close to:

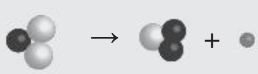
   A. 3×10^{8} J B. 6×10^{12} J C. 3×10^{16} J D. 9×10^{16} J

3. Tritium (hydrogen-3) has a half-life of 12.33 years and decays by β^- emission. Which of the following nuclear diagrams correctly indicates the decay of tritium?

   (Key:  = proton,  = neutron,  = electron)

   A. 

   B. 

   C. 

   D. 

4. Radium-226 has a half-life of 1.60×10^{3} years. A small piece of radium has an initial activity of 2.00×10^{5} Bq. The activity of this same sample after a period of 4800 years will have fallen to about:

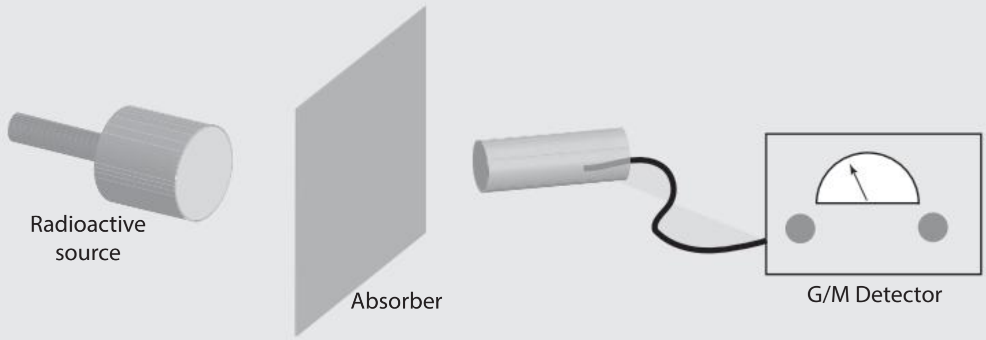
   A. 6.6×10^{4} Bq B. 5×10^{4} Bq C. 3.5×10^{4} Bq D. 2.5×10^{4} Bq

5. Uranium-238 decays by α-emission to an isotope of thorium. Which decay equation represents this transformation?

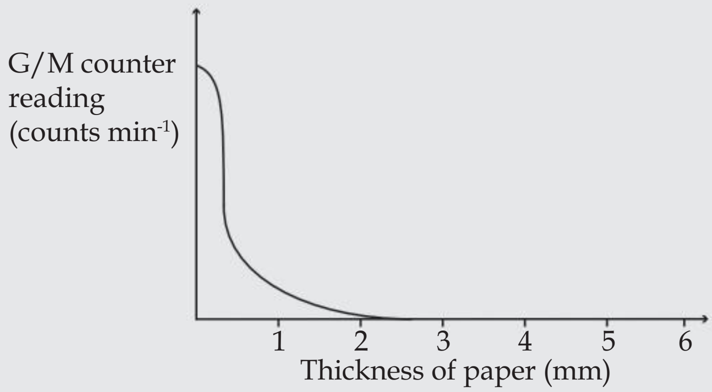
   A. $^{238}_{92}U \rightarrow {}^{236}_{90}Th + \alpha$ B. $^{238}_{92}U \rightarrow {}^{239}_{91}Th + \alpha$

   C. $^{238}_{92}U \rightarrow {}^{234}_{90}Th + \alpha$ D. $^{238}_{92}U \rightarrow {}^{236}_{88}Th + \alpha$

6. An experiment was set up to look at the absorbing power of thin sheets of paper using a radioactive source X and a Geiger-Muller (G/M) counter. The thickness of the paper absorber was gradually increased and corresponding G/M counter readings noted.



The graph on the right was drawn from these results.



The shape of this graph indicates that the source is emitting which kinds of rays?

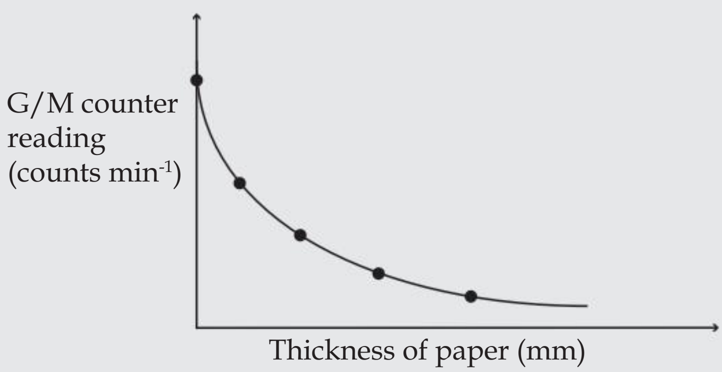
A. α and β

B. β and γ

C. α and γ

D. α, β and γ

7. Using the same experimental set up as in Q6, but with another source, Y, the absorbing ability of thin lead sheets was investigated instead of paper.
The graph for source Y using a lead absorber is shown below



Which of the following represents a valid deduction from this graph?

A. Source X is less radioactive than source Y

B. Source Y emits the same kind of radiation as source X

C. Each 1 mm of lead reduces the amount of transmitted radiation by about the same proportion

D. A thickness of 1 mm of lead is as effective in reducing radiation from Y as about 10 cm of Paper

8. In a thermal nuclear reactor the function of the moderator is to:

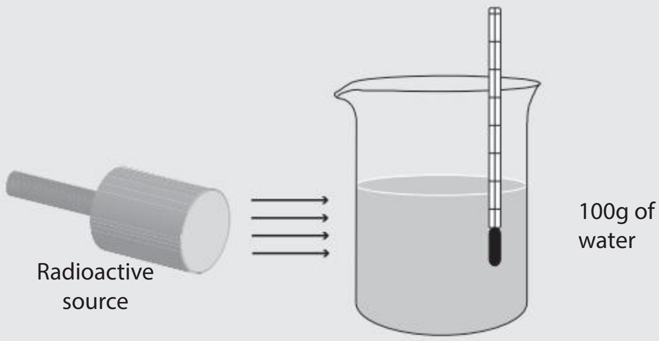
A. Increase the speed of the neutrons to produce a greater reaction rate

B. To reduce the rate of reaction of the neutrons so as to avoid any chain reaction

C. To absorb neutrons in order to prevent any unwanted explosive reactions

D. To slow neutrons down and raise the rate of power generation

9. A beaker containing 100 g of water at 20.0 °C was placed in front of a strong radioactive source for 1 minute after which time the temperature of the water had risen to 22.0 °C. If it requires 4200 J of energy to raise the temperature of 1 kg of water by 1 °C, we can deduce that the absorbed dose received by the water was:



A. 140 Gy B. 840 Gy C. 2200 Gy D. 8400 Gy

10. The Quality Factors (QFs) of different types of radiation are shown below:

Radiation type	**QF**
200 keV X-rays	1
γ-rays	1
β-rays	1
Protons	10
α -rays	10 – 20
Slow neutrons (<100 keV)	2
Fast neutrons (>1100 keV)	10

The 2.0 °C rise in temperature recorded was due to radiation from a slow neutron source. The same amount of water was exposed to a different source of the same activity for the same time and a temperature rise this time was recorded of 13.4 °C. This source most likely consisted of:

A. Fast β particles B. Fast α particles

C. 700 keV X-rays D. Neutrons

11. In 1919 Ernest Rutherford produced the first nuclear transformation by bombarding nitrogen-14 gas with α particles. Using the nuclear conservation rules, the products formed in this reaction would be:

A. $^{18}_{8}O + ^{-1}_{0}\beta$ B. $^{17}_{8}O + ^{1}_{1}H$ C. $^{14}_{7}N + ^{1}_{1}H$ D. $^{16}_{7}N + ^{2}_{1}H + ^{1}_{0}n$

12. Ernest Rutherford also found that there were 3 different kinds of rays emitted from his source, by deflecting the rays with a strong magnetic field:

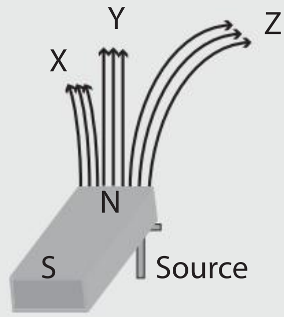
From the deflection of this magnet (into the page), Rutherford could tell that:

A. X is a beam of positive ions, Z is negative ions, Y has no charge

B. Z is a beam of positive ions, X is negative ions, Y has no charge

C. Y shows massive particles, Z heavy particles, light particles

D. Z shows light positive ions, Y heavy negative ions, X heavy negative ions



13. The atomic mass of helium-4 is 6.646×10^{-27} kg, measured using a mass spectrometer. Using the mass values given previously, the binding energy per nucleon of the helium-4 nucleus is calculated to be about:

A. 7 MeV B. 14 MeV C. 21 MeV D. 28 MeV

14. Which of the following is NOT an example of the application of radioactive technology?

A. Americium-243 is used in smoke detectors

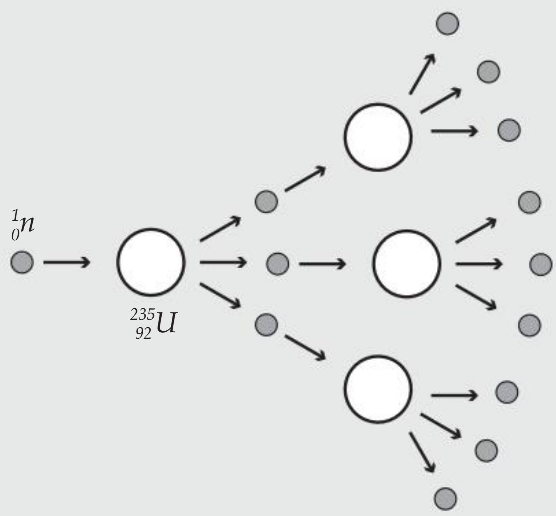
B. Carbon-14 is used in the dating of bone fragments

C. Thorium-232 is used in Factor 30 sunscreens to absorb UV radiation

D. Cobalt-60 sources are used to help cure breast cancer

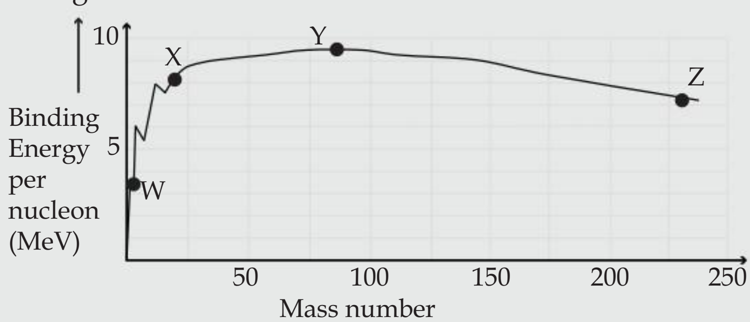
15. This diagram shows a chain reaction where a single neutron causes a U-235 nucleus to split and emit 3 more neutrons, and so on.

For each U-235 fission about 200 MeV of energy is emitted in a time of about 1×10^{-4} s in an uncontrolled reaction. In a small nuclear bomb this chain reaction occurred for about 0.005 s. At the end of this time the total amount of energy released would have been about:



A. 1×10^{-9} J B. 36 J C. 1×10^{3} J D. 36 kJ

16. By referring to the graph of binding energy per nucleon of each element, which of the following statements would be a valid conclusion?



A. Fusion of element W would yield an energy gain

B. Fission of elements Y and Z would yield an energy gain

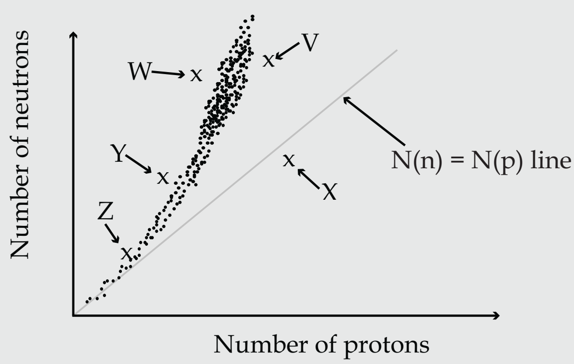
C. Fusion of element Z would yield an energy gain

D. Fission of element X and W would yield an energy gain

17. In samples of water open to the air the proportion of the Tritium-3 isotope is about 2.00×10^{-4}. Tritium decays by β-emission to helium-3 with a half-life of 12.33 years. A sample of water found in an old bottle was found to contain a ratio of 3.00×10^{-5} tritium atoms to hydrogen-1 atoms. The water had been sealed in the bottle for about

A. 18 years B. 25 years C. 14 years D. 120 years

18. This scattergram shows the naturally occurring elements on Earth with stable nuclei and the grey line shows the points where the number of neutrons and protons in the nucleus are equal. Which of the arrowed elements V to Z would most likely to be a positron emitter?



A. W and Y B. V and X C. X and W D. V and Y

19. A 20.0 Bq source is found to give 1.20 joules of heat energy to a 0.250 kg piece of meat in an hour. If the radiation absorbed consisted of neutrons with a quality factor of 7, then the Equivalent Dose received by the meat would be about:

A. 33 mSv B. 34 Sv C. 84 Sv D. 560 kSv

20. The table below shows the average equivalent dose received by each citizen in the city of Chalcos from all sources in a year. An LD_{50} dose rate of 4.5 Sv represents the total equivalent dose over a lifetime that will cause 50% of the population to die.

Radiation source	Biological equivalent dose mSv per year
Cosmic rays	0.28
Earth and air	0.28
Nuclei in body	0.39
Inhaled radon	2
Consumer products	0.1
Medical X-rays	0.4

The average Chalcos citizen will reach this dose in about:

A. 1300 years B. 780 years C. 200 years D. 90 years

Nuclear Physics Test

[50 marks total]

1. a) Give the main characteristics of α, and γ-rays, mentioning comparative mass, charge and ionising ability [6 marks]

α-rays ____

____

β –rays ____

____

γ-rays ____

____

b) Complete these nuclear reaction equations stating what x and y are. [6 marks]

(i) ${}^{131}_{53}I \rightarrow {}^{131}_{54}Xe + {}^{0}_{y}X$ x = __________ y = __________

(ii) ${}^{218}_{84}Po \rightarrow {}^{y}X + {}^{4}_{2}\alpha$ x = __________ y = __________

(iii) ${}^{12}_{7}N \rightarrow {}^{x}_{6}C + y$ x = __________ y = __________

2. Referring to the graph adjacent:

a) What is the half-life of uranium –238? [1 mark]

____

____

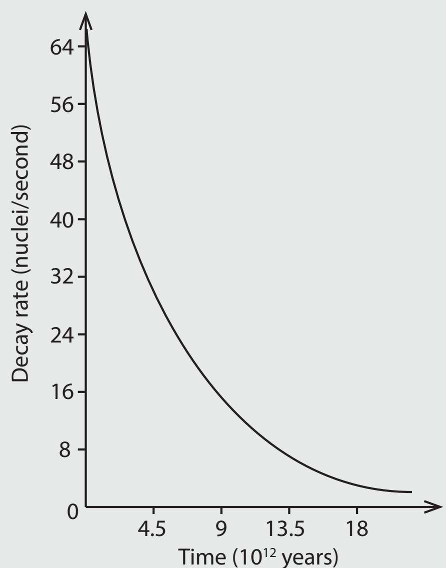
b) What is the expected decay rate after 3 half-lives? [2 marks]

____

____

____

____



Decay curve for uranium-238

3. In a radiation accident a worker absorbs 30.0 J of radioactive energy from alpha radiation.

a) If the worker has a mass of 60.0 kg, what is her absorbed dose? [1 mark]

____

____

b) What is the dose equivalent that she has received? [1 mark]

____

____

c) Is this dose enough to cause serious damage? Explain. [1 mark]

____

____

d) Explain how this radiation affects the body [2 marks]

____

____

____

4. Uranium –235 can fission according to the following equation:

$^{1}_{0}n + ^{235}_{92}U \rightarrow ^{148}_{57}La + ^{85}_{35}Br + x^{1}_{0}n + \text{Energy}$

a) Balance the equation and determine a value for x [1 mark]

x = ____

The masses of the various nuclei are:
Neutron = 1.00867 u; Uranium-235 = 235.03854 u;
Lanthanum-148 = 147.95736 u; Bromine-85 = 84.93617 u

b) Explain the term "Mass Defect" related to this fission reaction [1 mark]

____

____

c) What causes a mass defect in a nuclear reaction? [1 mark]

____

____

d) Calculate the energy that would be released from the reaction given above. [2 marks]

____

____

____

____

____

e) 1 kg of uranium-235 contains about 2.55×10^{24} atoms. Calculate the energy (in MeV) that the total fission of 1 kg of uranium-235 could produce. [2 marks]

____

____

____

____

____

____

5. (Use your results from the previous question to calculate this answer)

a) A coal power station produces 8.25×10^{12} Joules of electrical power per day. In theory how many kilograms of Uranium–235 would be required to produce this energy per day? (1 MeV equals 1.6×10^{-13} joules of energy)

[2 marks]

b) Explain the function of the following in a nuclear reactor [8 marks]

(i) Fuel rods

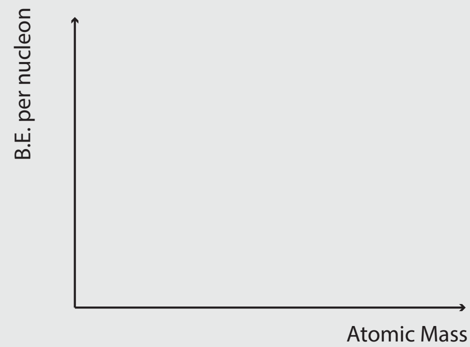
(ii) Moderator

(iii) Control rods

(iv) Heat exchanger

6. a) Calculate the binding energy for one oxygen–17 atoms, and its binding energy per nucleon, given that its mass = 16.99474 u [3 marks]

b) Sketch a graph of the Binding Energy per nucleon for all elements below and mark two areas on the graph: Area **A** where fusion reactions are possible and area **B** where fission reactions are possible [3 marks]



c) Why is it that energy is given out in a fusion reaction? [1 mark]

____

____

____

d) One of the fusion reactions occurring in stars is the conversion of two deuterium nuclei to a helium-3 nucleus plus another particle. Write a reaction equation for this reaction and identify the other particle. [2 marks]

____

____

e) Using the atomic mass values below calculate the amount of energy (MeV) given out by a single reaction of two deuterium atoms fusing together. [2 marks]

($^{1}_{0}n$ = 1.00867 u; $^{1}_{1}p$ = 1.00728 u; $^{2}_{1}H$ = 2.01347 u; $^{3}_{2}He$ = 3.01456 u; $^{0}_{-1}e$ = 0.000549 u)

____

____

f) A radioactive isotope of half-life 12.6 hours and activity 1.2 kBq is injected into a patient's body at 9.00 am on Monday. What would the activity of the isotope be on Tuesday at 4.00pm? [2 marks]

____

____

____

Chapter 3

ELECTRICITY

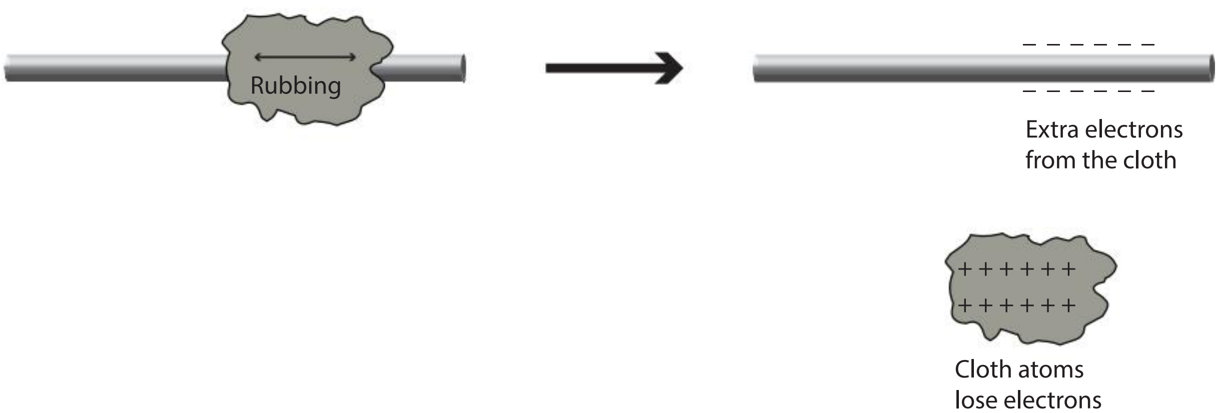
3.1 Electric Charge

The word 'electricity' comes from the Greek word ελεκτροσ (electros), which is the Greek word for amber, a fossilised tree resin. The Greeks found that when the amber was rubbed it gained a mystical ability to make small objects move. This "action at a distance" force remained a mystery until the late 1800s, when it was discovered that small, charged particles were being moved and a net electrical charge was accumulated, leading to an electric force.

We now know that when any insulator (poor conductor), such as plastic, is rubbed with a cloth some electrons are transferred from the rod to the cloth. The energy to separate these electrons from their atoms comes from the work done in rubbing against frictional forces.

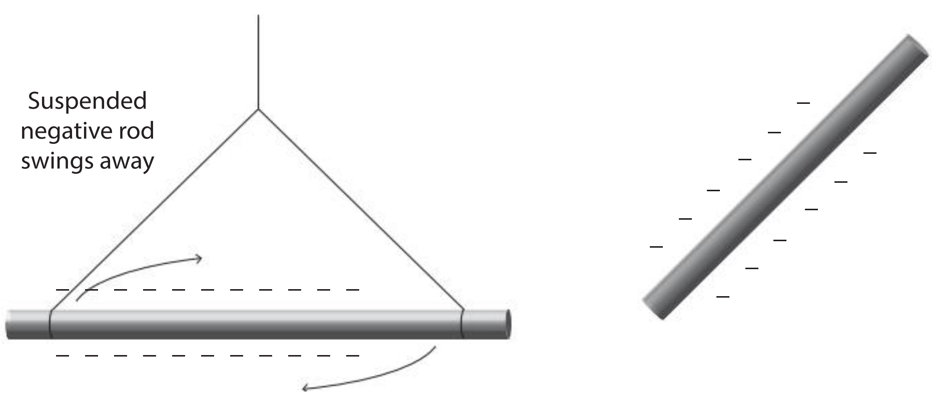
Uncharged objects have an equal number of + and – charges, so if extra electrons are added to an object it becomes negatively charged. A positively charged object arises due to the removal of electrons from the atoms, leaving the positively charged nuclei behind. Net charge accumulation will remain on an insulator as conduction cannot occur and so it is called static electricity.

Combs or nylon clothing can often become charged sometimes due to friction to create quite a large static charge; sometimes enough to produce a spark.



Good conductors can also become charged but, because electrons can move across the surface of a metal, charge will be conducted away to earth and "leak" away quickly. With plastics, the charge will stay in position and remain static.

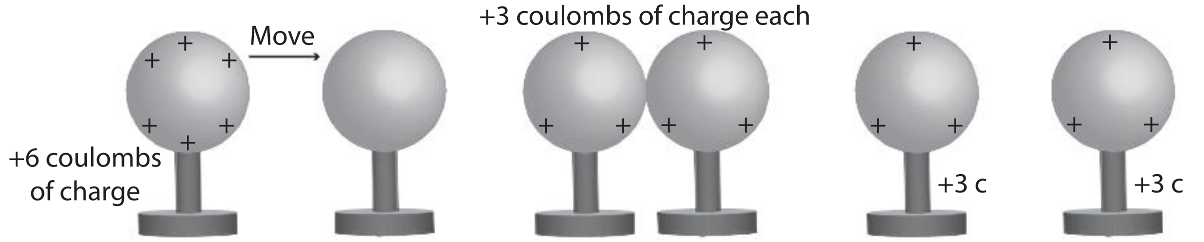
Like charges (- and – or + and +) repel and unlike charges (+ and -) attract. Demo:



3.2 Charging objects

Charging by touch

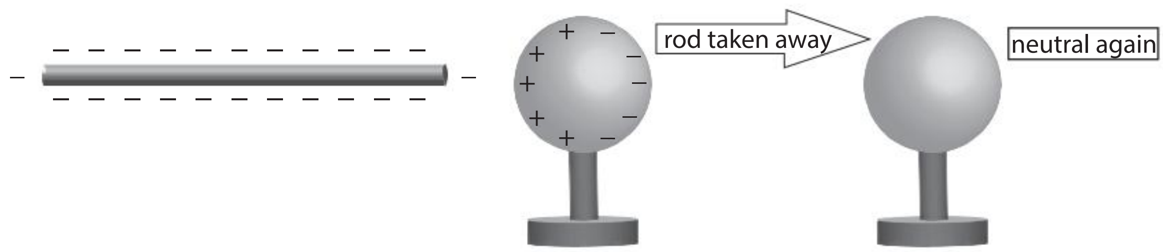
If a charged object touches another uncharged object, electrons will be transferred until each object has an equal amount of electrical energy. A larger object can hold a bigger charge because of its larger surface area (storage power = "capacitance"). Electric charge is measured in coulombs (C) — each electron has a charge of 1.60×10^{-19} C, so 1 coulomb requires 6.24×10^{18} electrons in total.



Note: in the preceding illustration it seems as though the + charge has moved from the left to the right ball but, in fact, only electrons can move so actually electrons moved from the right ball to the left one. On conductors the charges will repel each other and distribute evenly over an object.

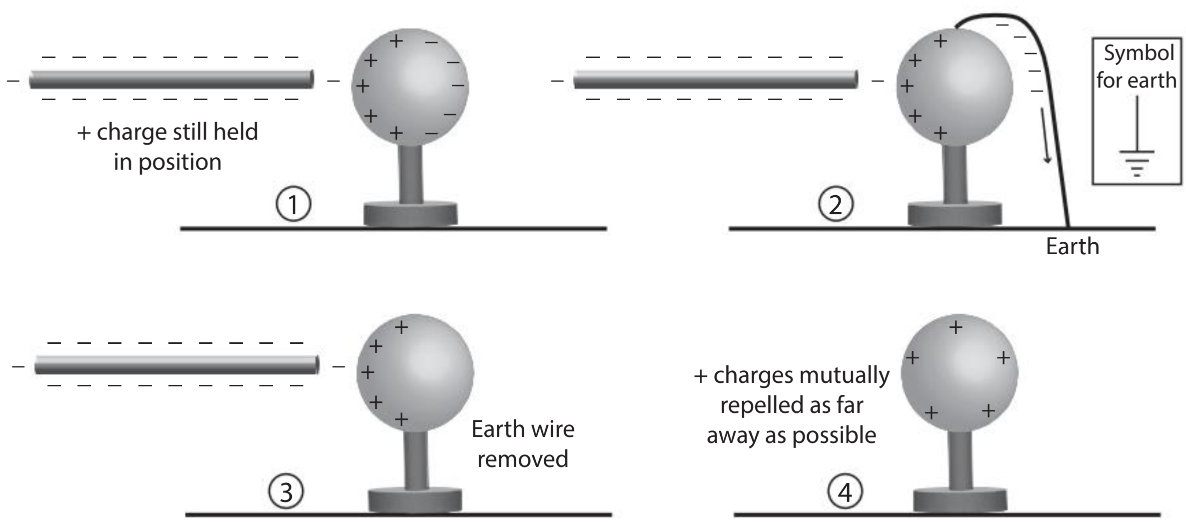
Charging by Induction

If a (–) charged object is held close to a neutral object electrons will be repelled to the other side of the ball.



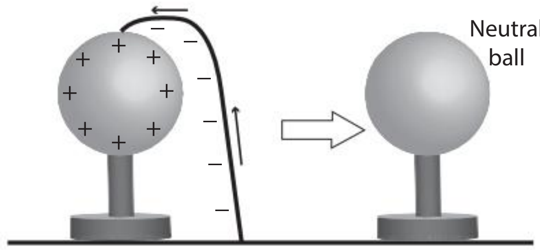
When the rod is taken away the electrons return to make a neutral object once more.

However, if one side of the ball is connected to Earth with a wire ('earthed') then the charge that is not attracted and held in position will go down into the Earth through the wire.

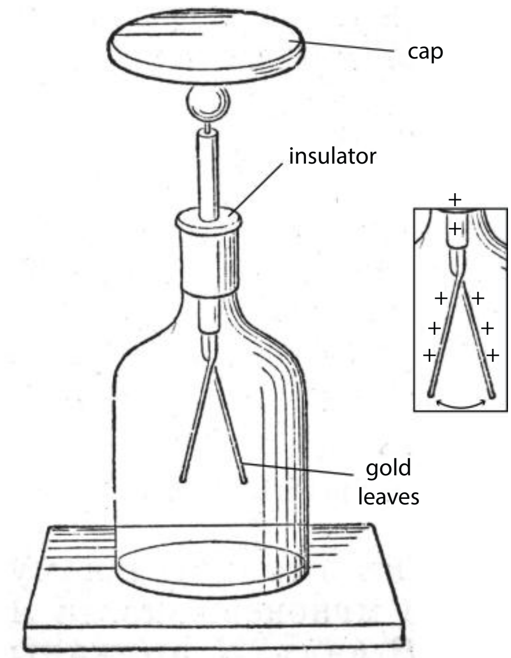


The Earth, itself, is so large that it can absorb any amount of (–) charge or supply any amount of electrons to neutralise a + charged object.

If a (+) charged ball is earthed with a wire then electrons will be drawn up from the earth to neutralise the positive charges.



3.3 The electroscope



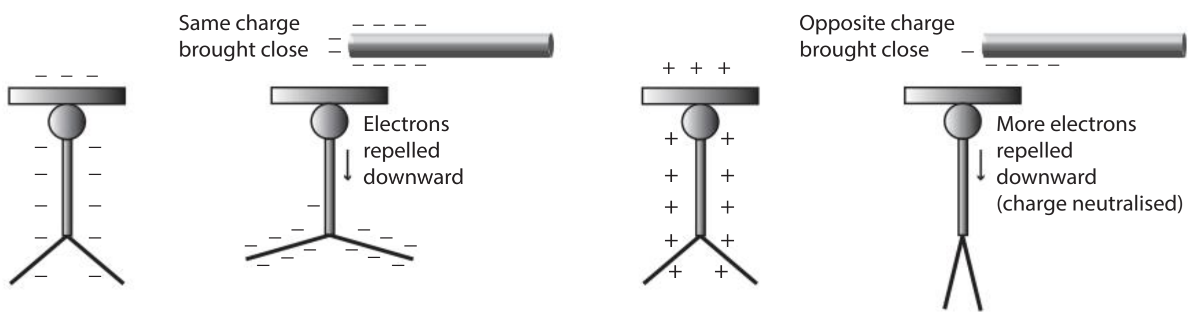
An electroscope is a simple device that uses the repulsion of like charges to detect and measure charge.

Any charge on the cap will flow down onto the gold leaves. Because the charge is the same on both leaves they repel each other.

The angle of divergence indicates the amount of charge present.

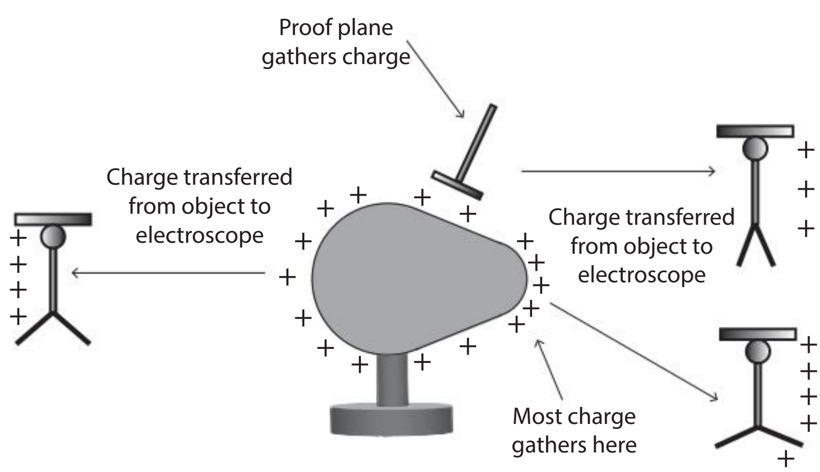
Testing for charge

An electroscope is first given a known charge (+ or -) and then the rod with the unknown charge is brought up to it. If the leaves diverge then the charge on the rod is the same sign. If the leaves go down further then the charge is different to the charge on the leaves.



Leakage of charge

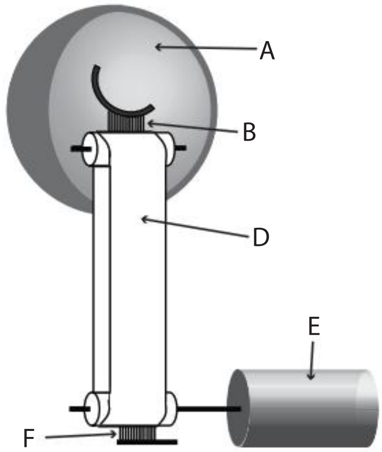
If a pear-shaped metal object is charged and tested with a 'proof plane' it is found that the charge tends to gather at areas where the radius is smallest.



This experiment shows that charge tends to gather at a pointed end. E.g. if a sharp needle or brush is placed on the top of a charged electroscope the charge will leak away to earth very quickly.

This fact is made use of in several electrostatic devices where charge needs to be collected or dissipated using sharp points. E.g. lightning conductor, photocopier and Van der Graaf generator.

The Van der Graaf generator

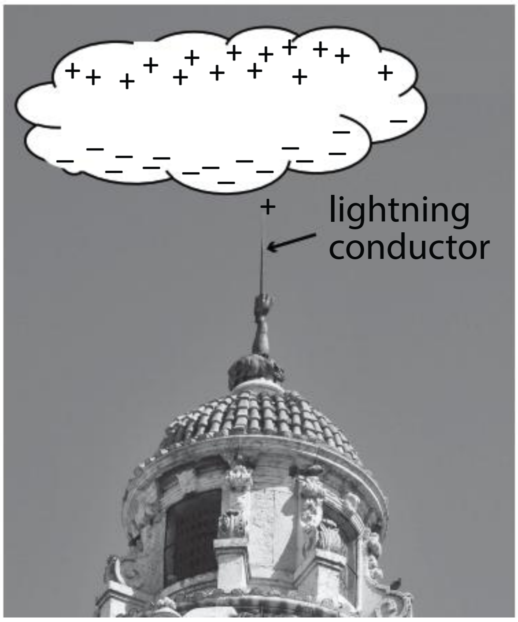


The rubber belt (D) is rotated by the motor (E) where electrons picked up from the negative power supply and sprayed onto the belt from a brush (F).

This charge is transferred off the belt to the dome (A) through the top brush (B), which has sharp points.

Because the dome has a large surface area it can store a large charge amounting to several thousand volts potential. Van der Graaf generators producing a million volts were first used to provide enough energy to split atoms in the early 1900s.

Lightning conductor



Lightning is caused by the build-up of charge on the water particles in clouds through friction with air.

A very large positive charge builds up on the top of the cloud and the negatively charged underside can cause the air to ionise, particularly near pointed objects, such as roofs.

Ionised air can conduct several coulombs of charge from a voltage build-up of several million volts which can sometimes destroy a building when lightning strikes.

However, if a sharply-pointed lightning conductor is fitted to a church spire the charge will be conducted slowly and not in one large lightning flash, saving the building from damage.

Electrostatics Quiz

1. A piece of plastic A is known to give a negative charge when rubbed with a piece of silk cloth. A comb also gives a charge after use but the sign of the charge is unknown. Explain how plastic can be used with an electroscope to determine the sign of the charge on the comb.

2. Explain why pieces of confetti paper are attracted to a charged rod, regardless of the charge on the rod.

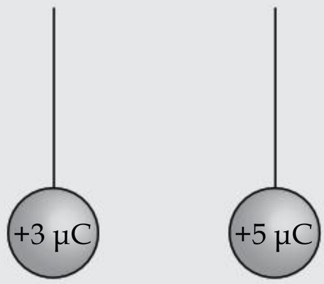
3. It is very important in flour factories that all metal objects are earthed and that the air is kept humid because of the fire risk. Explain how factory machines can become charged and how these precautions can prevent explosions and fires.

4. Use a diagram to explain how an ink-jet printer head is able to produce black letters on the paper.

5. Some metalloids like selenium can hold a charge, but lose it if light is shone onto the metalloid. Explain how this phenomenon is used in a photocopier or laser printer.

6. Golfers are always told not to shelter under trees during an electrical storm. Explain the logic of this advice.

7. Two balloons are charged by rubbing on a student's jumper and then hung on silk threads as shown. It was found that one balloon had a charge of +3.00 microcoulombs and the other a charge of +5.00 microcoulombs.



Draw a diagram to show how the two balloons will look after they are suspended on the threads.

8. An oil drop gains a net negative charge of 3.19×10^{-19} C.

a) Calculate the number of excess electrons present on the oil drop.

____

____

b) How many electrons are there on each droplet?

____

____

3.4 Current Electricity

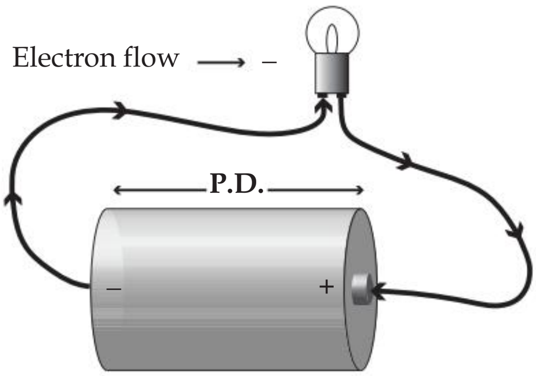
Static electrical charge and current are both caused by electrons, but current is the flow of these electrons down a wire caused by an attraction by a positive charge.

Current, in amps (symbol I), is defined as the flow rate of charge past a point i.e. charge per second or $I = q/t$. So if 20.0 coulombs of charge flows down a wire in 5.00 seconds then the current would be 20.0/5.00 = 4.00 amps (4.00 A).

3.5 Potential difference (P.D.)

In a battery the difference in reactivity of two metals is used to create a force on the electrons, or a potential difference (voltage). A battery stores chemical energy by using two metals that exert different repulsive forces on their electrons e.g. zinc and copper. Because the electrons in a metal wire are easily moved (a good conductor), when the battery is connected to each end of the wire it pushes these electrons round. If a globe (lamp) is inserted in this wire then the electrical energy the electrons have is converted to heat and light in the globe.

Electrons will not flow unless there is a complete circuit.



The P.D. between 2 points is defined as:

The amount of energy (Work done in joules) needed to transfer 1 coulomb of charge from 1 point to the other.

In other words: P.D. (volts) = Energy per coulomb of charge   Or $V = W/q$

From this definition energy $W = Vq$

Example 1

What energy is needed to move 20.0 C of charge across a voltage of 3.00 V? [3 marks]

Solution 1

Description	Marks
W = qV	1
= 3.00 × 20.0	1
= 60.0 J	1
Total	3

Example 2

If a 12 V car headlight carries a current of 60 mA and is left on for 2 minutes what energy is given out? [6 marks]

Solution 2

Description	Marks
q = It	1
= 0.06 × 2 × 60	1
= 7.2 C	1
W = Vq	1
= 12.0 × 7.20	1
= 86.4 J	1
Total	6

Charge and Energy Quiz

1. In a wire 12.0 C of charge passes each point per second. What current flows in the wire?

2. A current of 120 mA flows for 1.00 minute through a globe. What charge has passed?

3. A resistor carries a current of 0.300 mA and after a certain time 15.0 nC of charge has passed. For how long has the charge been passing?

4, 1 electron carries a charge of 1.60×10^{-19} C. In the last question how many electrons made up the 15.0 nC charge?

5. A detector of electrons counts 8.00×10^{21} electrons passing in a time of 2.00×10^{2} s. What current has passed?

6. An electron in a hydrogen atom is moving in a circle around the nucleus with radius 12.0 nm and with a speed of 2.40×10^{6} m s^{-1}. What is the electron current in a hydrogen orbit?

7. A 12.0 V car battery is recharged with a charge of 0.500 kC. What energy has been transferred to the battery?

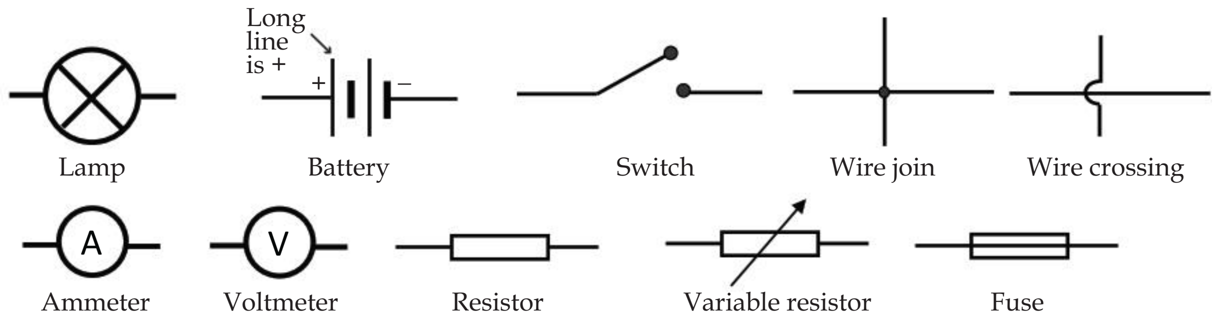
8. A charge of 360 mC is passed through a resistor releasing 72.0 J of energy. What voltage exists across the resistor?

9. A flashgun is charged to a potential of 9.20 V, holding a charge of 1.20×10^{-2} C each time. What energy is released when the flashgun is used?

10. A 240 V electric fire carries a current of 5.60 A and is left on for 1.50 hours. How much energy is given out in this time?

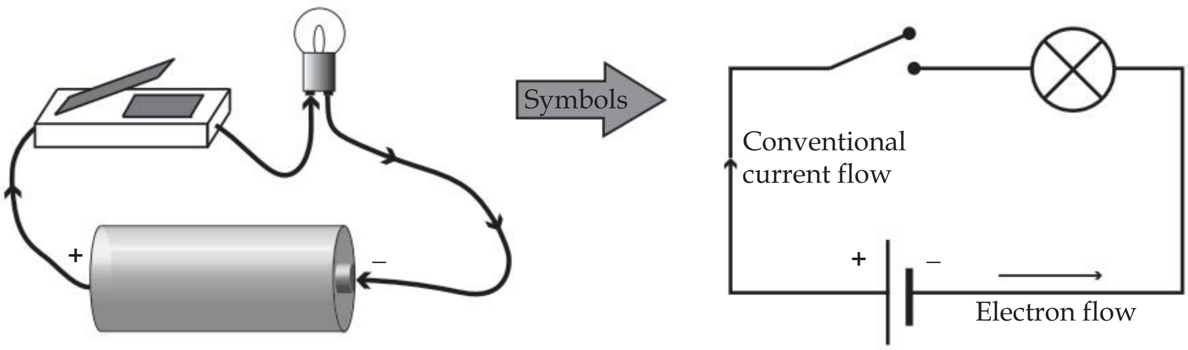
3.6 Symbols

Symbols are used to represent electrical components such as wires, batteries, switches, etc. Some of these are shown below.



3.8 Circuit diagrams

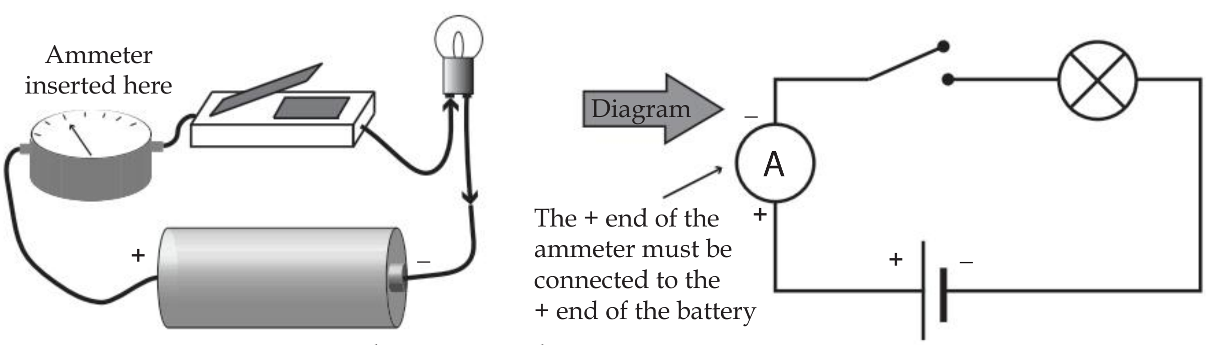
Components connected with wires into a complete circuit can be represented by a circuit diagram, using the symbols above.



Note: Although electron flow is from – to + arrows showing current are always drawn the other way round to indicate what is called 'conventional current flow' i.e. the movement of imaginary + charges. Conventional current will be explored further in the Year 12 course.

Ammeters

To measure the current in a circuit, the ammeter is inserted into the circuit so all the current runs through it. Ammeters have a very low resistance and so, do not impede the flow of electrons, nor convert a significant amount of electrical energy.

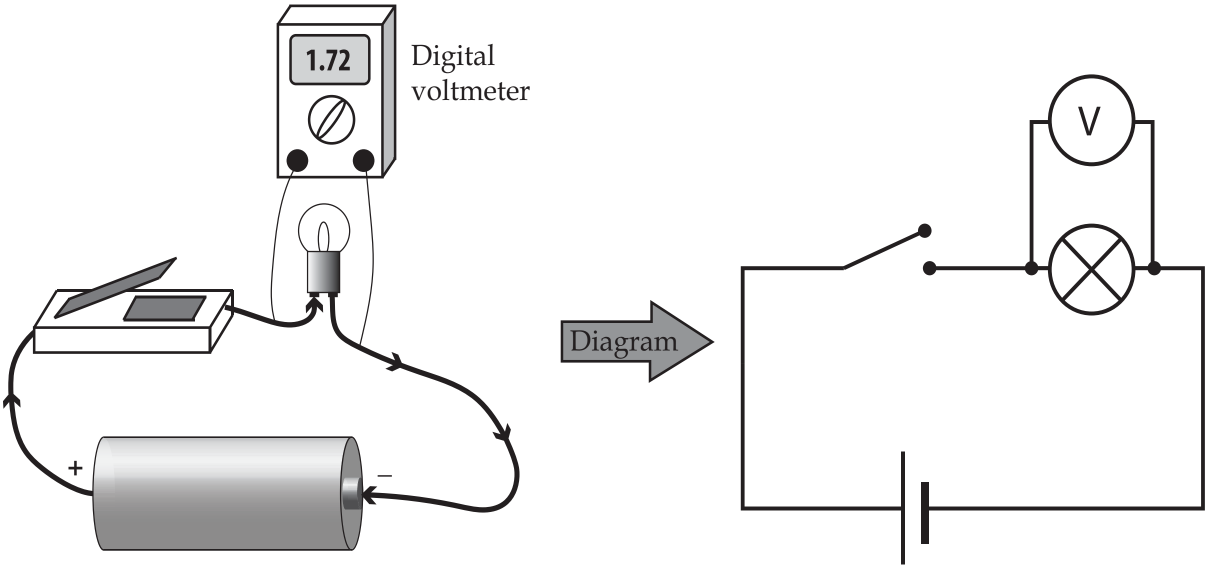


The positive end in circuits or components will be coloured red. The negative is coloured black.

Voltmeters

To measure the P.D. across the ends of a component a voltmeter must be connected across it to measure the difference in electrical potential between the two points.

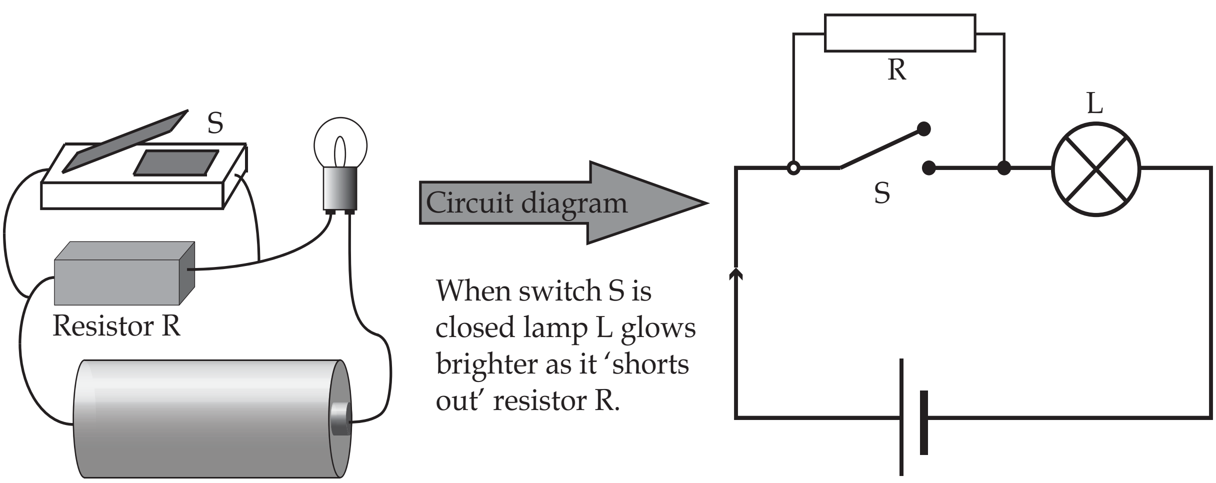
As voltmeters are placed in parallel with the circuit, they have a very high electrical resistance so as to not remove a significant amount of charge from the circuit that they are measuring. Otherwise it will affect the whole circuit by allowing an extra current to flow. Digital voltmeters are useful because they have an extremely high resistance and do not use a mechanical system to indicate voltage like analogue meters do, which use a magnetic deflection coil and needle.



3.7 Ohm's Law

Good conductors, such as metals, have electrons in their outer atomic orbitals that are completely free to move about all of the atoms ("delocalised"). The energy needed to separate these conduction electrons is so small that, at room temperature, there is enough energy available to release them all. Bad conductors (insulators) need much more energy to release the valence electrons and so, at room temperature, very few electrons are available to conduct. Non-metals, non-ionic liquids, gases and crystalline solids are all poor conductors, although everything conducts electricity if provided a large enough P.D. to force the electrons to flow.

A resistor is an electrical component made so that it restricts the flow of current in a circuit. Resistors can be made from resistance wire or from a carbon/clay mix so they have a range of values from low to high resistance. If a resistor were placed in the lamp circuit above, it would reduce the current and reduce the brightness of the lamp.

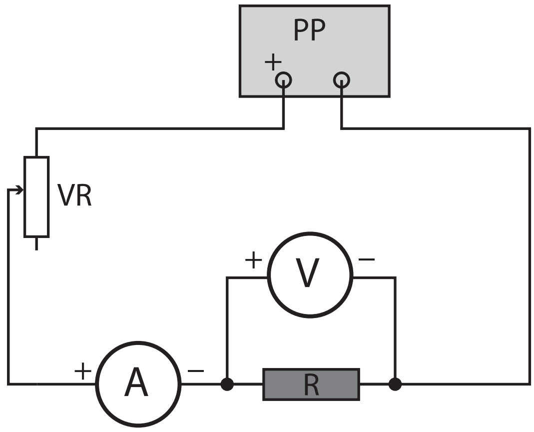


When switch S is closed lamp L glows brighter as it 'shorts out' resistor R.

<u>Current/voltage investigation for a resistor</u>

Georg Ohm was the first scientist to investigate how the voltage across a resistor affects the current that is forced to flow through it. The circuit overleaf can be used to do the same investigation in the lab.

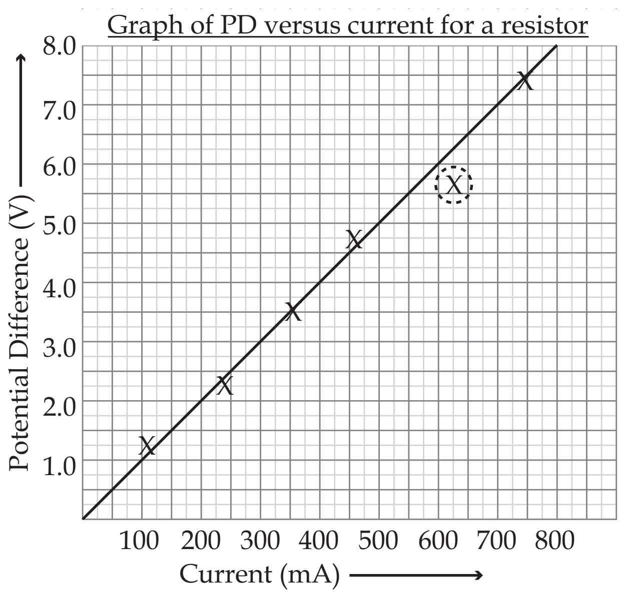
Here the power pack (PP) can be set at quite a high voltage and the P.D. across the resistor can be adjusted using a variable resistor placed in the ciruit (VR). The Votage across R is measured using a voltmeter connected across it. The current through R is measured using the ammeter placed in series.



Sample results are shown for this circuit in the table below from which a graph can be drawn.

V (V)	1.35	2.25	3.55	4.82	5.48	7.23
I (mA)	115	243	362	458	625	722

Graph



A line of best fit is drawn to have as many points on one side as the other. This is a way of averaging out the errors and disregarding outliers (e.g. point 5 on the graph is an outlier).

As this graph is a straight line it shows that there is a linear relationship between the two variables (P.D. and Current) i.e. the graph has an equation in the form: y = mx, where m is the gradient of the graph.

The relationship "*Current is proportional to applied voltage*" is called Ohm's Law, after its discoverer, Georg Ohm. The proportional constant is the gradient of the line and represents the resistance of the resistor (R). Gradient = V/I. To find the gradient of a line we divide the rise by the run for the largest triangle made by the line (not to a point!)

In this case $\text{Gradient} = \dfrac{8.0}{800 \times 10^{-3}} = 10.0 \text{ V A}^{-1}$

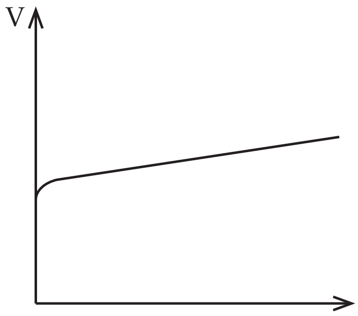
The resistance is therefore 10.0 volts per amp or ohms. (Greek letter omega (Ω) is used for ohms.)

Ohm's Law can also be expressed by the formula V = IR

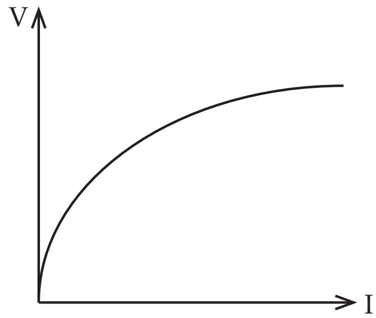
Rearranging, we obtain I = V/R and R = V/I as two other useful formulae.

Non-ohmic conductors

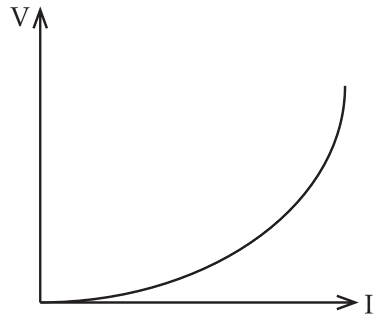
Some metal alloys and carbon obey Ohm's Law and show a linear relationship between volts and amps but many gases, liquids and solids have non-linear relationships and are known as non-ohmic conductors. The V/I graphs will indicate the type of conductor.



Resistance suddenly changes from high to low at a particular voltage (e.g. a diode)



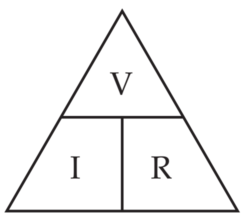
Resistance decreases as current rises (e.g. a semiconductor)



Resistance goes from low to high with a rise in temperature
(e.g. a light globe)

3.8 Ohm's Law calculations

Calculations of the current, voltage and resistances in circuits can all be made by using the three Ohm's Law equations – all shown in this triangle diagram.



Example 3

A 3.00 Ω resistor is connected to a 12.0 V battery

a) What current flows?

b) What value of resistor would be needed to cause a current of 60 μA to flow?

c) What voltage battery would cause a current of 150 mA to flow in the original 3.00 Ω resistor?

Solution 3

(a)

Description	**Marks**
I = V/R	1
= 12.00/3.00	1
= 4.00 A	1
Total	3

(b)

Description	**Marks**
R = V/I	1
$= 12.0/(60.0 \times 10^{-6})$	1
$= 2.00 \times 10^{5}$ Ω	1
Total	3

(c)

Description	**Marks**
V = IR	1
$= 150 \times 10^{-3} \times 3.00$	1
= 0.450 V	1
Total	3

Simple Ohm's Law Quiz

1. A 4.50 V torch lamp draws a current of 60.0 mA when working.

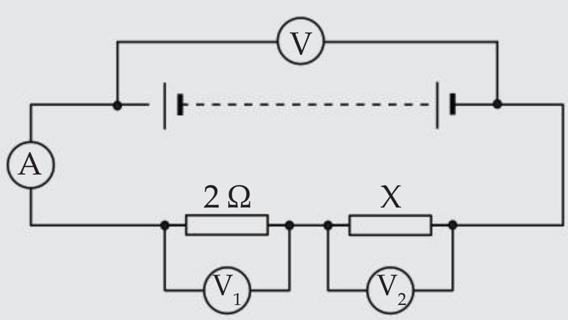
   a) Calculate the resistance of the lamp.

   b) When connected to a 3.00 V battery the resistance of the lamp is only 30.0 Ω. What current flows through the lamp in this case?

2. A toaster has an element of resistance of 48.0 Ω and is connected to a 240 V power supply. What current flows through the element?

3. A resistor is marked "*12.5 kΩ and 25.0 mA safe current rating*". What is the maximum supply voltage that can be used if the safe current is not to be exceeded?

4. A circuit is set up as shown with two resistors connected in series and a large battery supplying voltage at 96.0 V. The reading on the ammeter is 12.0 A.



   a) What is the total resistance of the circuit?

   b) What is the value of resistor X?

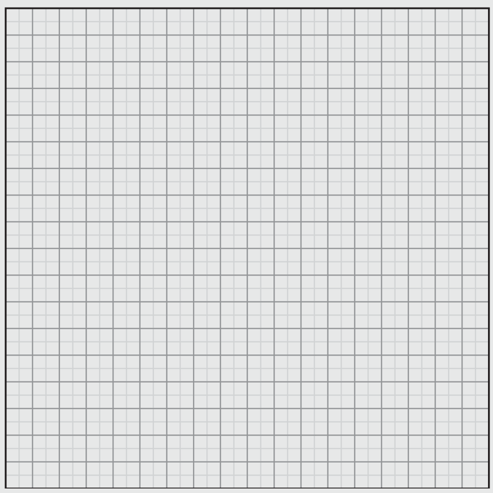
   c) What are voltmeter readings V_1 and V_2?

5. An unknown resistor R is placed into a circuit and the circuit current measured for various applied voltages. The results are shown in the table below.

V(v)	1.5	3.0	4.5	6.0	7.5
I(A)	0.75	1.50	2.25	3.00	3.75

a) Draw a labelled diagram of the experimental set-up

b) Plot a graph of voltage against the current



c) From the graph calculate the value of the unknown resistor R.

____

____

6. A high voltage pylon cable with a resistance of 1.50×10^{-8} ohms per metre length carries a current of 60.0 kA. A crow sits on the cable with its feet 5.00 cm apart.

a) Why isn't the crow electrocuted?

____

____

b) Calculate the PD existing between the bird's feet separated by 5.00 cm of cable.

____

____

3.9 Resistivity

If we want to compare the resistances of different materials we must allow for wires having different lengths and cross-sectional areas (i.e. control all the variables). To compare different materials we need to take a standard length of each (1 metre) with a standard area (1 m^2) and measure the resistance. The resistance of a 1 m length of any material with an area of 1 m^2 is called the resistivity of the material (symbol ρ)

ρ is defined by $\frac{RA}{l}$ – units of ρ are "Ω m"

Material	ρ (Ω m)	Material	ρ (Ω m)
Silver	1.60×10^{-8}	Tungsten	5.50×10^{-8}
Copper	1.70×10^{-8}	Tungsten (2000°C)	70.0×10^{-8}
Aluminium	2.80×10^{-8}	Nichrome	100×10^{-8}

Some values of ρ are shown in the table

The resistance of a wire with particular dimensions and made of a particular material can be calculated from the resistivity formula above.

Example 4

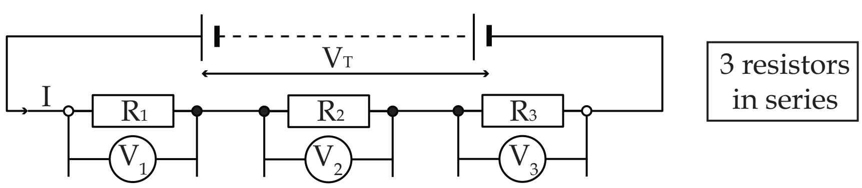
A power cable made of copper is 12.0 m long and has a diameter of 1.00 mm. Find its resistance.

Solution 4

Description	Marks
$A = \pi r^2$ $= \pi \times (0.5 \times 10^{-3})^2$ $= 7.85 \times 10^{-7}\ m^2$	1
$R = \frac{\rho l}{A}$	1
$= \frac{1.70 \times 10^{-8} \times 12.2}{7.85 \times 10^{-7}}$	1
$= 0.260\ \Omega$	1
Total	4

3.10 Resistors in series

Resistors connected end to end are said to be connected in series.



The total P.D. supplied to the circuit is V_T which must equal the sum of the P.D.s across each resistor: $V_T = V_1 + V_2 + V_3$. As a Volt is defined as a "Joule per unit Coulomb", this equation essentially obeys the law of conservation of energy.

Also, the current through each resistor must be the same $I_T = I_1 = I_2 = I_3$ (what goes into R_1 must come out of R_3 as no current can be lost).

Using Ohm's Law for each resistor: $V_T = V_1 + V_2 + V_3 = I R_1 + I R_2 + I R_3$

For a single resistor replacing R_1, R_2 and R_3 $V = IR_T = I R_1 + I R_2 + I R_3$

So $R_T = R_1 + R_2 + R_3$

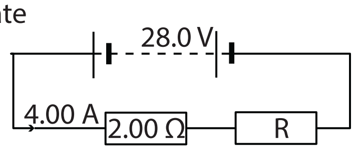
i.e. The total resistance of resistors in series equals the numerical sum of each resistance

Example 5

A 2 Ω resistor is connected in series with an unknown resistor R and a battery supplying 28.0 V. The current in the circuit was measured at 4.00 A. Calculate

a) The value of R

b) The voltages across each of the two resistors



Solution 5(a)

Description	Marks
R = V/I	1
= 28.0 / 4.00	1
= 5.00 Ω	1
Total	3

Solution 6 (b)

Description	Marks
$V_1 = I_1R_1$	1
= 4.00 × 2	1
= 8.00 V	1
$V_2 = V_T - V_1$	1
= 28.0 – 8.00	1
= 20.0 V	1
Total	6

3.11 Resistors in parallel

Connecting a resistor in parallel to another means the electrons must either flow through one resistor or the other, not both (see diagram below).

If R_2 is connected in parallel to R_1 the amount of current flowing in the circuit actually increases because R_2 allows current to flow in another path around R_1.

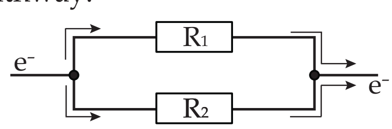
Imagine a 3.00 Ω resistor connected to a 6.00 V battery.

The current flowing from the battery will be 6.00/3.00 = 2.00 A

If another resistor of 6.00 Ω is now connected across the battery it forms a separate circuit and the current flow in this circuit is 6.00/6.00 = 1.00 A.

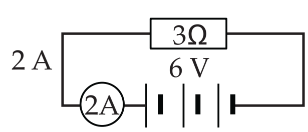
Therefore the total current flowing from the battery, measured by the ammeter will be 2.00 + 1.00 = 3.00 A.

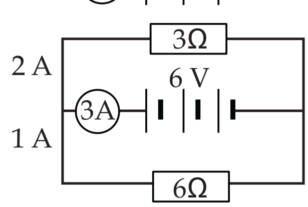
Therefore the total resistance of the 3.00 Ω and 6.00 Ω resistors in parallel must be V/I = 6.00/3.00 = 2.00 Ω. Which is a lower total resistance of either pathway.



The parallel formula will allow you to calculate the total resistance of a parallel circuit.

This is: $$\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \ldots$$





So in the case above R_1 is 3.00 Ω and R_2 is 6.00 Ω (R_3 does not exist)

add: $$\frac{1}{R_T} = \frac{1}{3} + \frac{1}{6}$$

$$\frac{1}{R_T} = \frac{2}{3} + \frac{1}{6}$$

Example 6

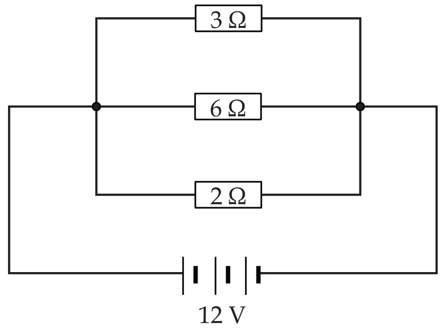
Three resistors of values 3.00, 6.00 and 2.00 ohms are connected in parallel to a battery of emf 12.0 volts.

Calculate:

a) the total resistance of the circuit

b) the total current drawn from the battery

c) the current through each resistor



Solution 6(a)

Description	Marks
$\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$	1
$= \frac{1}{3} + \frac{1}{6} + \frac{1}{2}$ $= \frac{6}{6}$	1
$R_T = \frac{6}{6} = 1.00\ \Omega$	1
Total	3

Solution 7(b)

Description	Marks
$I_T = \frac{V_T}{R_T}$	1
$= \frac{12}{1}$	1
$= 12$ A	1
Total	3

Solution 7(c)

Same P.D. across each so [6 marks]

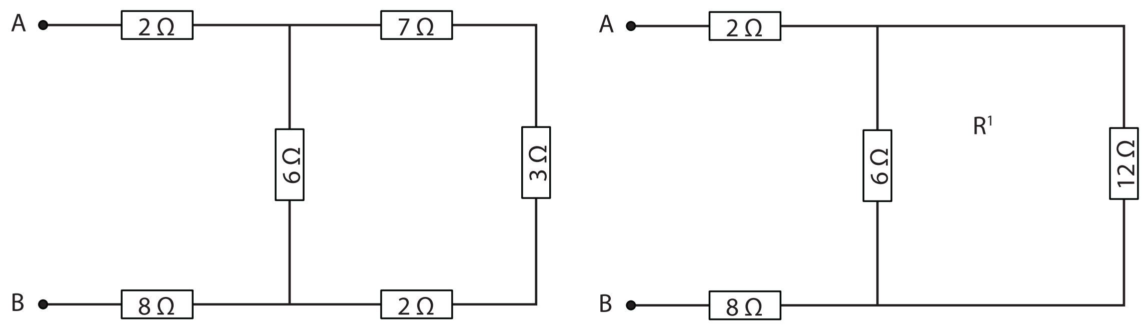
Description	Marks
$I_3 = \frac{V_T}{R_3}$ $= \frac{12.0}{3.00}$	1
$= 4.00$	1
$I_6 = \frac{V_T}{6}$ $= \frac{12.0}{6.00}$	1
$= 2.00$	1
$I_2 = \frac{V_T}{2}$ $= \frac{12.0}{2.00}$	1
$= 6.00$	1
Total	6

Note: 4 + 2 + 6 = 12 A total

Example 7

a) Find the total resistance of the complex circuit across points A B.

b) What P.D. exists across the 3.00 Ω resistor when a 28.0 V battery is connected?



Solution 7(a)

Description	Marks
Adding the 7.00, 3.00 and 2.00 resistors in series. $R_{E1} = 7.00 + 3.00 + 12.0$ $= 12.0\ \Omega$	1
This reduces the circuit to a 12.0 Ω in parallel with a 6.00 Ω $\frac{1}{R_{E2}} = \frac{1}{6} + \frac{1}{12} = \frac{2}{12} + \frac{1}{12} = \frac{3}{12}$	1
So $R_{E2} = \frac{12}{3} = 4.00\ \Omega$	1
R_{E2} is in series with the other resistors. $R_T = R_{E2} + 2.00 + 8.00$ $= 14.0\ \Omega$	1
Total	4

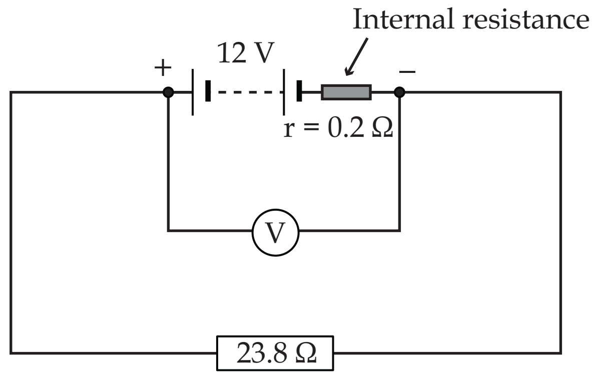
Solution 8(b)

Description	Marks
$I_T = V_T / R_T$ $= 28.0/14.0$	1
$= 2.00$ A	1
$V_{RE2} = I_T.R_{E2}$ $= 2.00 \times 4.00$	1
$= 8.00$ V	1
$I_{RE1} = V / R_{E1}$ $= 8.00 / 12.0$	1
$= 0.667$ A	1
$V_{3\Omega} = IR$ $= 0.667 \times 3.00$	1
$= 2.00$ V	1
Total	8

3.12 Internal Resistance

All power supplies (batteries and power packs) have some resistance within the devices themselves due to the plates, wires, electrolyte, etc. This (usually low) resistance is called the Internal Resistance of the device which will affect the actual terminal voltage that is supplied when a current is drawn. We can consider the internal resistance of a power supply to be a small resistor connected in series with it inside the terminals.

The battery shown has an e.m.f. of 12 V, which is the theoretical maximum voltage between the + and – terminals. If no current is drawn through the external circuit then the terminal P.D. will equal the e.m.f. at 12 V but if an external resistor is connected (23.8 Ω as shown), then the current through r will cause a 'loss' of voltage inside the cell.



This whole circuit can be regarded as a 12 V supply connected across two resistors in series (0.2 Ω and 23.8 Ω). Current flowing = 12/(0.2 + 23.8) = 0.5 A

Therefore the voltage across the resistor (terminal P.D.) = IR = 0.5 × 23.8 = 11.9 V

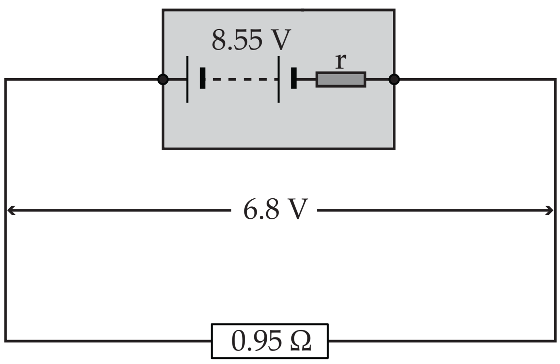
The output of the battery has dropped from 12 to 11.9 V because current has been drawn through the internal resistor and there are "lost volts" across r ("lost volts" = Ir).

A useful formula for this is $E = V + Ir$

"Lost volts" = 0.5 × 0.2 = 0.1 V and e.m.f = 11.9 + 0.1 = 12 V

Example 8

A battery has a measured voltage of 8.55 V on open circuit which falls to 6.8 V when a resistor of value 0.950 Ω is attached to the terminals.



Calculate

a) the *current flowing through the circuit when the resistor is connected,*

b) the *internal resistance of the battery.*

Solution 8(a)

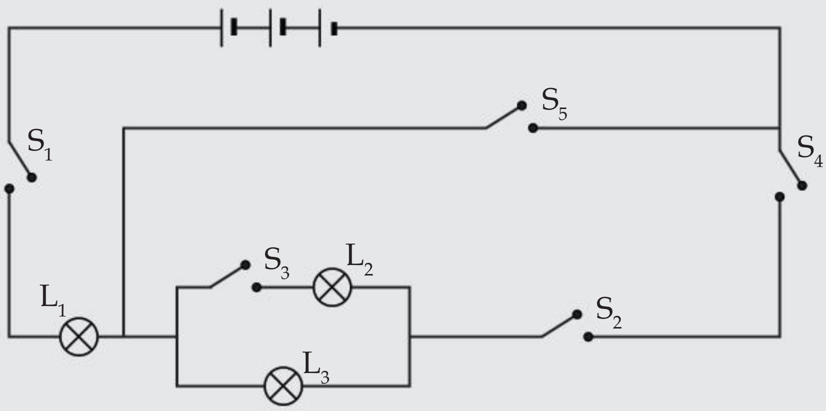
Description	Marks
$I = \frac{V}{R}$	1
$= \frac{6.80}{0.950}$	1
= 7.16 A	1
Total	3

Solution 8(b)

Description	Marks
E = V + Ir	1
8.55 = 6.80 + 7.16r	1
r = 0.244 Ω	1
Total	3

Ohm's Law Calculations Quiz

1.



A series/ parallel circuit shown contains 5 switches (S_1 to S_5) and 3 lamps of equal resistance (L_1 to L_3). Which combination of switches that are closed would give the correct sequence of lamps that are on?

	Switches closed	Lamps on
A	S_1, S_2, S_4	L_1, L_2, L_3
B	S_1, S_2, S_3, S_4, S_5	L_1
C	S_1, S_3, S_4, S_5	L_1, L_2
D	S_1, S_2, S_3, S_4	L_1, L_3

2. Which of the following statements about conductivity is NOT true?

   A. Metals are all good conductors at room temperature because electrons are released from atoms by heat energy

   B. As the temperature rises, the conductivity of a poor conductor also rises

   C. If a metal is cooled its resistance increases

   D. The resistance of a good conductor rises when its temperature increases

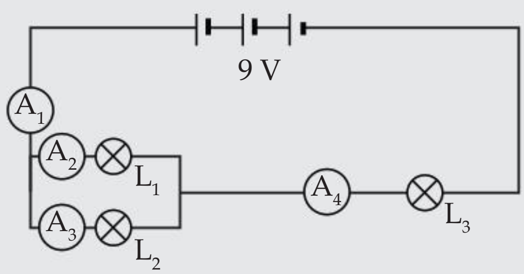
3. A resistor allows current of 5.00 mA to flow when a potential difference of 2.00 kV is applied across it. The resistor value is:

   A. 400 kΩ B. 40.0 kΩ C. 400 Ω D. 0.4 Ω

4. A toaster element has a resistance of 40.0 Ω. When connected to a 240 V alternating supply the current that will flow is:

   A. 166 mA B. 1.20 A C. 6.00 A D. 96.0 A

5.



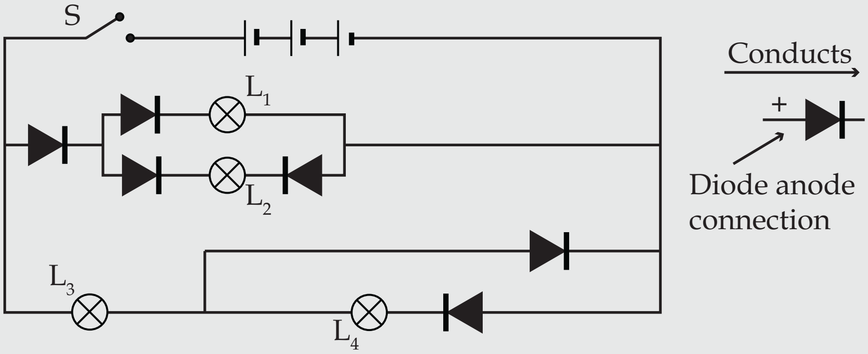
Three equal resistance lamps are connected in the series/ parallel arrangement shown with ammeters A_1 to A_4 placed in the circuit as indicated. A 9.00 V battery causes a current of 450 mA to flow when it is connected to just one of the lamps. Which set of current readings would be correct for the circuit shown above?

	A_1 (mA)	A_2 (mA)	A_3 (mA)	A_4 (mA)
A	450	225	225	450
B	300	300	300	300
C	300	150	150	300
D	450	150	150	300

6. A quartz-halogen lamp of resistance 80.0 Ω is marked as having a current rating of 150 mA. On what voltage is this lamp designed to operate?

A. 12.0 V B. 16.0 V C. 19.0 V D. 53.0 V

7.



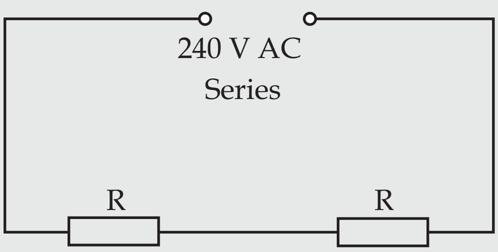
A semiconductor diode will only conduct when the anode is connected to the + supply. Which lamps will light up when switch S is closed?

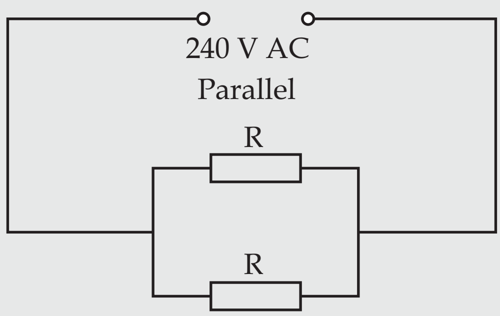
A. L_1, L_3 B. L_1, L_3, L_4 C. L_1, L_2 D. L_1, L_2, L_4

8. The resistivity of nichrome wire is quoted as 1.10×10^{-6} Ω m. The length of 1.00 mm diameter nichrome wire needed to make up a 1.00 Ω resistor would be about:

A. 0.27 m B. 0.7 m C. 29 m D. 1430 m

9. Two equivalent toaster elements can be connected to the 240 V mains supply in a series or a parallel arrangement.

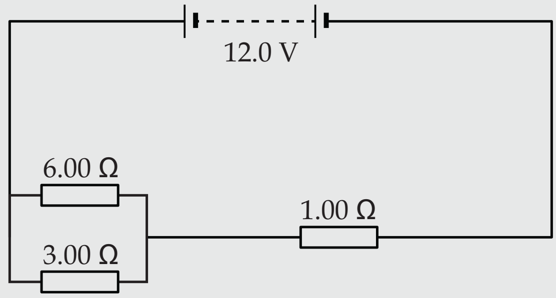




The ratio of the total current flowing in the parallel circuit compared with the total current flowing in the series circuit is about:

A. 4 : 1 B. 3: 1 C. 2 : 1 D. 1 : 1

Diagram for questions 10 and 11



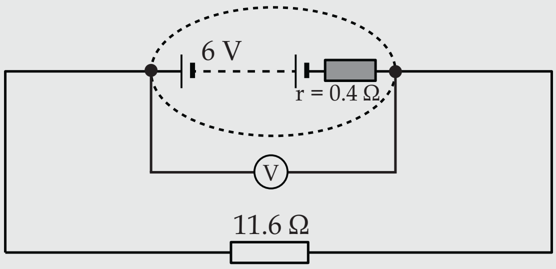
10. The series/ parallel arrangement of resistors is connected to a 12.0 V DC power supply shown above. The total resistance of this circuit is about:

A. 0.70 Ω B. 1.20 Ω C. 3.00 Ω D. 10.0 Ω

11. The current running through the 3 Ω resistor in the circuit above is about:

A. 1.3 A B. 2.7 A C. 3.6 A D. 4.0 A

Diagram for questions 12 and 13



12. The 6.00 V battery shown above has an internal resistance r of 0.40 Ω that can be regarded as a series resistor in the circuit inside the battery. When an external resistor of value 11.6 Ω is connected across the terminals of the battery it is found that the terminal voltage is no longer 6.00 V but drops immediately the external resistor is connected. This is because:

A. Some of the electrons have been used up in the internal resistance

B. The battery is running flat by driving some voltage through the resistor

C. Less current is being drawn with 11.6 Ω than with the 0.40 Ω, increasing the output voltage

D. Some voltage drop is occurring inside the battery, lowering the output

13. In the circuit shown above the reading of the voltmeter will be about:

A. 4.9 V B. 5.3 V C. 5.6 V D. 5.8 V

14. Which statement about meters and their correct connection into circuits is TRUE?

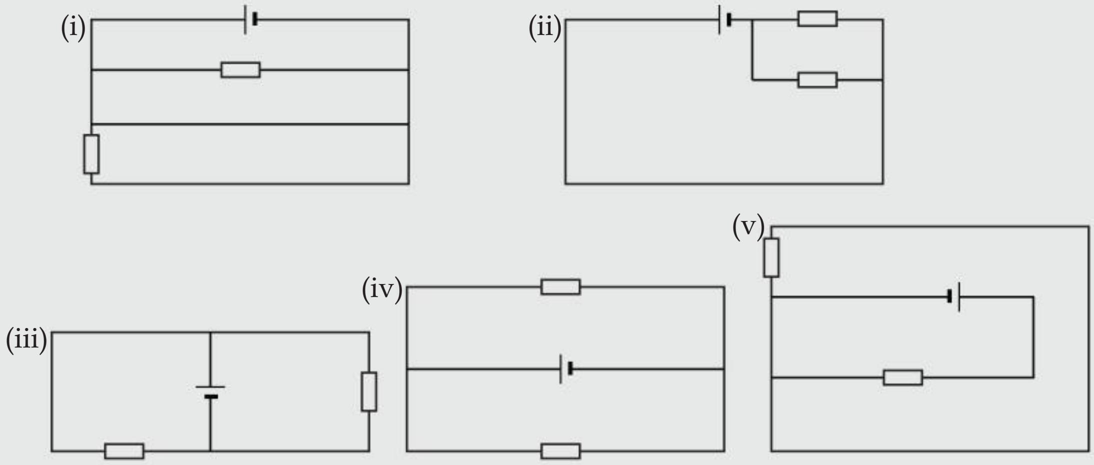
A. A voltmeter should always have a low resistance and should always be connected in series with a component

B. An ammeter should always have a high resistance and should always be connected in parallel with a component

C. A voltmeter should always have a high resistance and should always be connected in series with a circuit

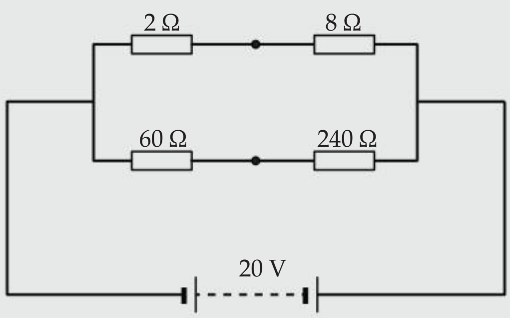
D. An ammeter should always have a low resistance and should always be connected in series with a component

15. Which of the following circuits are electrically equivalent?



A. (i), (iii), (v) B. (ii), (iii), (v) C. (i), (ii), (iv) D. (ii), (iii), (iv)

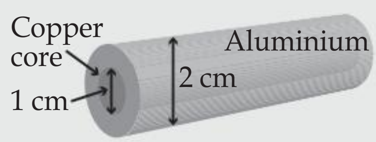
16. The series/ parallel circuit shown is set up and a high resistance voltmeter is connected across points X and Y.



The voltmeter reading obtained would be close to:

A. 0 volts B. 2 volts C. 4 volts D. 20 volts

17. A cable produced for the Australian grid consists of a 1.00 cm diameter copper cable surrounded by aluminium sheathing, so the total cable diameter is 2.00 cm. What would be the approximate resistance of a 1.00 km length of this cable?



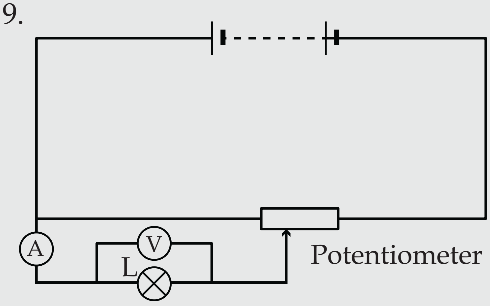
The resistivity for copper = 1.72×10^{-8} Ω m, for aluminium = 2.82×10^{-8} Ω m
(Consider the copper and aluminium cables to be connected in parallel)

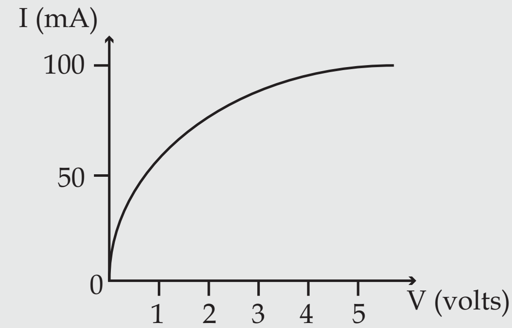
A. 0.22 Ω B. 0.19 Ω C. 0.077 Ω D. 0.023 Ω

18. A battery of emf 15.0 V and negligible internal resistance is connected to a 5.00 Ω resistor. The voltage across this resistor is then measured with an accurate voltmeter of coil resistance 45.0 Ω. The current in the circuit has been affected by the inclusion of the meter, so the voltage reading will not be a true one. The % change in current due to the inclusion of the voltmeter is about:

A. 1% B. 3% C. 8% D. 11%

19.

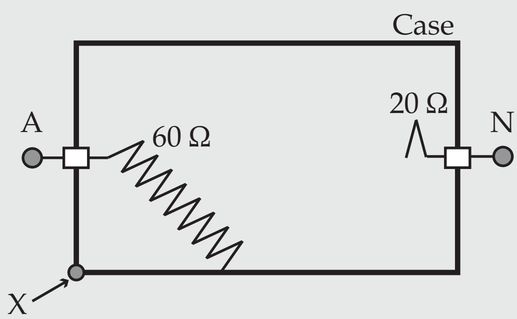




The current/voltage characteristics of a torch lamp L were found by changing the P.D. across it with the potential divider circuit shown and then measuring the current flowing through the lamp (I) with the ammeter. The graph shown was produced. If the normal working voltage of the lamp is 5.00 volts, the approximate resistance of the lamp under normal conditions is

A. 20 Ω B. 35 Ω C. 50 Ω D. 65 Ω

20. The diagram shows an electric fire whose heating element has just broken so that one end is touching the outer metal case. The resistance of this part of the coil is 60.0 Ω. Accidentally, the case has become disconnected from earth. The fire is plugged into the 240 V mains supply at the same time as a man is touching the metal case at point X. At the time chosen the potential at point X, where the man is touching will be at about:



A. 240 V B. 160 V C. 60 V D. 0 V

21, A DJ has a set of 4 loudspeakers, each with a resistance of 15.0 Ω and he wants to know how many different ways there are of connecting them to his amplifier. What are the different series/parallel arrangements that can be formed and the value of their resistances?

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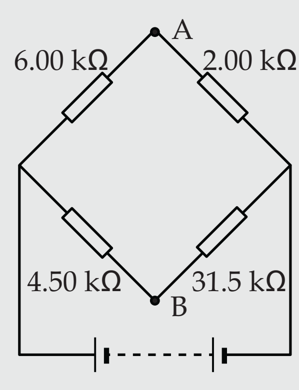
22. A 'bridge' system of resistors is connected as shown.



a) Calculate the total resistance of the circuit.

____

____

b) What reading would a voltmeter give if connected across the points A, B?

____

23. A set of 20 Christmas tree lights (set A) are made to be connected in series straight to the 240 V mains supply and draw a total current of 0.600 A.

a) What voltage does each lamp run on and what is the resistance of each?

b) Another set of 20 garden lights (set B) are made to be connected in parallel to the 240 V mains supply and draw a total current of 0.0600 A.
What voltage does each lamp run on and what is the resistance of each?

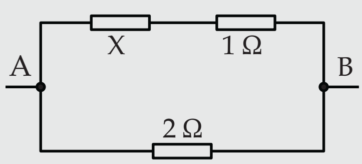
c) Lights from each set accidentally become mixed up so that one wrong light becomes connected in circuit. What would be the effect of connecting:

(i) One light from set A into the set B system?

(ii) One light from set B into the set A system?

24. 2.70 m of aluminium wire of diameter 0.280 mm is connected to a battery of e.m.f. 6.10 V and internal resistance equal to 0.820 Ω. What would the reading be of a voltmeter connected across the wire (assume the voltmeter has an infinite resistance and the resistivity of aluminium = 2.80×10^{-8} Ω m).

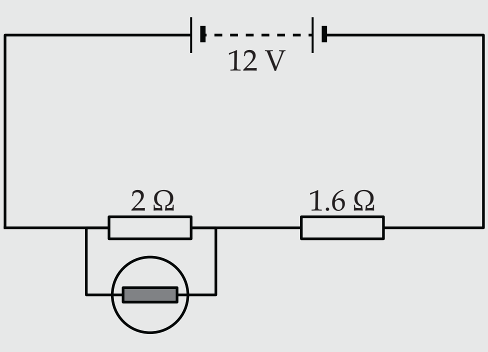
25. a) Find the resistance of resistor X in this circuit so that its value is equal to the total resistance of the circuit.



b) If a 6.00 V supply were connected across points A and B what would be the potential difference existing across resistor X?

26. A 12.0 V supply is connected across two resistors in series with values of 2.00 Ω and 1.60 Ω.

a) Calculate the P.D. existing across the 2.00 Ω resistor



A moving coil voltmeter with a resistance of 5.00 Ω is now connected across the 2.00 Ω resistor which gives a false reading due to the interference of its own resistance in the circuit.

b) Calculate the new total circuit resistance and the reading of the voltmeter after it was connected.

27. Two resistors, one 1.20 kΩ and one unknown X, are connected in parallel. This combination is then placed into a circuit and the circuit current measured for various applied voltages. The experimental results are shown in the table below.

V (V)	1.5	3.0	4.5	6.0	7.5
I (mA)	3.75	7.50	11.3	15.0	18.8

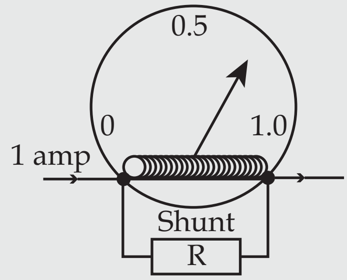
a) Draw a labelled diagram of the experimental set-up

b) Plot a graph of voltage (up) against the current (along)

From the graph calculate the total resistance of the combination of resistors, explaining how the graph was used.

c) Using the value from b), calculate the value of the unknown resistor X.

28. An ammeter coil has a resistance of 5.00 Ω and can carry a maximum current of 2.00 mA for full-scale deflection (fsd). This meter is to be adapted so that it can read currents up to 1 amp fsd by connecting a small resistor ('shunt') in parallel with the coil.



a) By calculating the currents and maximum P.D. to be allowed across the ammeter, calculate what value is required for this 'shunt' resistor.

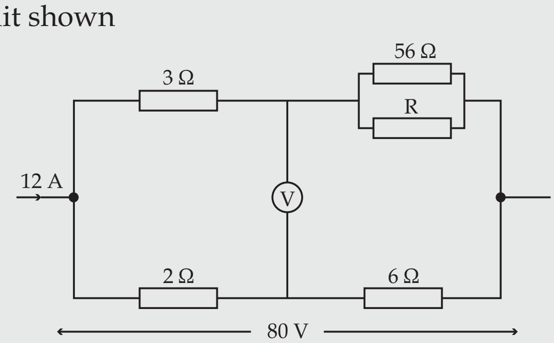
b) The shunt in part a) is to be made from a length of nichrome wire of diameter 2.60 mm and resistivity 1.10×10^{-6} Ω m. Calculate the length of wire required for this purpose.

29. A car battery has an e.m.f. of 12.2 V and an internal resistance of 0.600 Ω. The front and back light globes of the car have a total series resistance of 2.40 Ω when turned on.

a) If a voltmeter were connected across the battery when the lights are on what voltage would be recorded across the battery terminals?

b) When the car engine is started the starter motor is connected in parallel with the lights. When the car is started with the lights on it is noticed that the battery output voltage drops to 8.40 V. Use these figures to calculate the resistance of the starter motor.

30. a) Find the total resistance of the circuit shown

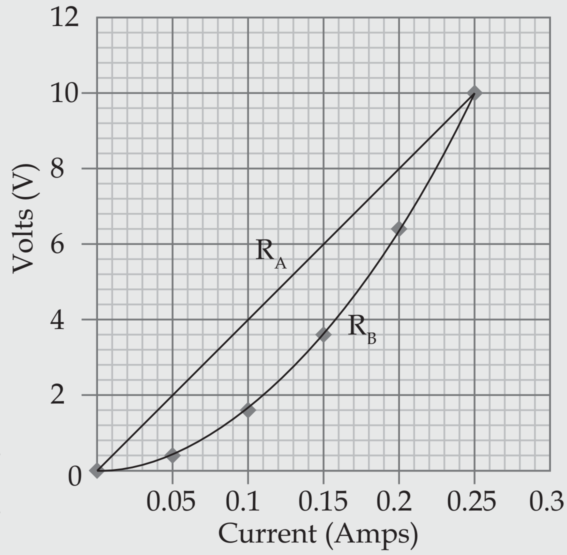


b) Find the value of R

c) Find the current through R

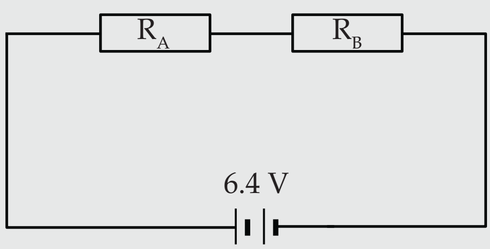
d) Find the reading of the voltmeter

31. The voltage/current plots for an ohmic resistor (R_A) and a non-ohmic resistor (R_B) are shown in the graphs opposite.



a) What are the values of resistance for R_A and R_B when a 6.00 volt potential difference is applied across their ends?

The two resistors are now connected in series with a 6.40 V battery as below.



b) R_A and R_B will not be equal but, using the graph, estimate the current flowing in the circuit. (Hint: think about the current and voltage for series resistors).

c) Find the value of resistor R_B in this situation.

3.13 Electrical Power

The definition of power is "the amount of energy used per second" i.e. joules per second. 1 joule per second equals one watt of power.

From section 3.1 we have: The P.D. between 2 points is defined as "the amount of energy (joules) needed to transfer 1 coulomb of charge from 1 point to the other".

i.e. $V = W/q$ or $W = Vq$ If we divide each side of this equation by time we get:
$W/t = Vq/t$ Energy per second = power and charge per second = current
So: Power = Volts × Amps, or $P = VI$ (measured in watts)

Substituting $V = IR$ from Ohm's Law gives $P = I^2R$

or substituting $I = V/R$ gives: $P = \frac{V^2}{R}$ — all useful equations.

Example 9

A 100 watt electric globe runs off a 240 V supply. What current is drawn?

The same globe is now connected to a 220 V supply. What power is used now?

If the globe has a 10% rise in current, what power is used now?

Solution 9(i)

Description	Marks
$P = VI$ so $100 = 240I$	1
$I = 100/240$	1
$= 0.416$ A	1
Total	3

Solution 9(ii)

Description	Marks
$P = V^2/R$	1
$= 220^2/576$	1
$= 84$ W	1
Total	3

Assuming the resistance remains the same, so $R = 240/0.416 = 576\ \Omega$

Solution 9(iii)

Description	Marks
I now equals $0.416 \times 1.1 = 0.458$ A	1
$P = I^2R$	1
$= 0.209 \times 576$	1
$= 121$ W	1
Total	4

3.14 Power Costs

The more powerful an electrical device is, the more it costs to run. Also, the longer a device is on, the more it will cost - so costs are calculated on these two variables – power and time used. The unit used for domestic and industrial power costs is the kilowatt-hour (kW-h)

<u>Kilowatt-hour units = No. of kilowatts × No. of hours</u>

1 kW-h represents an energy value of 1000 W × 3600 s = 3.60 MJ

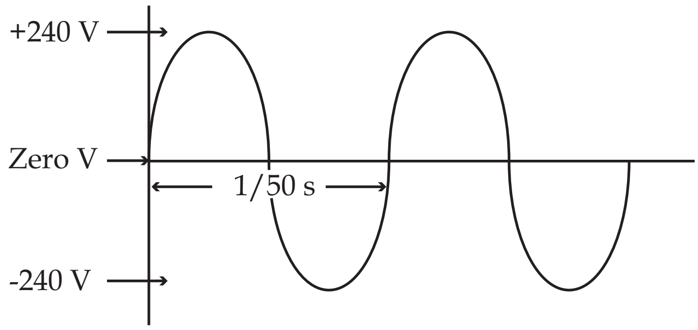
The cost of one unit (1 kW-h) varies but, say, at 30.0 cents per unit, the cost of running a 2500 W electric heater for 3 hours 45 minutes would be: 2.50 × 3.75 × 30.0¢ = $2.81

3.15 Household Electrical Supply

The voltage from a battery is called direct current (DC) because the terminals give a voltage that is always in the same direction (one terminal remains + and the other -)

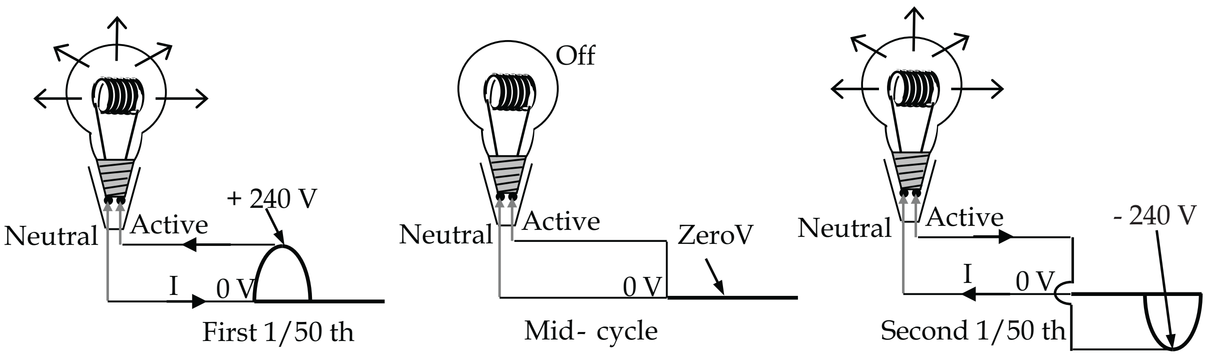
In Australia all houses work on a 240 Volt Alternating Current supply, running at 50 hertz. This means that all devices run from a voltage that changes 50 times per second from + 240 V to – 240 V. The reason AC is supplied is because transformers in the system can be used change the voltage easily to a higher or lower value (e.g. a mobile-phone charger)

An electrical device working on a 2-pin plug has one pin at earth potential (zero volts, which is called the neutral pin. The other (active) pin is connected to a voltage coming from the power station which changes from + 240 to – 240 volts and back again 50 times per second.



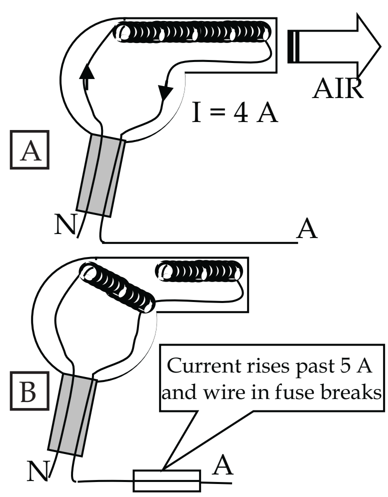
This means that the current through an AC device will reverse every 0.02 seconds according to the sine wave supply.

The current in a lamp or a heater is actually reversing 50 times a second but light and heat energies are still given out regardless of current direction and so can be used just as well on AC or DC.

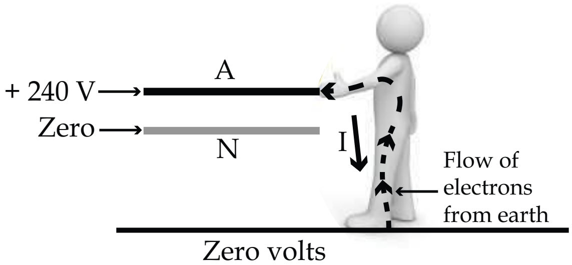


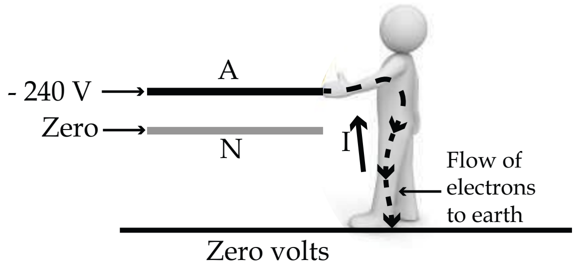
3.16 Electrical Safety

A fuse is a safety device placed in series; it acts as a weak point should the current in the circuit become too large. Without a weak point the wiring itself would get very hot and possibly melt. For example, suppose a hairdryer (diagram A) heating coil has a resistance of 60.0 Ω, then the normal current drawn will be 240/60.0= 4.00 amps but if a fault occurs and the coil short-circuits the current drawn will become much higher. If the coil breaks and touches the Active lead, as in diagram B, then the resistance in circuit is now only 30.0 Ω. The current would now theoretically rise to 8.00 A which would burn out a 5.00 A cable. The 5.00 amp fuse in series would melt when the current goes above 5.00 A, cutting the current off and making the hairdryer safe until it is repaired.

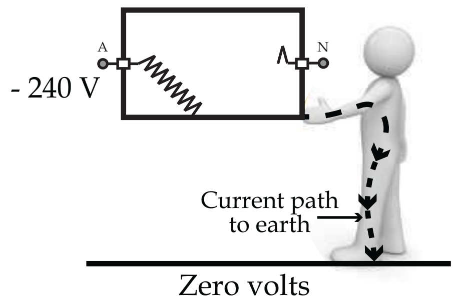


If a person accidentally touches the active wire then they can get an electric shock as current passes through them to earth. This is because the person's body completes the circuit.



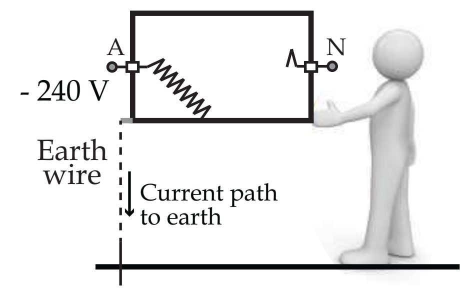


If the person touches the neutral wire no current will flow, as there is no P.D. across the person's body. Adding an earth wire to electrical devices can prevent electrocution in the case where the active wire breaks and touches the outer metal case of the device.



Consider, for example, an electric toaster whose electric element has broken and is touching the case: If contact is good, the person's body provides a resistive path to earth and so electrocution can occur if the current through the heart is high enough. A 50.0 mA current through the body will normally cause a severe shock and even kill.

The average resistance of a person's body is about 2.00 kΩ so by touching a 240 V supply, a current will flow of about 240/2000 = 120 mA which will probably be fatal, depending on the time of contact.



An earth wire connected to the case of the toaster connects straight into the ground. If a short circuit occurs from the active to the case then the current will run straight to earth, as a result, a person touching the case will carry almost no current. Their resistance is very high compared with the earth wire which has almost zero resistance. The large current flowing to earth will break the fuse and hence disconnect the device but this will take a few milliseconds, which may be too long to save the person.

If an electrical device has a plastic outer case then it is not necessary to have an earth wire connected (e.g. hairdryer, drill). These devices only have a 2-wire cord and are called "double-insulated" devices.

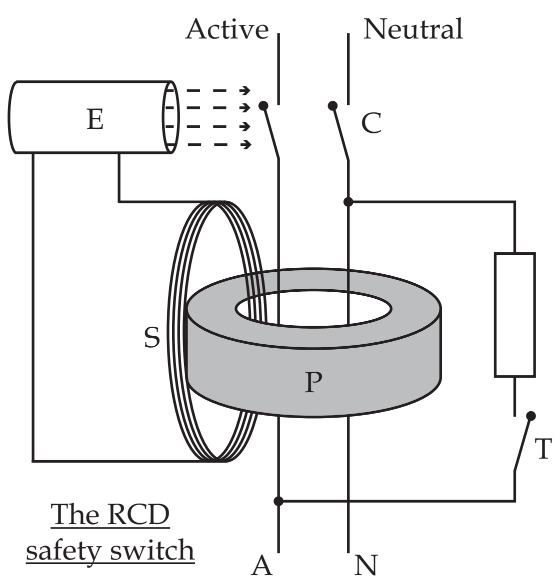
Safety Switches

Devices that disconnect the current very swiftly are therefore much safer and have now replaced many of the old wire fuse systems. These safety switches are called "earth leak trips" or "residual current devices" (RCDs) and are connected in series with the cabling system. They are very sensitive electronic switches that can sense any leakage of current to earth through the person and "trip out" a safety switch within a few milliseconds.

The Active and Neutral cables for the whole house pass, side-by-side through the primary coil of a transformer. As long as the currents through these conductors are equal and opposite (these currents should always flow in different directions) then their magnetic fields will cancel and so no current will be induced in the Primary coil of the transformer (P).

If a current is running from Active to earth through a person, then these currents will be different and a small current will run through the Primary coil, inducing a current in the Secondary coil (S).

This current will switch on an electromagnetic switch (E) which attracts the switch terminals (C) to turn off the current very quickly.

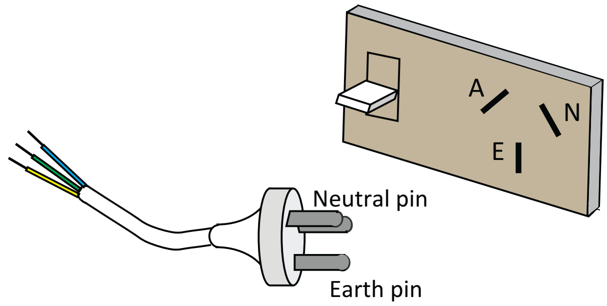


The RCD safety switch

(T) is a test switch that, when pressed, should cut off all the current to the circuit.

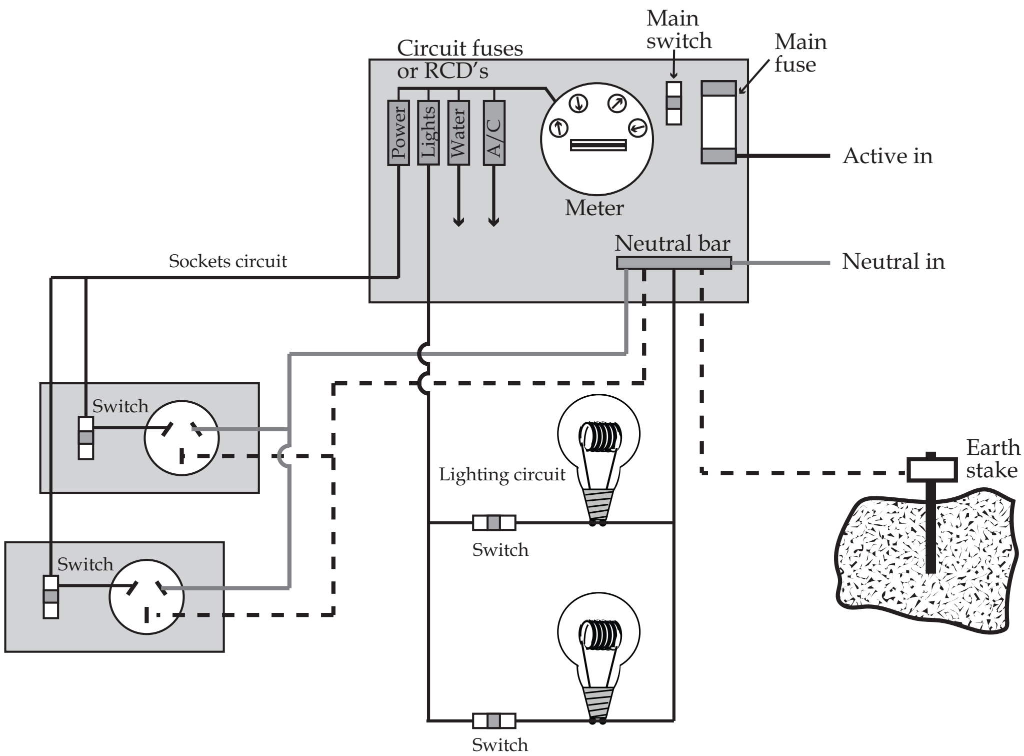
Cable colours

Cable colour-coding ensures that the active, neutral and earth connections are never confused. The international conventions are that active wires are brown; neutral wires are blue and earth wires are yellow with green stripes.



3.19 Household Wiring Systems

High power circuits, such as power sockets, require thicker cabling and include larger rated fuses than lower power circuits, such as the lighting circuit. All outlets are connected in parallel so each device has the same voltage. All switches must be placed in the active cable line so no 240 V connection remains inside when a device is turned off.



Power and Safety Quiz

1. Calculate the power of:

   a) A lamp if the P.D. across it is 9.00 V and the current through it is 1.50 A

   b) A kettle element whose resistance is 1.20 kΩ and draws a current of 2.20 A

   c) A lamp of resistance 12.0 Ω having a P.D. across it of 9.00 V

   d) A heater of resistance 3.20 kΩ connected to a 240 V supply

   e) A water heater working off the 240 V mains and drawing a current of 13.0 A

2. A electric iron has a resistance of 60.0 Ω and uses a current of 4.50 A

   a) What is its power rating?

   b) What heat does it give out in 15 minutes of ironing?

3. An electric radiator rated at 1.20 kW and 240 V is run for 2.00 hours.

   a) Find the heat energy produced

   b) Find the resistance of the heating coil

   c) What size fuse would be appropriate for the heater from a choice of 2 A, 4.5 A, 6 A, 12 A?

4. If electricity costs 30¢ per kW-h, calculate the cost of using

   a) a 1200 W heater for 2.00 h

   b) a 100 W globe for 9.00 h

   c) a 2.00 kW electric fire for 4.00 h

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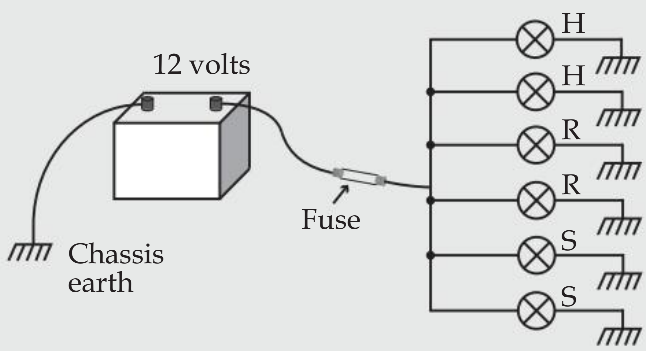
d) a 250 W T.V. for 3.00 h, 3 × 60.0 W lamps for 5.00 h, a 1000 W heater for 2.50 h and a 5.00 kW electric cooker for 45 min

5. Two lamps are connected in parallel to a 240 V power supply and give off 100 W each. What change in total power would there be if the same two lamps were connected in series to the same power supply?

6. A kettle rated at 240 V and 2.50 kW is used to heat 1.50 L of water at 20.00 °C to boiling point. If it takes 3.50 minutes to boil the water what % loss of power is there in the kettle? (C_{water} = 4180 J kg^{-1} K^{-1})

7. A 240 V electric car jack needs a current of 2 A to lift a 1 tonne car off the ground. If this takes 10 s to lift it up by 0.3 m what is the efficiency of the jack?

8. A car 12.0 V lighting diagram shows 6 lamps connected to a common fuse. The lamps, all running from the battery are: 2 × head-lights (H), at 42.0 W each; 2 × rear-lights at 21.0 W each (R); 2 stop-lights at 36.0 W each (S).



a) What current is drawn from the battery when all the lights are on?

b) Which fuse would be appropriate from the list: 2.5 A; 15 A; 20 A; 30 A ?

c) The battery can supply a charge of 20,000 coulombs before it is inadequate when the engine is not running. How long can the lights be left on before this happens?

9. A fuse has a 4.00 cm length of wire in it with the following statistics:
Melting point = 920 °C; Diameter = 0.300 mm; Specific Heat Capacity = 490 J $Kg^{-1} K^{-1}$; Resistivity = 2.00×10^{-8} Ω m; Density = 6500 kg m^{-3}. Calculate:

a) the mass of the fuse wire

___

b) the resistance of the fuse wire

___

c) the heat required to heat the wire from room temperature to melting point

___

A short occurs in the power circuit one day and a current runs through the fuse of 800 A.

d) How much power is generated in the fuse by this current?

___

e) How long does it take for the fuse to melt?

___

Electricity Test 1

Constants to use for this section
Electron charge $q_e = 1.6 \times 10^{-19}$ C
Coulomb's proportional constant k = N m^2C^{-2}
Formulae: $V = IR$ $R = \frac{\rho l}{A}$

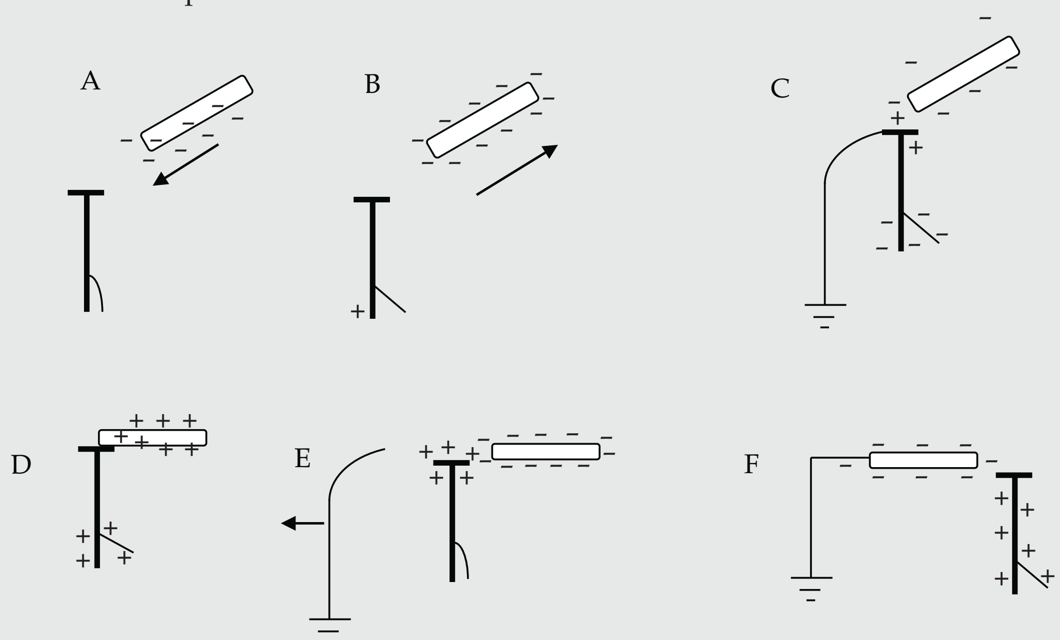
1. a) A camera flash-gun passes 6.00×10^{12} electrons between its electrodes in a discharge time of 1.60 milliseconds. Calculate the average current that flows during the flash discharge.

____

____

____

b) The following stage diagrams show possible actions used in the charging of an electroscope



What are the correct stages (in order) to charge E positively by induction?

Hint: Not all are used.

____

2. a) Which of the following statements about conductivity is NOT true?

A. Metals are all good conductors at room temperature because electrons are released from atoms by heat energy

B. As the temperature rises, the conductivity of a poor conductor also rises

C. If a metal is cooled its resistance increases

D. The resistance of a good conductor rises when its temperature increases

____

b) Before aeroplanes were invented, airship balloons carried people around the country. These were made from a plastic fabric filled with hydrogen. A very famous disaster occurred in the 1937 in America, where the Hindenburg airship, carrying hundreds of people, caught fire when it attempted to dock to a metal tower. Use your knowledge of electrostatics to explain why you think this accident may have happened.

3. a) A resistor allows current of 5.00 mA to flow when a potential difference of 2.00 kV is applied across it. What is the value of the resistor?

b) A toaster element has a resistance of 40.0 Ω. When connected to a 240 V alternating supply what current will flow?

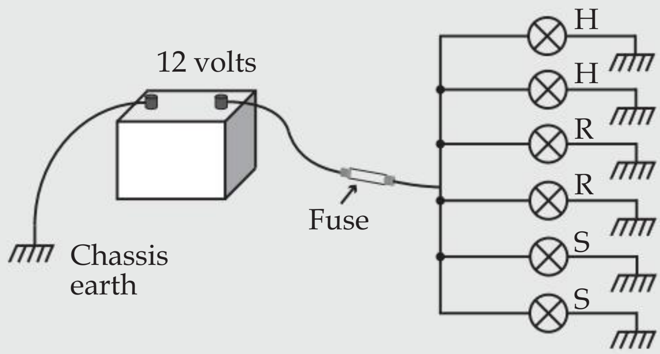
c) What voltage is required to be connected to a 1.50 MΩ resistor to make a current of 75.0 μA flow?

d) A quartz-halogen lamp of resistance 80.0 Ω is marked as having a current rating of 150 mA. On what voltage is this lamp designed to operate?

4. a) Calculate the resistance of a 50.0 m coil of copper wire of cross-sectional area 2.50×10^{-7} m^2 if copper has a resistivity of 1.72×10^{-8} Ω m.

b) The resistivity of nichrome wire is quoted as 1.10×10^{-6} Ω m. What length of 1.00 mm diameter nichrome wire would be needed to make up a 1.00 Ω resistor?

5. A car 12.0 V lighting diagram shows 6 lamps connected to a common fuse. The lamps, all running from the battery are: 2 × head-lights (H), each drawing a current of 1.85 A 2 × rear-lights (R); each drawing 0.75 A and 2 stop-lights (S) each drawing 1.25 A.



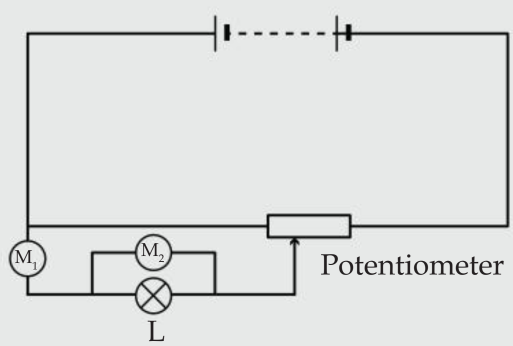
a) What value for the fuse would be best for normal operation of the lighting system?

A. 2.5 A B. 5 A C. 8 A D.12 A E. 15 A

Show your calculations for this here.

b) Just the headlights and rear lights are turned on for 6.00 minutes in a storm. What amount of charge passes through the battery in this time?

6.

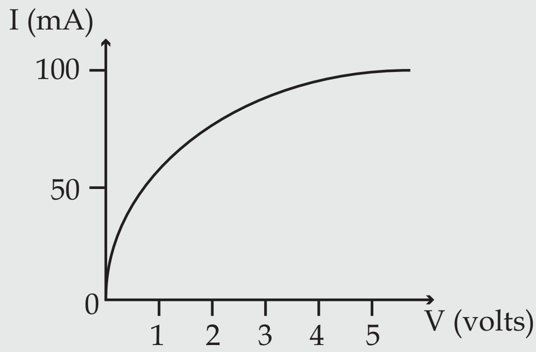


The current/voltage characteristics of a torch lamp L are found by changing the voltage across it (V) with the potential divider circuit shown and then measuring the current flowing through the lamp (I).

a) What type of meter is M_1?

What type of meter is M_2? ______

The following graph is produced:



The normal working voltage of the lamp is 5.00 volts.

b) What is the approximate resistance of the lamp under normal conditions?

______

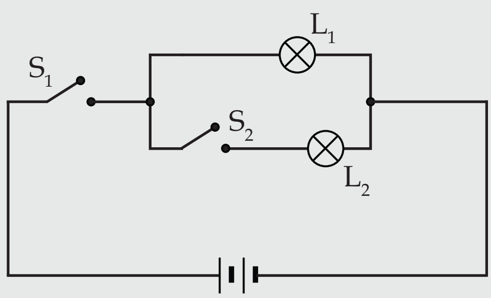
______

c) Explain the shape of the graph

______

______

7.



Explain what happens to lamps 1 (L_1) and 2 (L_2) when switches S_1 and S_2 are closed.

Insert the words "on" or "off" into the two right-hand columns below.

Switch position	Switch position	Lamp L_1 on/off	Lamp L_2 on/off
$S_{1\ open}$	$S_{2\ open}$		
$S_{1\ open}$	$S_{2\ closed}$		
$S_{1\ closed}$	$S_{2\ open}$		
$S_{1\ closed}$	$S_{2\ closed}$		

Electricity Test 2

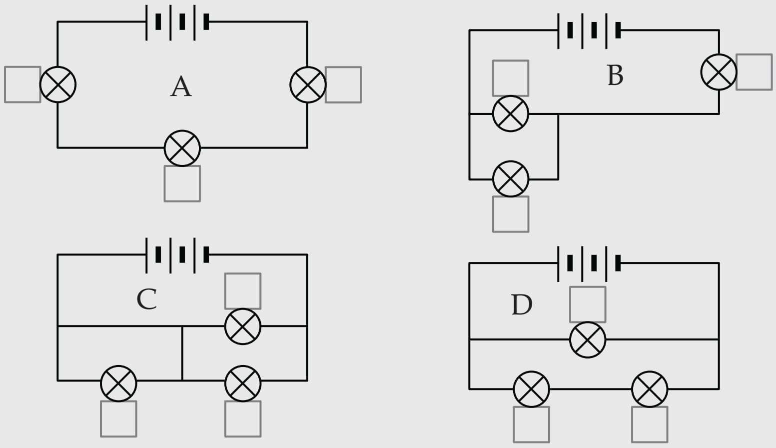
[Total marks = 40]

Constants to use for this section:

Electron charge $q_e = 1.60 \times 10^{-19}$ C kW-h = kW × h E = V - Ir

Formulae: V= IR P = VI Q = It E = Pt $R = \frac{\rho l}{A}$

1.



Above are 4 circuits all containing identical lamps, running from a battery made of THREE cells. One cell will light up a single lamp to normal brightness. Place a letter in the grey box beside each lamp describing the brightness of the lamp as follows:

Normal **N;** Brighter than normal **B;**
Dimmer than normal **D;** Off **O** [6 marks]

2. Harry is playing soccer in a field when he goes over to touch a fence that is electrified at 2.00 kV

a) Explain why Harry gets an electric shock when he touches the fence. [2 marks]

____

____

b) A bird seems quite happy sitting on the fence. Why does it not receive a shock? [2 marks]

____

____

3. a) Explain why an earth wire is installed on some electrical appliances (a diagram is required) [2 marks]

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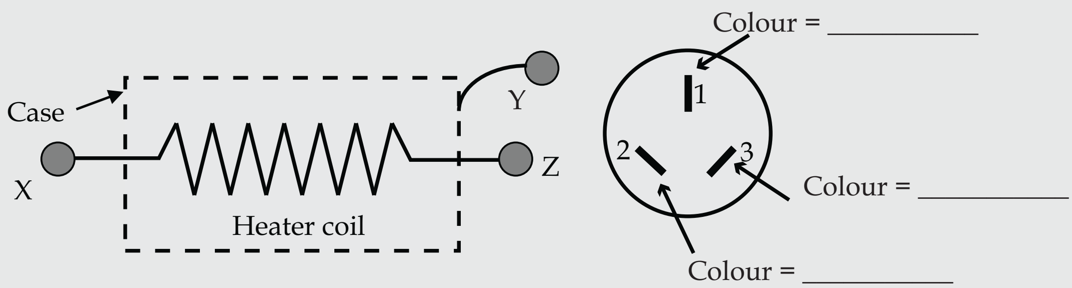
b) The diagram below shows an electrical heater and an Australian plug. Draw wires from the fire connections (X, Y, Z) to the correct pins on the plug. Also insert the correct colours on the plug pins to show the correct wire colours [3 marks]



c) Two electric toaster elements are rated at 180 W. How much current does each element draw when connected to the 240 volt AC mains? [2 marks]

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d) If two toaster elements are connected **in series** to the 240 V mains, what is the **total** power output? [3 marks]

____

____

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4. a) From what you know about electrical safety, which one of the following statements is true? (circle the correct answer) [1 mark]

A. If you grab the terminals of a 12.0 volt car battery it could kill you because this kind of battery is made to supply a current of about 200 amps.

B. In a film, James Bond threw an electric fire into the bath water of a spy while he was in it. It would not have killed the spy because the water would have shorted the active and neutral connections out.

C. If a person hung suspended by the bare Active cable of an overhead power line he could be electrocuted by the build-up of electrical charge on his body.

D. A fuse is inserted in the Active line of an electrical circuit so that if a person touched the cable the fuse would burn out, preventing a dangerous current from passing through the heart.

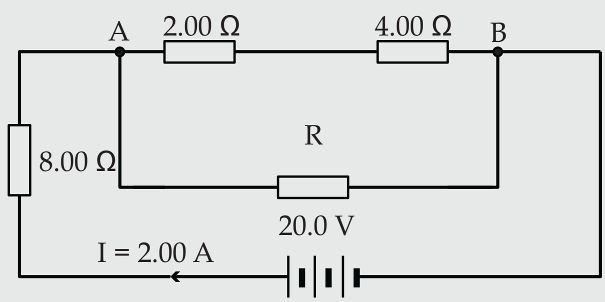
b) Jenni needs to budget for her electricity bills a year in advance and has spent the week doing a survey around her home of electrical power usage. In a week, her list is:

Device	**Power rating**	**Time of use**
Cooker	4.20 kW	2.70 h
Lighting	5 × 100 W	34.0 h
Water heater	3.20 kW	42.0 h
TV	250 W	15.3 h
Kettle	2.40 kW	1.70 h

Power costs for her are 31 cents per unit.
Use these figures to estimate her power bill for the year [3 marks]

c) A current of around 20.0 mA through a person's heart is normally fatal. If the resistance of a man's body is about 15.0 k Ω then what is the lowest voltage that could possibly kill him? [1 mark]

5.



a) Calculate the total resistance of the circuit, given the values above [1 mark]

b) Calculate the value of R [3 marks]

c) If R is made from 5.00 m length of resistance wire with resistivity $\rho = 3.80 \times 10^{-6}\ \Omega$ m, what is the diameter of the wire? [3 marks]

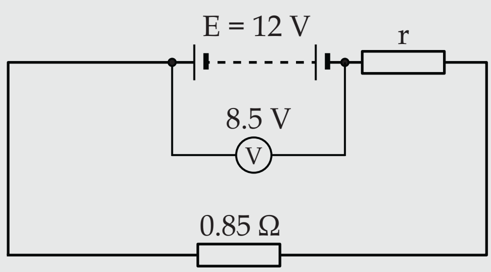
d) Find the potential difference between the points A and B [1 mark]

e) Calculate how much heat energy is given out by R in one hour [1 mark]

6. a) Two batteries L and D both have the same e.m.f. of 12.0 volts. When a low resistor R is connected straight across the terminals of D the output voltage drops from 12.0 to 8.50 V. Explain why the output voltage of battery D changes. [2 marks]

b) When the same resistor R is connected straight across the terminals of battery L the output voltage only drops from 12.0 to 11.5 V. What does this tell you about the difference between battery L and battery D? Explain. [1 mark]

c) Referring to part a) of this question, the resistor connected across battery D in this case had a resistance of 0.850 Ω when the output voltage dropped to 8.50 V.



Use these figures to calculate the internal resistance (r) of battery D. [3 marks]

LINEAR MOTION AND FORCE

Chapter 4

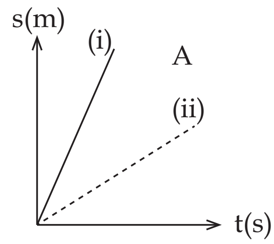
4.1 Speed and velocity

The speed of an object is the distance it moves in one second and is a scalar quantity. Velocity is a vector because it is defined as the displacement (symbol s) in one second. (See next section on vectors)

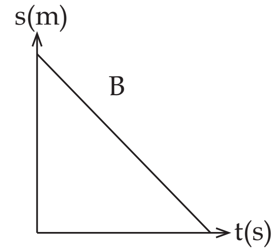
$$\text{Average velocity} = \frac{\text{Total displacement}}{\text{Total time}} \qquad v = \frac{s}{t}$$

In a graph of displacement against time, the gradient of the line will indicate the velocity of the object.

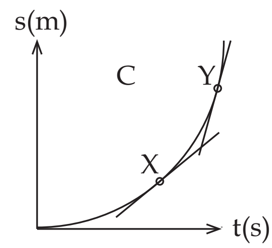
Graph A shows two objects moving at constant positive velocity (constant slope) (i) indicates a high positive velocity and (ii) shows a lower positive velocity.



Graph B also shows a constant velocity but here the displacement is getting less with time. In other words the object is moving towards the observer (a negative gradient).



In graph C the displacement is increasing in a non-uniform way i.e. the velocity is increasing with time. This indicates an accelerating body because the gradient (velocity) at point Y is greater than that at point X.



Example 1

A boy jogs home from school - a distance of 2.40 km, in 15.0 minutes. Calculate his average speed a) in km h^{-1} b) m s^{-1}

Solution 1

Description	Marks
$v = \frac{s}{t}$	1
$= \frac{2.40}{0.25}$	1
= 9.60 km h^{-1}	1
Total	3

b) To change km to m multiply by 1000 and to change per hour to per second divide by 3600 so overall dividing km h^{-1} by 3.6 will convert to m s^{-1}: 9.60/3.60 = 2.67 m s^{-1}

Example 2

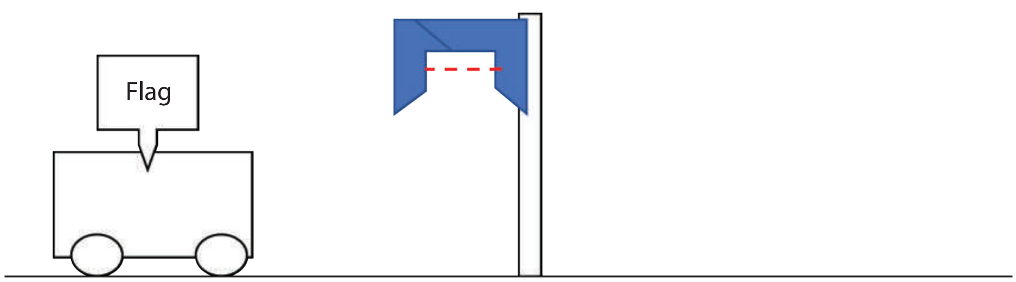
In travelling to Geraldton, a car driver records his speeds and times: 60 km h^{-1} for 1.5 h; 80 km h^{-1} for 2.0 h then 100 km h^{-1} for 2.5 h. What was the driver's average speed?

Solution 2

Description	Marks
s = v.t	1
= (60 × 1.5) + (80 × 2) + (100 × 2.5)	1
= 500 km	1
v_{ave} = s/t = 500/ (1.50 + 2.00 + 2.50)	1
= 83.7 km h^{-1}	1
Total	5

4.2 The Photogate

A photogate is a device that can calculate the speed of an object by measuring the time that an object moves through the gate.



A flag can be placed on a dynamics cart that can then block a laser beam as it passes through the gate. By measuring the time the beam is split, and knowing the length of the flag, the speed can be determined as s = vt.

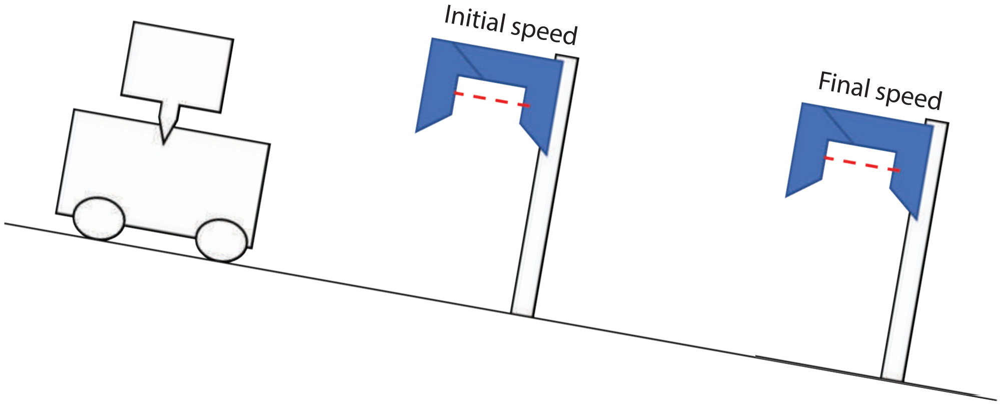
Eg: If an 8.00 cm flag splits the beam for a time of 0.0750 s, then

v = s/t

= 0.08 / 0.0750

= 107 cm s^{-1} = 1.07 m s^{-1}

By having multiple photogates along the track, we can analyse the motion of a moving object.


Initial speed
Final speed

Uniform Motion Quiz

1. A mosquito travels 2.40 m in 0.800 s. What is the average speed of the insect?

2. A Ford car won the first world speed record in 1904. It covered a distance of 1.60 km (one mile) in 40.0s.

   a) What was its speed in km h^{-1}?,

   b) in m s^{-1}?

   c) Assuming constant speed, how long was it from the start until it reached the 1.00 km mark?

3. In warming up, an athlete runs the first 200 m in 32.5 s, then sprints the last 100 m in 12.5 s. What was the average speed of the athlete over the whole distance?

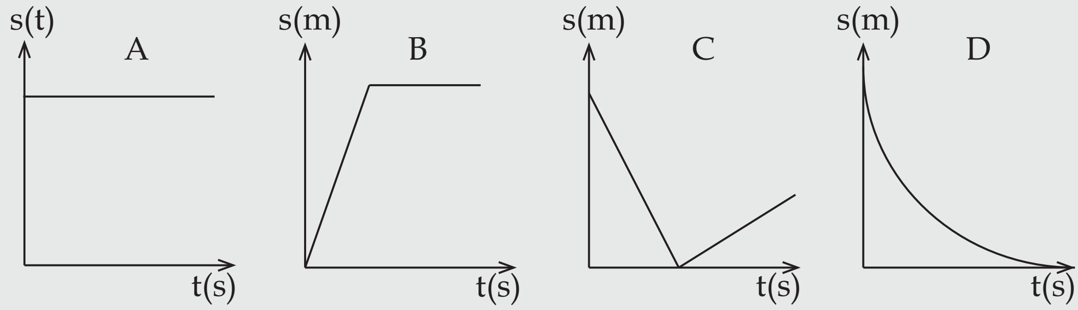
4. A train travels for 1.00 hour at 75.0 km h^{-1} then slows to 60.0 km h^{-1} for ½ hour and finally for a time at 40.0 km h^{-1}. If the average speed of the train for the journey was 55.0 km h^{-1} for how long did it travel at 40.0 km h^{-1}?

5. Jason can only run at a speed of 5.00 m s^{-1} and so John gives him a 2.00 minute start. After the 2.00 minutes John starts running after Jason at a speed of 7.00 m s^{-1}.

   a) How long will it be before John catches Jason?

   b) How far from the start will John catch Jason?

6.



For each of the s/t graphs above explain what kind of motion of the object is represented.

A ______________________________

B ______________________________

C ______________________________

D ______________________________

7. The Prospector train from Kalgoorlie has a length of 320 m and goes past a repair-man of the track at Merriden at a speed of 108 km h^{-1}.

a) How long does the train take to pass the man?

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b) A naughty boy throws an apple core forwards out of the train at a speed of 3.50 m s^{-1}. With what speed does the apple core hit the track?

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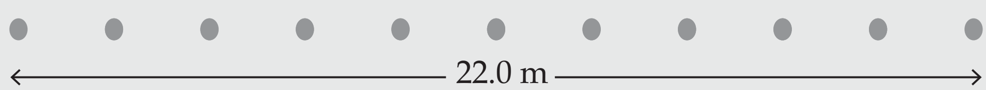
8.



A painter walks along a pavement at a speed of 1.50 m s^{-1} holding a leaking 1 litre tin of paint. A photograph shows that, in a space of 22.0 m, there were 11 spots of paint on the ground. If the rate of loss of paint from the tin is constant, how long will it take to lose the whole litre of paint from the tin if each paint spot contains 0.3 mL of paint?

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4.3 Accelerated motion

For objects and bodies undergoing uniform acceleration, a series of equations (sometimes called *suvat*) can be derived to describe the motion. The following equations can be derived, given that the area under a velocity time graph provides the displacement of the object.

Given:

s = displacement (m)

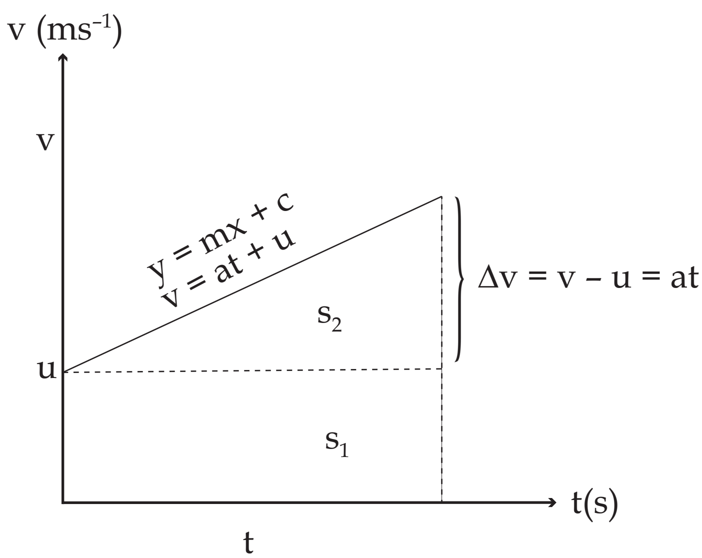
u = initial velocity (m s^{-1})

v = final velocity (m s^{-1})

a = acceleration (m s^{-2})

t = time (s)

Consider an object accelerating from an initial velocity “u” to a final velocity “v” in a time “t”.



By analysing the linear equation, the motion can be expressed as:

$v = u + at$ $\quad a = \frac{v - u}{t}$ (the gradient of the graph)

$u = v - at$ $\quad t = \frac{v - u}{a}$

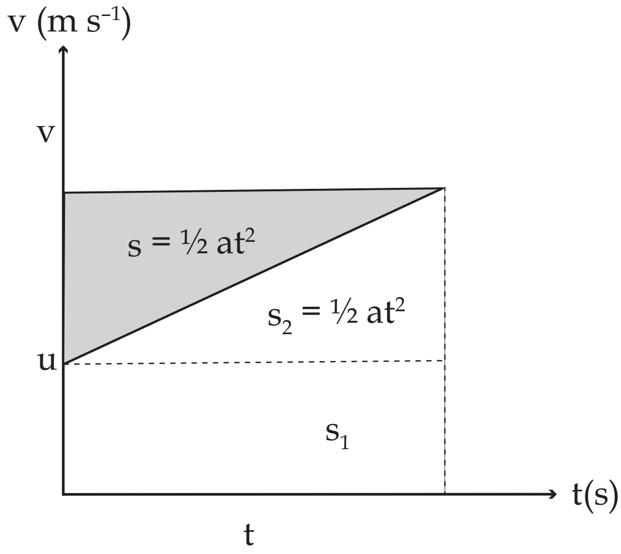
The area underneath the V–T graph can be expressed as:

$s = s_1 + s_2$

$= ut + \frac{1}{2} t (v - u)$ $\quad$ given $v - u = at$

$= ut + \frac{1}{2} t(at)$

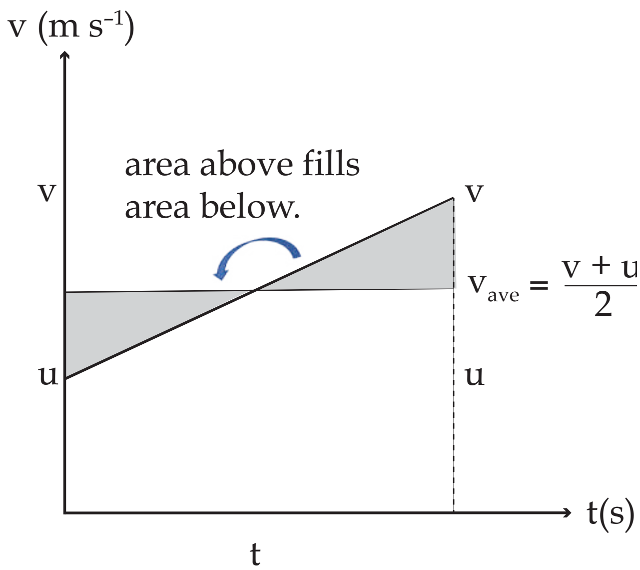
$= ut + \frac{1}{2}at^2$



Due to similar triangles, the area under the V-T graph could be considered to be vt subtracted the triangle that is not under the function. Hence:

$s = vt - \frac{1}{2}at^2$

Finally, we can slice the area mid-way along the vertical (average velocity) such that the area above the average velocity "fills" the area below. We can now obtain two more sets of equations.



$$t = \frac{v - u}{a}$$

$$v_{ave} = \frac{s}{t} = \frac{v + u}{2} \quad \text{and} \quad s = \frac{v + u}{2} \times \frac{v - u}{a} = \frac{(v + u)(v - u)}{2a} = \frac{v^2 - u^2}{2a}$$

We can now group the equations into 5 families:

$v = u + at$ $u = v - at$	$a = \frac{v - u}{t}$ $t = \frac{v - u}{a}$	Does not require "s"

$s = ut + \frac{1}{2}at^2$	Does not require "v"

$s = vt - \frac{1}{2}at^2$	Does not require "u"

$v^2 = u^2 + 2as$	Does not require "t"
$\frac{s}{t} = \frac{v + u}{2}$	Does not require "a"

Given there are 5 variables involved, knowledge of these families of equations will be helpful when you are given only 3 variables and asked to solve for another; there will always be an equation to select to solve directly.

Also, given 4 variables, there will often be multiple equations that will enable you to solve. In this case, familiarisation of the equations will allow you to select the easiest equation to solve.

Example 3

A car accelerates from rest to 22.0 m s^{-1} with an acceleration of 4.00 m s^{-2} over a time of 5.50 s

$u = 0$

$v = 22.0$

$a = 4$

$t = 5.50$

$s = ?$

Solution 3

1. $s = ut + ½at^2$
   $= 0(5.5) + ½(4)(5.5)^2$
   $= 60.5$ m

2. $s = \frac{v + u}{2}.t$
   $= \frac{(22 + 0)5.5}{2}$
   $= 60.5$ m

3. $s = \frac{v^2 - u^2}{2a}$
   $= \frac{22^2 - 0^2}{2(4)}$
   $= 60.5$ m

4. $s = vt - ½at^2$
   $= 22(5.5) - ½(4)(5.5)^2$
   $= 60.5$ m

Example 4

A ball approaches an inclined ramp with a speed of 2.30 m s^{-1}. It is seen to travel 1.55 m up the ramp before coming to rest.

a) Assuming a constant acceleration, calculate the time taken to come to rest.

Solution 4

Description	Marks
$s = \frac{v + u}{2}.t$	1
$1.55 = \frac{0 + 2.30}{2}$	1
$t = 1.35$ s	1
Total	3

b) Calculate the acceleration of the ball as it is on the ramp.

Description	Marks
$v^2 = u^2 + 2as$, $a = \frac{v^2 + u^2}{2m}$	1
$= \frac{0^2 - (2.30^2)}{2(1.55)}$	1
$= 1.71$ m s^{-2} down the incline.	1
Total	3

Acceleration due to gravity

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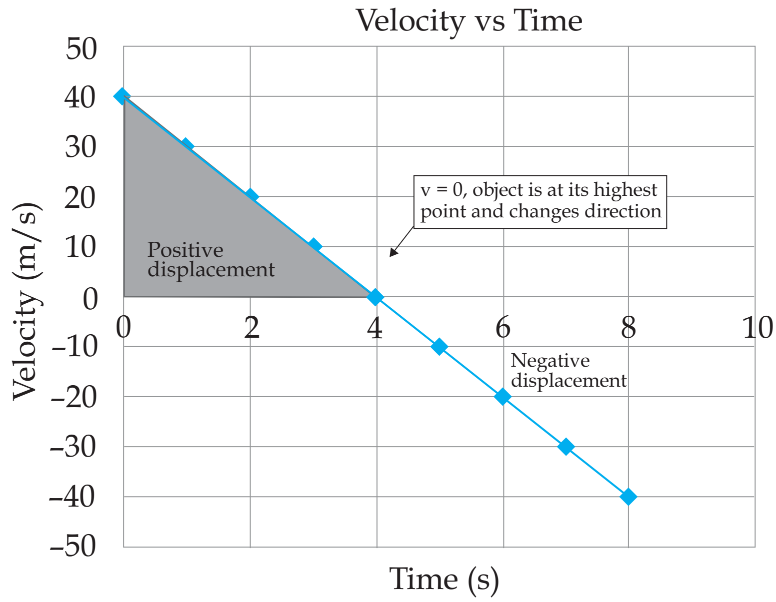
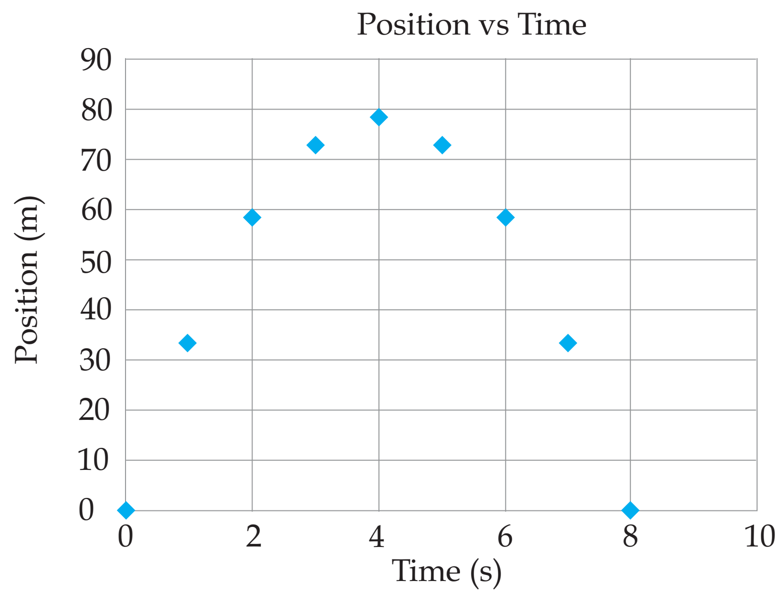
If we look at the gradient of a V-T of an object falling to earth we see that the velocity changes at a constant rate. This rate is known and the acceleration due to gravity.

$g = -9.80 \text{ m s}^{-2}$

If we plot the motion of an object that was fired upward:

Time (s)	Velocity (m/s)
0	+39.2
1	+29.4
2	+19.6
3	+9.8
4	0
5	-9.8
6	-19.6
7	-29.4
8	-39.2





We can use the equations of motion to determine the displacement and velocity at any time throughout the flight:

$v(t) = u + at$ $\quad v(5.00) = +39.2 + (-9.80)(5.00)$

$\quad = -9.80 \text{ m s}^{-1}$

$s(t) = ut + \frac{1}{2}at^2$ $\quad s(5.00) = +39.2(5.00) + \frac{1}{2}(-9.80)(5.00)^2$

$\quad = +73.5 \text{ m}$

In order to find the maximum height reached, we can use the fact that the velocity is zero at that height.

$$s = \frac{v^2 - u^2}{2a} = \frac{0^2 - 39.2^2}{2(-9.80)} = 78.4 \text{ m}$$

The time taken to reach this maximum height can also be determined knowing the final velocity is zero.

$$t = \frac{v - u}{a} = \frac{0 - 39.2}{-9.80} = 4.00 \text{ s}$$

Solving for the time taken to hit the ground s = 0 is a little more complicated but still achievable knowing that the displacement equation is a quadratic and the trajectory of the object is a parabola.

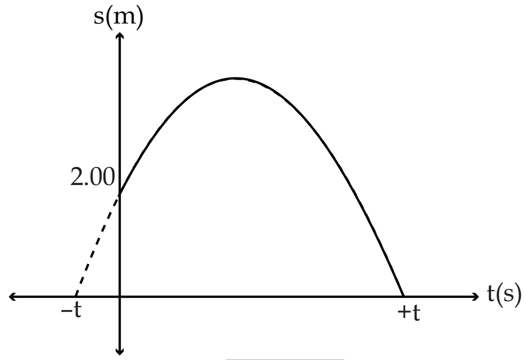
$s = ut + \frac{1}{2}at^2$ could be written as $s(t) = \frac{1}{2}at^2 + ut + s_i$

$$y(x) = ax^2 + bx + c$$

Consider an object that is thrown from a 2.00 m high balcony with a velocity of 3.00 m s^{-1} upwards.

We could set the y-intercept as 2.00 m. The formula for the displacement of the object can now be modelled as:

$$s(t) = -4.9t^2 + 3t + 2$$



Given the quadratic solution: $x = \frac{-b \pm \sqrt{(b^2 - 4ac}}{2a}$, we can solve for the x-intercept; the time that the object is at the ground.

$$t = \frac{-3 \pm \sqrt{(3^2 - 4(-4.9)(2)}}{2(-4.9)} = \frac{-3 \pm 6.94}{9.8} = 0.984 \text{ or } -0.402$$

Obviously, the trajectory only exists in the +s and +t quadrant so the negative time can be disregarded.

You might notice also that the discriminant "$\sqrt{b^2 - 4ac}$" is simply the velocity on impact $v = \sqrt{u^2 + 2as}$

And then the rest of the quadratic solution is simply $t = \frac{v - u}{a}$.

The quadratic solution is simply one suvat equation substituted into another:

$$t = \frac{-u \pm \sqrt{u^2 - 2as}}{a}.$$

Students that are wary of the quadratic solution will simply find the final velocity first:

$$v = \sqrt{u^2 + 2as} = \sqrt{3.00^2 + 2(-9.80)(-2.00)} = \pm 6.94 \text{ m s}^{-1}$$

and then use a different suvat equation:

$$t = \frac{v - u}{a} = \frac{-6.94 - 3.00}{-9.80} = 0.984 \text{ s}$$

Example 5

It is always said that cats land on their feet. A cat is perched on top of a 1.83 m fence when it falls off. Calculate the time the cat has to arrange its feet correctly before hitting the ground.

Solution 5

Description	Marks
$s = ut + \frac{1}{2}at^2$ set $u = 0$, $t = \sqrt{\frac{2s}{a}}$	1
$= \sqrt{\frac{2(-1.83)}{-9.8}}$	1
$= 0.611$ s	1
Total	3

Example 6

A gardener has adjusted a water hose nozzle for a hard stream of water. She points the nozzle vertically upwards at a height of 1.70 m above the ground. When the nozzle is quickly moved off the vertical, the water is observed to remain striking the ground next to her for 2.30 s.

(a) Calculate the speed that the water leaves the nozzle.

Solution 6

Description	Marks
$s = ut + \frac{1}{2}at^2 + s_i$	1
$-1.70 = u(2.30) + (\frac{1}{2})(-9.8)(2.30)^2$ $24.2 = 2.30u$	1
$u = +10.5$ m s^{-1}	1
Total	3

(b) Calculate the maximum height the water travels above the ground.

Description	Marks
$v^2 = u^2 + 2as$, $s = \frac{v^2 - u^2}{2a}$ set $v = 0$	1
$s = \frac{0 - (10.5^2)}{-19.6} + 1.67$ $= 5.63 + 1.67$	1
$= 7.33$ m	1
Total	3

Accelerated Motion Quiz

1. A ball rolls down an incline and reaches a velocity of 0.800 m s^{-1} in a time of 0.500 s. What is its acceleration?

2. A biker, speeding along at 40.0 km h^{-1}, slams on her brakes and decelerates to 10.0 km h^{-1} in 1.40 s. What was her average acceleration?

3. An object thrown vertically upwards, slows down at a rate of 9.80 m s^{-2}. If it leaves the hand at a velocity of 15.0 m s^{-1}, how long will it take to reach the top of its flight?

4. A ball is hit vertically upwards at 11.0 m s^{-1}. How long will it be before its velocity is 2.00 m s^{-1} upwards?

5. What is the velocity is an object moving if it is thrown downwards and, after 2.00 s falling, it has reached a speed of 30.0 m s^{-1}? (Remember: $g = 9.80$ m s^{-2})

6. Mei Lin can accelerate her bicycle from rest at 0.767 m s^{-2}. How far will she have travelled by the time she achieves a speed of 7.00 m s^{-1}?

7. A sailor rowed out from the shore from rest in his boat with an acceleration of 0.110 m s^{-2}. What speed would be reached after travelling 30.0 m to his yacht anchored off the shore?

8. Michael was driving to the local delicatessen when a dog jumped out onto the road 40.0 m in front of his car. Being dazzled by the car's headlights, it stopped, staring at the oncoming vehicle. It took Michael 0.150 s before he applied the brakes that slowed the car from 16.5 m s^{-1} to zero with a deceleration of 3.85 m s^{-2}. Michael managed to stop the car before it struck the dog. By how far did he miss the dog?

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9. A shunting train pulls out of a station with an acceleration of 0.750 m s^{-2}, which it maintains for 1.00 minute, and then it remains at a constant speed for 2.5 minutes. The train is then brought to a stop by the brakes in 30.0 s. Sketch a v/t graph and calculate:

   a) The maximum velocity of the train

   b) The deceleration in the last 30.0 s

   c) The average speed of the train over the whole journey.

10. A pellet hits a block of putty and is stopped in 0.150 s and buries itself to a depth of 22.0 mm,

    a) What is the pellet's acceleration?

    b) At what velocity did it hit the wooden block (Hint: sub in for u to produce another equation)

11. A diver enters the water at a velocity of 9.00 m s^{-1} and stops moving after a time of 1.80 s.

    a) What is her acceleration?

    b) How far below the water is she when she stops moving?

12. A car travelling at 20.0 m s^{-1} is slowed down by the brakes at an intersection at a rate of 1.50 m s^{-2} for 6.00 s. Over what distance does the braking take place?

13. A drag car accelerates from rest over a 1.00 km so that it completes the distance in 9.80 s. What is the car's acceleration and its final speed?

14. A motorcyclist travelling at 60.0 km h^{-1} sees a pedestrian standing on a crossing 50.0 m away. The reaction time of the motorcyclist is 0.200 s and his stopping time is 4.00 s at a deceleration rate of 4.20 m s^{-2}. Does the motorcyclist hit the pedestrian?

15. A car-driver, moving at 8.00 m s^{-1}, watches the traffic lights, which are 60.0 m ahead, change from green to amber and so accelerates at a rate of 1.60 m s^{-2} for a time of 5.00 s before maintaining constant speed.

a) Does he make it to the lights before they change to red 5.00 seconds later?

b) What is the car's speed as he goes through the lights?

16. A girl long-distance runner is coming into the home straight of the race with 100 m to go before the finish line. She is moving at 5.00 m s^{-1} at this time and decides to sprint the last 100 m which she does with an acceleration of 0.400 m s^{-2}.

a) How long does it take for her to reach the finish line?

b) At what speed does she pass the finish line 100 m ahead?

17. A balloonist 1200 m above the ground is taking photos when he drops the camera from the gondola.

a) If the balloon is ascending at a speed of 3.50 m s^{-1} when the camera is dropped, with what velocity does the camera hit the ground?

b) How long does it take for the camera to hit the ground?

18. A pole-vaulter just clears a pole height of 5.25 m and falls onto the mat, which is 0.750 m off the ground.

    a) With what velocity does he hit the mat?

    b) If the mat compresses up to a minimum thickness of 0.050 m when the athlete hits it, what is the man's acceleration as he hits the mat and slows?

19. An archer on the wall of a castle 35.0 m up fires an arrow at a speed of 55.0 m s^{-1} up into the air so that it rises and then comes down into the ground below.

    a) What maximum height does the arrow reach

    b) How long does the arrow take to reach the ground?

    c) With what speed does the arrow strike the ground?

20. *(Hard question)* A camel called Ahmed leaves from a farm accelerating at 1.30 m s^{-2} for 1.92 s, then moves at constant speed for the rest of the journey. Another camel called Ali leaves the same farm 52.5 seconds after Ahmed with an acceleration of 1.45 m s^{-2} for 2.84 seconds and then then moves at constant speed for the rest of the journey. How long will it be before the Ali catches up to the Ahmed and how far away will he be?

21. *(Hard question)* A woman decides to put on her lipstick in the lift, which is travelling upwards with a velocity of 2.50 m s^{-1} and an acceleration of 1.25 m s^{-2}. She drops the lipstick from her bag, which is 1.20 m above the lift floor.

    a) How long does it take for the lipstick to hit the floor?

    b) With what relative velocity does the lipstick strike the lift floor?

4.4 Vectors and Scalars

In physics there are 2 types of quantities: scalars and vectors. With scalar quantities a direction does not need to be specified and addition is done algebraically (simple addition, taking account of the + or – sign).

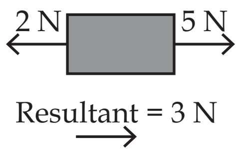
Scalar quantities include: volume, mass, distance, speed.

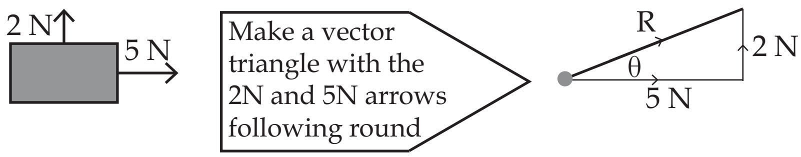
Addition of scalars: 2 kg + 5 kg = 7 kg. 7 litres – 3 litres = 4 litres.

Adding vectors

With vector quantities, direction must always be specified as this type of addition always produces a sum (resultant R) that depends on the direction of each vector present. Vector quantities include: force, displacement, velocity and momentum.

Vectors are added by constructing a triangle from the vector diagram. e.g. This method is known as the 'tail to top' vector addition. Place the tail of the next vector on the top of the vector preceding it. The resultant vector 'R' is then a new vector pointing from start to finish.

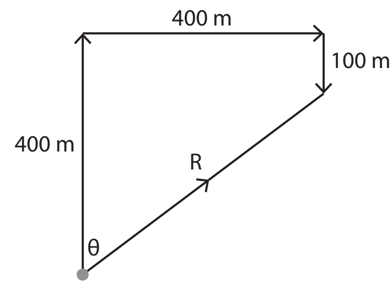




$R^2 = 2^2 + 5^2$ So R = 5.39 N and tan $\theta = 2/5$ so $\theta = 21.8^o$

Example 7

A man walks around a park, firstly 400 m north in 7 min, then 400 m east for 7 min, then 100 m south for 2 min 40 s to a drinking fountain.



a) What total distance did the man walk?

b) What is the displacement of the drinking fountain from his starting position?

c) What is the man's average speed for the walk?

d) What is the man's average velocity for the walk?

Solution 7(a)

Description	**Marks**
Scalar addition 400 + 400 + 100	1
= 900 m	1
Total	2

Solution 7(b)

Description	**Marks**
Draw a scale diagram	1
Resultant displacement R is given by $R^2 = 300^2 + 400^2$ So R = 500 m at an angle θ	1
Tan θ = 4/3 so θ = N 53.1° E	1
Total	3

Solution 7(c)

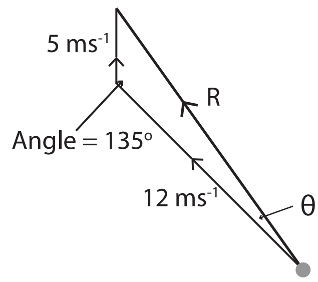
Description	**Marks**
Total time taken = 16 min 40 s = 1000 s	1
Scalar speed = d/t	1
= 900/1000	1
= 0.9 ms^{-1}	1
Total	4

Solution 7(d)

Description	**Marks**
Displacement has symbol 's'. Vector velocity = s/t	1
= 500/1000	1
= 0.5 ms^{-1} at N 53.1° E	1
Total	3

Example 8

A bird can fly at 5.00 m s^{-1} in still air but tries to fly due north with a wind coming from the south-east at 12.0 m s^{-1}. Find the bird's resultant velocity with the wind blowing.



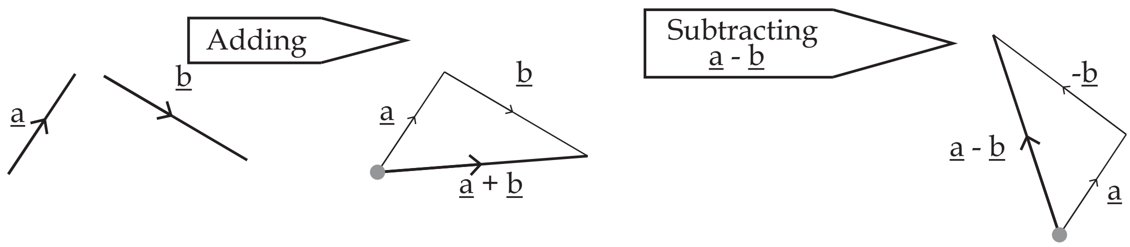
Solution 8

Description	Marks
$R^2 = 5^2 + 12^2 - 2 \times 5 \times 12\cos 135$ R = 15.9 m s^{-1}	1
To find θ the sine rule must be used: R/sin135 = 5/sin θ	1
Sin θ = 5sin135/15.9 = 0.2219 so θ = 12.83°	1
So R is at 45 – 12.83° from the north = 32.2° west of north	1
Total	4

<u>Subtracting vectors</u>

Whenever a vector changes from one value to another to find the change we need to subtract vectors. The value of the change = final vector – initial vector.

Subtracting vector b from a is the same as adding 'negative b' to a. This often helps visualising the vector subtraction by adding 'negative b'.

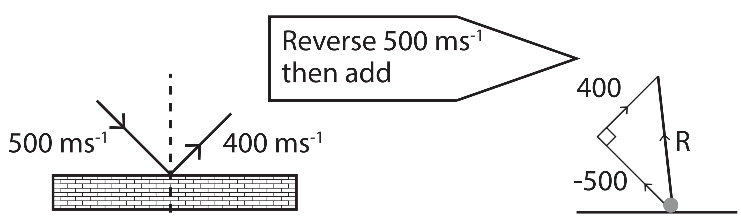


You can see in the vector subtraction diagram above; -b was added to a. The resultant is now a – b.

Example 9

A bullet moving at 500 m s^{-1} strikes a wall at 45° and bounces off at 45° at a speed of 400 m s^{-1}. Find the bullet's change in velocity.

Solution 9



The change in velocity (Δv) = $v_{final} - v_{initial}$.

Description	Marks
$R^2 = 400^2 + 500^2$ R = Δv = 640 m s^{-1}	1
tanθ = 400/500 So θ = 38.7°	1
Direction of Δv = 45 + 38.7 = 83.7° to wall.	1
Total	3

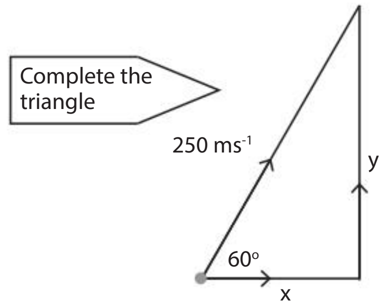
4.5 Components

The magnitude of a vector that acts in one particular direction is called its component in that direction. The horizontal and vertical components of a vector can be found by calculating the other 2 sides of the vector triangle.

Example 10

A rocket is fired at 60° to the horizontal and a speed of 250 m s^{-1}. How fast is it moving along the ground and how fast is it rising vertically?

Solution 10



Description	Marks
cos 60 = x/250 So x = 250 cos 60 = 125 ms^{-1}	1
sin 60 = y/250 So y = 250 sin 60 = 217 ms^{-1}	1
Total	2

The horizontal component of the rocket = 125 m s^{-1}; vertical component = 217 m s^{-1}

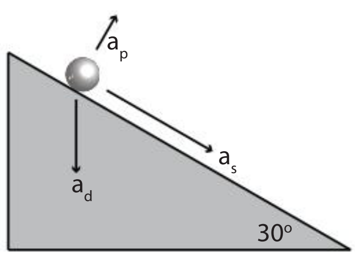
Vectors can also be resolved into components that are parallel to an incline and perpendicular. In this case, given parallel and perpendicular are at right angles, a right angle triangle can be constructed with one side length and one angle known.

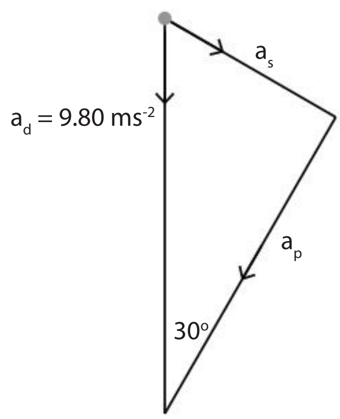
Example 11

A ball falling under gravity will accelerate downwards at 9.80 m s^{-2}, but what will be its acceleration down a slope of 30.0°?

Solution 11

Construct a vector diagram to find the components of a_d down the slope and perpendicular to the slope.





Description	Marks
a_s = 9.80sin30.0 = 4.90 m s^{-2}	1
a_p = 9.80cos30.0 = 8.49 m s^{-2}	1
Total	2

Vectors Quiz

1. Two ice skaters hold one arm of a third skater and each pulls with a force of 200.0 N. What is the resultant force pulling the third ice skater forward if the angle between his arms is a right angle?

2. A swimmer can achieve a speed of 1.50 m s^{-1} in still water. She heads directly across a rip in which the water is moving at a velocity of 3.50 m s^{-1} West. What is her resultant velocity?

3. An aeroplane is flying due south with a velocity of 500 km h^{-1} whilst a wind is blowing from the west with a velocity of 180 km h^{-1}. What is the aeroplane's resultant velocity and direction of flight?

4. An archer stretches a bow so the strings make angles of 38.0° to the arrow. If the string tension is 220 N, what force is exerted on the arrow at the time of release?

5. A car is travelling northwest at a speed of 35.0 m s^{-1} when a man throws a can out of the window at a speed of 10.0 m s^{-1} at right angles to the car.

   a) What is the resultant velocity of the can relative to the ground?

   b) If the can lands after 2.50 s, how far has it travelled from the point of projection?

6. A canoeist can paddle at a speed of 2.50 m s^{-1} in still water but wants to cross a stream where a 2.00 m s^{-1} current flows.

   a) What would his resultant velocity be if he heads directly across the stream at top speed?

   b) The stream is 40.0 m wide. How far downstream would he land on the opposite bank?

   c) At what angle to the bank must he point his canoe if he wants to land on the other bank directly opposite where he started?

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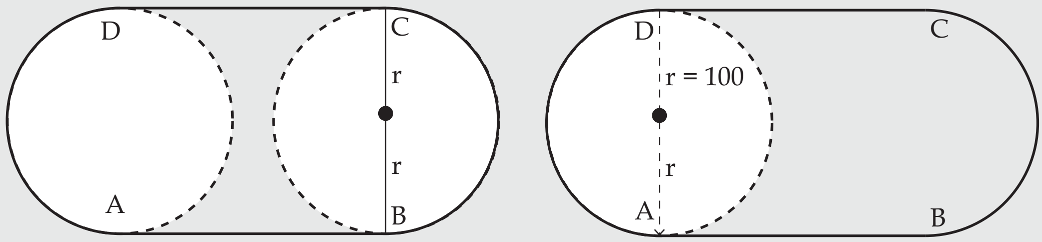
7. A bullet travelling at 400 m s^{-1} hits the outer surface of a tank at an angle of 35.0° and then rebounds at 35.0° with a velocity of 250 m s^{-1}. What is the change in velocity of the bullet?

8. A girl is part of a 400 m relay team where each girl (A, B, C, D) has to run 100 m before handing over the baton. Girl A runs her 100 m leg in 12.5 s then hands the baton to girl B who runs 100 m round the bend in 12.1 s. Unfortunately, girl C drops the baton at her position just as it is being handed over.



Calculate

a) The displacement of girl C at the start from girl A,

b) The average speed of girls A and B up to the point where the baton was dropped

c) The average velocity of girls A and B up to the point where the baton was dropped

9. An archer fires an arrow with a velocity of 35.0 m s^{-1} at an angle of 20.0° to the horizontal. What is the velocity of the arrow horizontally along the ground?

10. Rachel reaches a constant speed of 36.0 km h^{-1} while sliding down a water slide inclined at an angle of 30.0° to the horizontal. How long does she take to descend a vertical height of 12.0 m once she reaches this speed?

11. A powerboat tows a water skier. The skier is skiing well to the side of the boat, but is travelling in the same direction as the boat. The rope tension is 250 N and the rope makes an angle of 45.0° to the direction of travel of both boat and skier. What minimum force must the skier apply to the water to maintain this path?

12. In a football game a player kicks the ball west at a constant horizontal speed of 15.0 m s^{-1} directly towards a team-mate who is 40.0 m away. There is a wind blowing across the pitch from the south at 10.0 m s^{-1}.

a) How much time does the team-mate have to get into position to catch the ball?

b) How far does the team-mate have to run in a northerly direction to catch the ball?

13. A woman doing gardening is pulling a 100 kg roller across the lawn to flatten the grass. She pulls the roller handle with a force of 350 N at an angle of 17.0° to the horizontal. With what force is the roller being pulled in the forward direction, parallel to the ground?

14. A boy of mass 68.0 kg stands on his 2.00 kg skateboard on a hill that is sloped at 8.00° to the horizontal. What is the magnitude of total weight of the boy and skateboard acting down the hill?

15. A fighter jet is moving at 1600 km h^{-1} and at an angle of 12.0° to the horizontal downwards. If the jet releases a bomb at the same constant speed while it is 5300 m above the ground, how far horizontally along the ground will the bomb land from the initial position of the plane?

4.6 Newton's Laws of Motion


Sir Isaac Newton

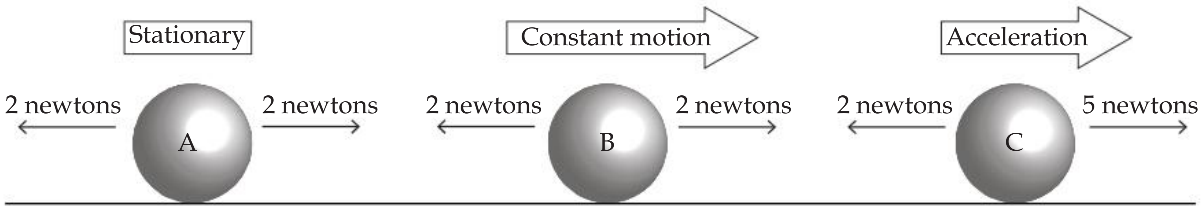
Inertia is the ability of an object to "stay doing what it is doing" which is linked to its mass. i.e. a moving car has a large inertia because, when the brakes are applied in the rain, the car carries on moving. If the same car is stationary then it is difficult to start it moving because, again, of its inertia. On the other hand, a fly is so hard to catch because it has so little inertia: it can change its direction more easily to avoid capture because it has such a small mass.

The property of an object that is linked to inertia we call Mass: the ability of an object to stay doing what it is doing at the moment (could be described as "laziness"). Mass is measured in kilograms.

4.7 Newton's Laws

Newton's First Law of motion states:

Any object in a state of rest or uniform motion will remain so unless acted upon by an unbalanced force.



Ball A has forces on it but they balance each other out so the object remains in its stationary state.

Ball B is moving but the forces on it are also balanced, so the ball will continue on at its original velocity.

Ball C can start off as stationary or moving but it will accelerate because it has a net force acting on it to the right of 3 newtons.

A one newton force will accelerate a one kilogram mass at a rate of 1 metre per second every second.

Newton realised that any mass is attracted to any other mass by the Gravitational force. The weight of an object is the pull of Earth's mass on it – measured in newtons.

Newton's Second Law states:

The rate of change of momentum of an object equals the force acting on it

As seen above, any unbalanced force acting on an object will make it accelerate.

A more common form of the 2nd law is that the net force on an object equals the product of mass multiplied by the acceleration.

$$\Sigma F = ma$$

Newton's Third Law states:

For every action there is an equal and opposite reaction.

If a cricket bat hits a ball, the force forwards on the ball must equal the force backwards on the bat. Because the ball has less mass, the forward force will produce a larger acceleration on the ball than the backward acceleration on the more massive bat.

When a man pushes up from the ground (the earth) the man rises and the earth recoils because the forces are equal and opposite but this force will have far less effect on the earth because of its large mass (about 10^{24} kg). It may look like there is only one force on the man because we cannot see the Earth recoiling, but these two forces must be equal, according to the 3rd Law.

4.8 Special Forces

Because all objects on Earth accelerate at a rate of 9.80 metres per second squared, the weight force (F_g) of any object on Earth will be its mass multiplied by 9.80 (i.e. w = mg). The Moon has a mass of only about 1/6 of the mass of the Earth, so a man with a mass of 80 kg will have a weight of 80 × 9.8 = 784 newtons on the Earth, but his weight on the moon would only be about one sixth of this i.e. 784/6 = 131 N. However, his mass would still remain the same, regardless of the gravitational force acting as the amount of matter the man has is not changed by being on the Moon.

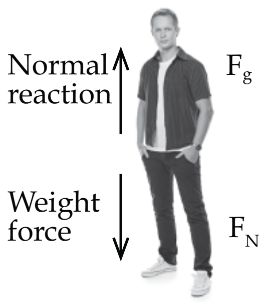
The force of friction (F_F) always acts when two surfaces are in contact. Whichever way an object moves the frictional force will always oppose the motion of the object as one surface is dragging on the other.

There are two types of frictional force: Static and Kinetic friction. It is harder to start an object sliding than to keep it moving once it is already moving, so static friction always has a greater value than dynamic friction. ABS brakes on cars work by using sensors on the wheels that start the wheels rolling again once a skid starts. The ABS computer releases the brake again so the wheel is only just turning, keeping the friction at the static value and maintaining a larger braking force. When in operation, the brakes feel like they are vibrating.

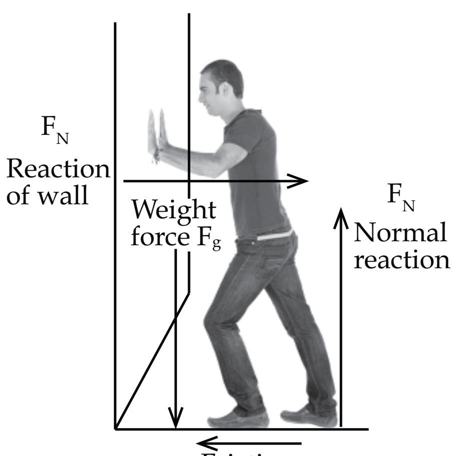
A **reaction** (F_N) force always occurs when one object touches another.

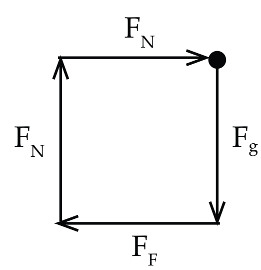
If a man is standing still on the ground there is no acceleration, therefore there can be no net force acting on him, according to the 1st Law. His weight force down must be counteracted by an equal, opposite, force upwards to bring him into equilibrium.

This is called the Normal Reaction Force.



If the man leans against a wall and is in equilibrium, then, again all the forces must balance out in all directions– in a vector diagram. The normal reaction force equals the man's weight and the reaction force from the wall must equal the frictional force on the ground from the man's feet.



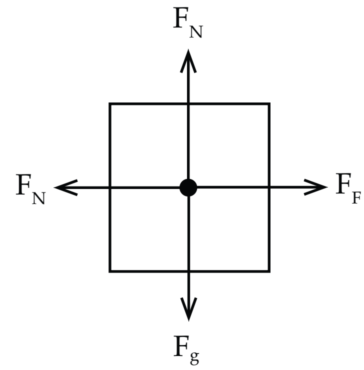


Be careful to know the distinction between a Vector Diagram and a Free Body Diagram. A Vector diagram adds the vectors 'tail to top' to determine the resultant (if any).

i.e: Vector Diagram

Whereas in a Free Body Diagram, the object is drawn as a box and labelled scaled vectors point outwards from the centre to indicate their direction.

i.e: Free Body Diagram



Newton's Laws Quiz

1. A car of mass 1000 kg accelerates from the lights with an acceleration of 2.50 m s^{-2}. What was the net force exerted by the engine?

2. Jane pulls an elastic band holding a paper pellet back with a force of 3.00 newtons.

   a) If the pellet has a mass of 5.00 grams, what is its acceleration?

   b) If the pellet was accelerated for a time of 20.0 milliseconds what was the maximum velocity it reached?

3. Roger has a book as a present for his wife on the back seat of his car. He pulls up sharply to avoid a cyclist and finds that the book hits the back of his seat. Explain this.

4. A model rocket can accelerate at a rate of 500 m s^{-2}. If the rocket motor exerts a force of 60.0 N, what is the mass of the model rocket?

5. A tennis player's racquet exerts a force of 120 N on a tennis ball of mass 120 g.

   a) What acceleration is produced on the ball?

   b) If the time of contact of the racquet with the ball was 55.0 milliseconds, with what speed did the ball leave the racquet?

6. A car of mass 1200 kg is stopped by its brakes with an acceleration of – 25.0 m s^{-2}.

   a) Calculate the stopping force exerted by the brakes.

b) In what distance will it stop from a speed of 100 km h^{-1} ?

7. Rifles that fire high velocity bullets need to have quite a high mass for safety. Explain why this is so.

8. A rocket of mass 5200 kg has an acceleration of 150 m s^{-2} when leaving Earth.

a) What force is being exerted by the rocket engine?

b) How does the acceleration of the rocket vary with time? Explain.

9. A meteor of mass 105 kg hits the Earth and decelerates from 250 m s^{-1} to zero in a distance of 30.0 cm. What is the retarding force exerted by the Earth?

10. A 75.0 kg man slides down a rope which will break if the force on it exceeds a value of 680 N. Find the least value of the acceleration downwards that the man can have without breaking the rope.

11. When a fielder in cricket catches a fast-moving ball he always pulls his hands backwards after the ball enters his hands. Explain this move.

12. A woman walks with her 25.0 kg case into a lift. The lift first accelerates upwards at a rate of 2.00 ms^{-2} to a velocity of 8.00 m s^{-1} which is maintained for 20.0 s and then the lift decelerates at 3.00 m s^{-2} to stop at the 10th floor. What is the tensile force in the woman's arm:

a) During the initial acceleration?

b) While the lift is moving at 8 m s^{-1}?

c) When the lift is decelerating?

13. Emily is skiing on a slope in the Victorian ski fields where the slope is 17°. Her mass is 60 kg and at one point she is moving downhill at a constant speed. Calculate the value of the dynamic frictional force of the snow on the skis at this point in time.

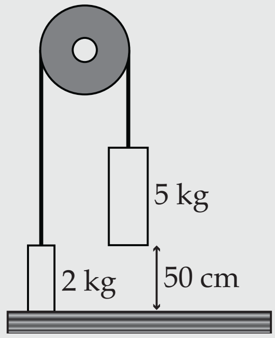
14. The catapult launching aid system on an aircraft carrier is a mechanical device that accelerates jet fighters across the deck up to take-off speed in quite a short distance. A jet has a mass of 900 kg and needs to achieve a take-off speed greater than 220 km h^{-1}. This is achieved with a catapult system capable of pulling the jet with a force of 15.0 kN. With these requirements, what would be the acceleration of the plane and the minimum distance along the deck needed for a successful take-off?

15. A truck of mass 2700 kg is towing a trailer which contains rubble with a total mass of 1300 kg. If the engine is supplying a force of 8000 N, calculate the tension force in the tow-bar.

16. In a game of baseball the most successful hitters hit the ball and "follow through" with the bat in the direction of the ball. Why do they do this?

17. A bullet of mass 10.0 g, moving at a velocity of 150 m s^{-1} hits a block of wood and is stopped in a time of 50.0 ms. What force acts on the block as the bullet slows?

18. A string has two weights attached to it and placed over a frictionless pulley, as shown.

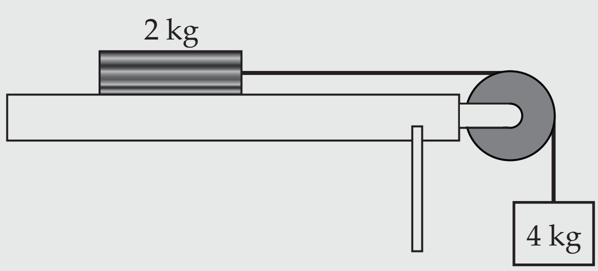


a) What will the acceleration of the 5.00 kg weight be?

b) What will be the tension in the string as it falls?

c) If the 5.00 kg mass starts from rest at a point 50.0 cm above the table, how long will it take before it hits it?

19. A 4.00 kg weight is used to accelerate a 2.00 kg block of wood on a table, as shown in the diagram. The 4.00 kg weight is attached to a string on a pulley at the end of a bench with no frictional force from the bench.



a) Calculate the acceleration of the wooden block.

b) Calculate the tension in the string.

4.9 Momentum

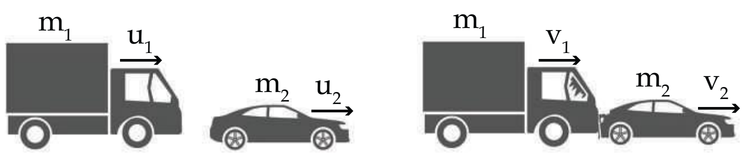
Newton did a study of objects that collided with each other and noted that a quantity associated with the objects, called momentum, was important for the subsequent motion.

He defined momentum (p) by:

$$\text{Momentum} = \text{mass} \times \text{velocity}$$
$$p = mv$$

In experiments he noticed that in all cases the sum of momentum remained constant i.e. Total momentum before the collision = Total momentum after the collision

So, for instance, if one car hits another from behind the total momentum of the system of 2 cars will be the same after the collision as it was before. The truck on the left, moving at a velocity of u_1 crashes into the car on the right travelling slower at u_2. After the collision, if the truck is then moving at v_1 and the car at v_2:



For the momentum of the system to be conserved: $\mathbf{m_1 \times u_1 + m_2 \times u_2 = m_1 \times v_1 + m_2 \times v_2}$

Suppose the truck's mass is 1300 kg with a velocity of 20.0 m s^{-1} before the collision and 13 m s^{-1} after the collision. And the car's mass is 1100 kg with a velocity of 15 m s^{-1} before the collision.

To calculate the velocity of the car after the collision:

Σ p before = (1300 × 20) + (1100 × 15) = 42500 kg m s^{-1}
Σ p after = (1300 × 13) + (1100 × v_2) = 16900 + 1100v_2
Hence the car's final velocity = 23.3 m s^{-1}

Example 12

A shotgun of mass 1.25 kg fires a cartridge with shot of mass 30.0 g so the shot leaves the barrel at a speed of 150 m s^{-1}. With what velocity does the gun recoil?

Solution 12

Description	Marks
ΣMomenta before collision = zero ΣMomenta after = (0.03 × 150) + 1.25v	1
Momentum is conserved So 4.5 + 1.25 v = 0	1
hence v = -3.6 m s^{-1} (negative indicates backward direction)	1
Total	3

Example 13

A 120 kg rugby player moves at 5.00 m s^{-1} and collides with a stationary player of mass 80.0 kg. What is their combined velocity after the collision?

Solution 13

Description	Marks
Before collision: p_1 = 120 × 5 = 600 kg m s^{-1}	1
After collision: p_2 = (120 + 80) × v_2 = 200v_2	1
So v_2 = 600/200 = 3 m s^{-1}	1
Total	3

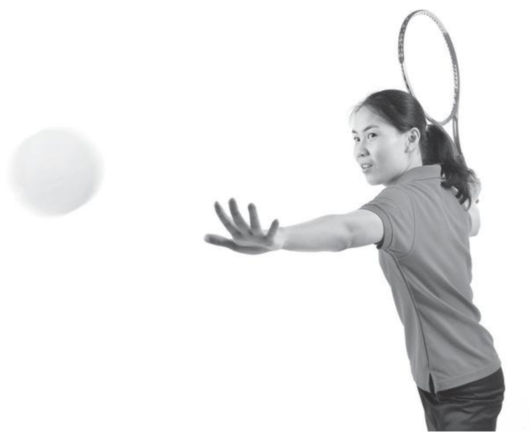
Elastic Collisions are ones where all the kinetic energy is conserved – these can only occur where colliding objects do not actually touch (magnets, atoms). All collisions in the "big" world involve a conversion of kinetic energy into heat during the collision. We know that low speed atomic collisions are always elastic because a sealed cylinder of gas will maintain its pressure indefinitely. If KE were lost, the pressure would decrease with time as the speed of the molecules decreased.

4.10 Impulse

Whenever a collision occurs a force acts on each object colliding for a certain time. The force on each is the same, according to Newton's 3rd Law. The force acting multiplied by the time over which it acts is called the Impulse of the force.

$$\mathbf{I = F\Delta t}$$

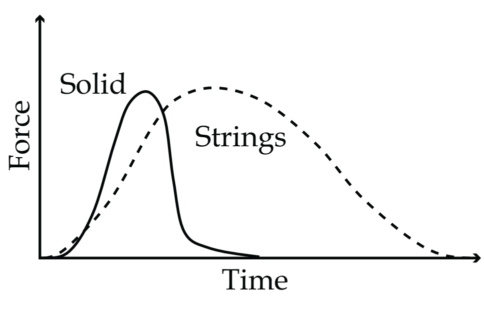
If we take the example of a tennis racquet hitting a ball: the harder the player hits the ball the more impulse is given and the faster the ball will rebound - but the time of contact is also important. By making the racquet strings of a stretchy material then the force is applied for a longer time, which gives more impulse and a larger momentum change to the ball.



By Newton's 2nd Law: $F = \Delta p/\Delta t$ so $F \times \Delta t = \Delta p$

This means that impulse is equal to momentum change – they have the same value.

Suppose we had one racquet made of solid wood and another made with stretchy strings. If the ball was hit with each racquet, using the same force, then the force/time graphs for each would look as shown below. The larger impulse given by the stringed racquet would equate to more momentum change and therefore a greater final velocity.



A measure of force × time is the area under the graph, because the String's area is larger, this indicates more impulse and therefore more momentum change

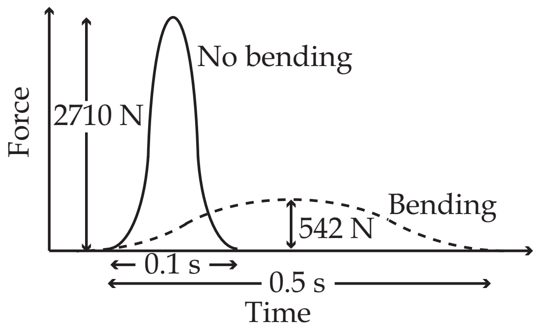
4.11 Safety devices

Devices made to prevent injury from impact all involve trying to decrease the force acting by extending the time of contact. If a 50.0 kg person jumps from a desk 1.50 m high and lands onto the floor the change in momentum change in momentum will be $\Delta p = mv - mu = -mu$.

Using $v^2 = u^2 + 2as$, the impact velocity will be 5.42 m s^{-1} and Δp = 271 kg m s^{-1} which cannot be changed, but the decelerating force on the legs can be changed by bending them to make the momentum change occur over a longer time. For example, with no bending of legs t_1 = 0.100 s and with bending of legs t_2 = 0.500 s, then the rate of change in momentum in each case will be:

F_1 = 271/0.100 = 2710 N and F_2 = 271/0.500 = 542 N = 5 times less force by bending the legs!

Remember: the area under the graph must be the same. So if the base widens, the average force must decrease.



Most safety devices in a car work like this – we cannot do anything about the amount of momentum change occurring but if the time over which it takes place is extended then the force acting becomes less.

It is the force on drivers that injures them! With car safety devices: a seat belt stretches in a crash extending the deceleration time; an airbag also makes the time taken for the body to stop moving considerably longer. Cars are designed with crumple zones that are designed to collapse (are the expense of writing off the car!) in order to increase the time that the impulse acts over.

Example 14

In chopping wood, an axe strikes the block with a force of 55.0 N for a time of 0.150 s.

a) Calculate the impulse that the block received;

b) Calculate the velocity with which the axe struck, if its mass was 0.8 kg.

Solution 14(a)

Description	Marks
Impulse on axe = impulse on wood	1
= Ft = 55 × 0.15	1
= 8.25 N s	1
Total	3

Solution 14(b)

Description	Marks
Impulse = I = mv – mu	1
so 8.25 = 0.8 × Δv	1
so Δv = 10.3 m s^{-1}	1
Total	3

Momentum and Impulse Quiz

1. A tee-ball player with a 1.20 kg bat hits a 0.150 kg ball off the tee. If the bat has a velocity of 18.0 m s^{-1} before, and 11.0 m s^{-1} after hitting the ball, what was the speed with which the ball leaves the tee?

2. A dart of mass 25.0 g is thrown at a dart-board of mass 2.75 kg suspended from the ceiling on strings. If the dart's speed before the collision was 45.0 m s^{-1}, with what velocity did the board recoil?

3. What impulse does Tom's bat produce when it hits a cricket ball and applies a 63.0 N force to the ball over a period of 0.100 s?

4. A gust of wind blowing for 13.0 s acts on a model yacht, changing its momentum by 195 N s in the direction of the force. Calculate the magnitude of the force.

5. A stolen car m, of mass 850 kg, rams a police car M, of mass 1500 kg head-on. Just before the collision the police car is travelling at 65.0 km h^{-1}.
Immediately after they collide and lock together the combined wreckage is calculated to be travelling to the left at 25.0 km h^{-1}.

a) At what speed, in km h^{-1}, is the stolen car travelling just before impact?

b) What energy is converted to heat during the collision?

6. A battleship of mass 20,000 tonnes fires its two 15.0 inch guns forwards while it is steaming forward at 20.0 m s^{-1}. If the shells have a mass of 550 kg each and move at 150 m s^{-1}, by how much does the ship slow down when the shells are fired.

7. During a collision between two cars, a passenger's head strikes the unpadded dashboard with an average force of 48.0 N for 3.00×10^{-3} s. With suitable foam padding, the impact would have lasted 6.00×10^{-2} s. Calculate the average reaction force the padded dashboard would exert.

8. A rocket of mass 1.50 tonne moves forward by ejecting hot gases backwards at a speed of 500 m s^{-1}. If the mass of gas ejected per second is 600 kg what is the forward velocity of the rocket?

9. When parkour athletes land on the ground, they are taught to hit the ground and progressively collapse and roll onto the ground. Explain this.

10. A shopper applies a constant force to a 46.0 kg stationary shopping trolley, accelerating it to a speed of 2.00 m s^{-1} in 8.00 s. Determine the impulse the shopper produces in that time.

11. An open railway truck of mass 2.20 tonne is used in Kalgoorlie to transport gold ore to the refining area. The truck moves under a chute at a velocity of 3.50 m s^{-1} to where the ore is loaded and a load of 4.2 tonne of ore is dumped straight into the truck while it is moving. At what velocity does the truck move after the ore is loaded?

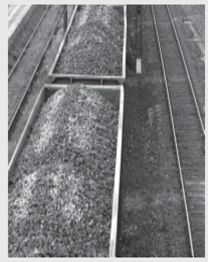
12. A hand-grenade is thrown in an army range at a speed of 15.0 m s^{-1} so it moves horizontally and then explodes. After the explosion one part of the grenade of mass 300 g moves forwards at 450 m s^{-1} and the other 400 g part moves backwards. What is the speed of this part relative to the ground?

13. In the game of netball, players often move quickly and then come to a sudden stop. How does the abrupt nature of the game relate to the knee injuries netball players frequently suffer?

14. Why do car designers put crumple zones at the front of motorcars?

15. In Judo the "Break fall" is used to prevent injury when the body hits the ground. For this the judokas (person) strike the floor with the flat of their hands, as they are about to land on their back. Explain how the Break fall works.

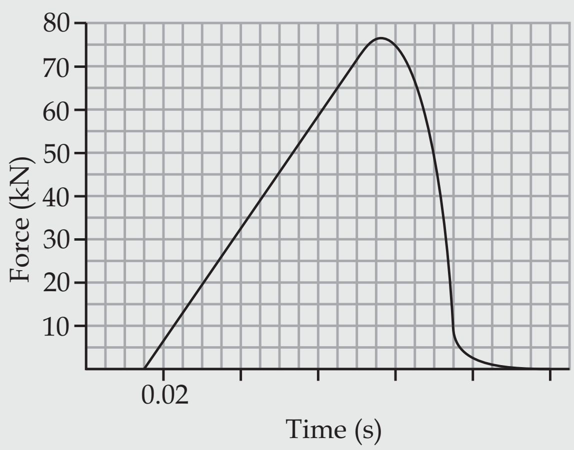
16. A railway coal truck of mass 4.80 tonne and moving at 12.0 m s^{-1} collides with a 15.2 tonne stationary truck on the track and locks together with it. At what speed do the 2 trucks continue moving after the collision?



Show whether the collision is elastic or inelastic.

17. A railway engine pushed a stationary truck to accelerate it to a speed of 6.00 m s^{-1}. The engine then applies an equivalent force over the same time on a second truck to accelerate it from rest to a speed of 8.00 m s^{-1}. The second truck rolls down the track, collides with the first, and the two lock together. The engine must now push the two stationary trucks to the other end of the shunting yard. If the engine applies the same impulse, what speed could the two railway carriages attain?

18. The graph below shows how the force on the bumper of a crash-test car varies as it strikes a wall.



a) From the graph estimate the impulse exerted on the wall by the car.

b) If the car had a mass of 900 kg, at what speed did the car strike the wall?

19. A basketball of mass 400 g is thrown downwards at the ground at 8.50 m s^{-1}. The ball rebounds upwards at a velocity of 8.00 m s^{-1}.

a) What is the change of momentum of the ball?

____

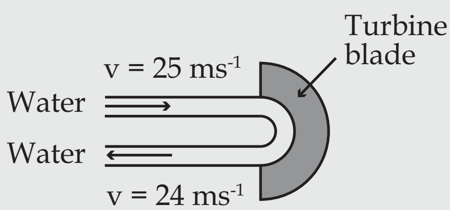
b) If the ball was in contact with the floor for 250 ms, what force was exerted on it?

____

c) This collision seems to contravene Newton's idea that no net momentum change occurs in any collision, as the ball has had a momentum change. Discuss your ideas.

____

20. A jet of water strikes the curved blade of a turbine at a speed of 25.0 m s^{-1} and returns in the opposite direction at 24.0 m s^{-1}. The mass of water striking the blade per second is 41.0 kg.



a) Calculate the force exerted on the single turbine blade by the water

____

b) If the whole turbine comprises 55 blades, each of mass 250.0 g, calculate the acceleration with which the blades recoil under the impact of the water.

____

21. A 90.0 kg man stands at the bow of a rowing boat which is 0.50 m from the jetty and tries to step onto it by moving forwards at a speed of 3.00 m s^{-1} relative to the boat. The boat has a mass of 180 kg but starts to move backwards as the man moves forwards.

a) Explain why the man moves towards the jetty at less than 3.00 m s^{-1}.

____

b) If the man maintains his forward velocity for a period of 0.300 s, determine whether the man can successfully step onto the jetty without falling into the water.

____

4.12 Work

Work is done whenever the point of action of a force is moved through a distance. Examples:

- A weight is lifted against a gravitational force
- One magnet is pulled away from the magnetic force of another magnet
- One negatively charged rod is pushed against the repulsive electrical force of another negative rod.
- A bag of sand is dragged across the ground against a frictional force

In just holding a heavy weight in your hands, no work is done because the force is not moved through any distance!

The amount of work done equals the value of the force multiplied by the distance moved against the force i.e. Units of work are newtons × metres, or joules.

$$W = F \times d$$

Example 15

Calculate the work done by a man who drags a 25.0 kg bag of salt across the pavers against a frictional force of 55.0 N for a distance of 12.0 metres.

Solution 15

Description	Marks
W = F × d	1
= 55 × 12	1
= 660 joules	1
Total	3

Example 16

What work is done by a 45.0 kg girl when she climbs 15.0 m upstairs to bed?

Solution 16

Gravitational force on the girl is mg = 45 × 9.8 = 441 N

Description	Marks
W = F × d	1
= 441 × 15	1
= 66.1 kilojoules	1
Total	3

4.13 Energy

When we say we feel energetic, it means we can do a lot of work.

Energy is a store of work that can be used. In the case of humans, energy is stored in the chemicals contained in our food (e.g. carbohydrates, fats). Apart from chemical energy, work can be stored because of the position of an object e.g. a demolition ball lifted up high can be used to knock down a wall – the ball has stored gravitational potential energy (PE). As it swings and moves fast the PE becomes converted into kinetic energy, or energy of movement.

$$PE = mgh$$

Other ways in which energy can be stored are through: heat energy, sound energy, nuclear energy, electrical energy, electromagnetic energy and elastic.

The Law of conservation of energy states that energy is never created nor destroyed, but only converted from one form to another. In the case of the demolition ball, the chemical energy in the crane's fuel was converted to potential energy of the ball, which became converted to kinetic energy of the ball and then to heat and sound energy as the ball hit the wall. The fuel itself was formed millions of years ago when the Sun's electromagnetic energy (light) caused plants to photosynthesise (store chemical energy as starch) which then became incorporated into the fuel when they fossilised.

Example 17

A sledge hammer of mass 15.0 kg is lifted to a height of 2.20 m above its normal position and then allowed to strike the concrete floor. With what kinetic energy does it collide with the floor?

Solution 17

Description	Marks
Work done = PE stored = mgh	1
= 15 × 9.8 × 2.2	1
= 323.4 J. This is converted to KE. So KE of ball = 6468 J	1
Total	3

For the ball falling through 2.2 m: $v^2 = u^2 + 2as$ So $v^2 = 0 + 2gh$ Or $h = v^2/2g$

If we substitute this into PE = mgh we get $mg(v^2/2g)$ or $½mv^2$ this is the KE gained

KE = $½mv^2$

Example 18

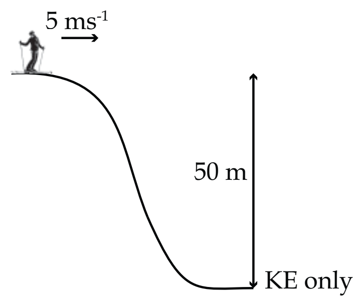
From the previous question, find the velocity with which the ball strikes the wall.

Solution 18

Description	Marks
$mgh = ½mv^2$ (mass cancels out) so $v^2 = 2gh$	1
$v^2 = 2 × 9.8 × 2.2 = 43.12$	1
So v = 6.57 m s^{-1}	1
Total	3

Example 19

A skier moving at 5.00 m s^{-1} comes over a ski slope which is 50.0 m above a valley. What will her speed be when she reaches the bottom?



Solution 19

Description	Marks
Conserving energy: PE + KE at top = PE + KE at bottom	1
$m × 9.8 × 50 + ½m × 5^2 = ½mv^2$ (m cancels throughout) $9.8 × 50 + ½ × 25 = ½v^2$	1
So v = 31.7 m s^{-1}	1
Total	3

Example 20

The floodlights at a local footy pitch run from a hydroelectric generator in the mountains. Outline the energy conversions in this system.

Solution 20

Electromagnetic energy from the sun (visible and infrared rays) evaporates the water on Earth to give it PE. The water is collected in a dam where PE is stored and converted to KE as it runs down tubes to the hydroelectric power station. The turbine turns a dynamo round where the rotational KE is converted to electrical energy. The electrical energy relayed to the footy lights is converted to heat and light in the spotlights.

HEAT ENERGY → POTENTIAL ENERGY → KINETIC ENERGY → KINETIC ENERGY → ELECTRICAL ENERGY → HEAT AND LIGHT

4.14 Power

Two boys, Tom and Jerry, have equal mass of 62.0 kg and run up the school staircase which is 4.20 m above the ground. The work done by each boy against the gravitational force is mgh = 62.0 × 9.80 × 4.20 = 2552 J i.e. they both do the same amount of work. However, Tom runs up in 6.50 seconds while Jerry takes 8.20 seconds.

Each second Tom's body does an amount of work = 2552/6.50 = 393 joules per second while Jerry's body can only do 311 joules of work per second.

We say that Tom is more powerful than Jerry because he can do more work per second. The amount of work done (or energy gained) per second is called power and it is measured in J s^{-1} or Watts (W). Power = the rate of doing work:

$$\boxed{\mathbf{P = W/t}}$$

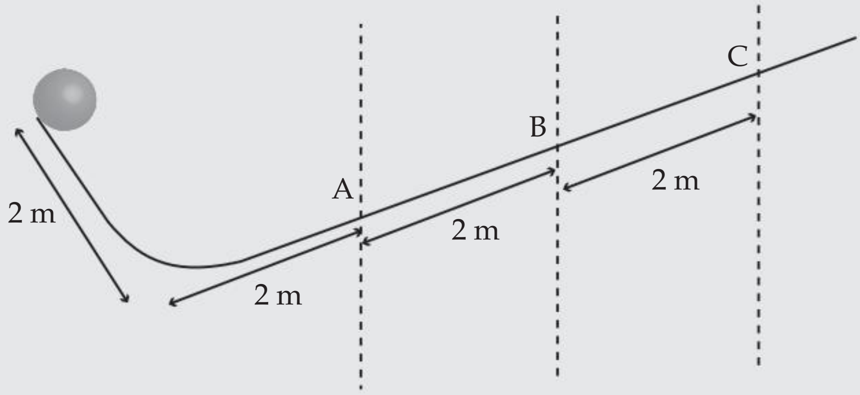
Tom's power output when running upstairs is 393 W, whilst Jerry's is 311 W.

Also: $P = \frac{F \times d}{t}$ but $\frac{d}{t} = v$ so P = F × v – which is another formula that can be used.

e.g. If a car's engine is providing a force of 2.50 kN when it is moving at 16.5 m s^{-1}, so the power developed by the engine is P = Fv = 2500 × 16.5 = 41250 W or 41.25 kW.

Work, Energy and Power Quiz

1.



A heavy iron ball is released from the top of a left-hand ramp so that it moves down and then up the opposite ramp.

a) If friction is negligible, to what position will it rise up the ramp, A, B or C?

___

b) Explain why you gave this answer

___

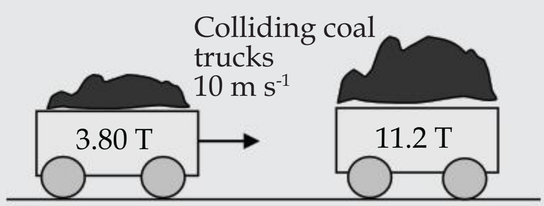
2. In a circus act Bimbo, The Human Cannonball, is fired from the muzzle of a cannon that is angled at 60.0° to the horizontal and sits 3.00 m from the floor.

If Bimbo has a mass of 65.0 kg and leaves the muzzle of the cannon at a velocity of 20.0 m s^{-1} what total energy will his body possess at any time during the flight?

___

___

3. During shunting in a railway yard, one truck of total mass 3.80 tonne and loaded with coal is moving at 10.0 m s^{-1} towards another stationary coal truck of total mass 11.2 tonne. The trucks then lock together and move off down the track.



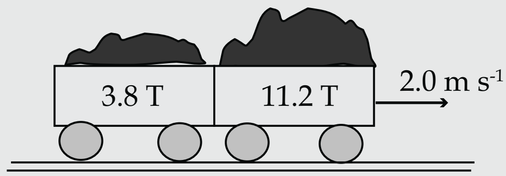
The following statements were proposed by two railway-men about the collision:

i) The kinetic energy of the first truck becomes evenly distributed between the two trucks
ii) The momentum lost by the first truck equals the momentum gained by the second truck
iii) There is no momentum change by either truck
iv) The sum of the momenta of both trucks remains the same

Which of the preceding statements are correct?

A. i) and ii) B. ii) and iii) C. i) and iii) D. ii) and iv)

4. At a later stage the joined trucks referred to in the last question (Q. 3) are moving together at a speed of 2.00 m s^{-1} when the linesman decides to bring them to a halt. If the brakes can exert a total force on the wheels of 500 N,



a) In what distance would the trucks stop?

____

b) How much heat would be generated in the brakes?

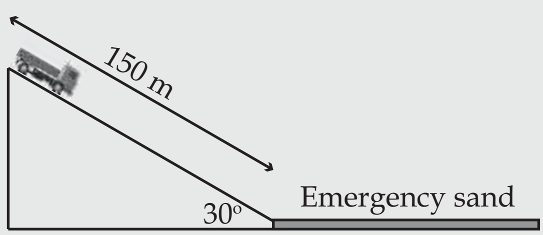
____

5. A large aeroplane landing on a runway puts its brakes on so that it stops in 270 m. If the mass of the plane is 27.0 tonnes and its landing speed is 160 km h^{-1}, how much heat is dissipated in the brakes when stopping?

____

____

6. A truck driver on the top of a hill lets his hand brake off in neutral gear so that his truck drifts 150 m down the hill to a level road. Near to the bottom he realises that he cannot stop and will need to use the emergency slip road track at the bottom filled with sand.



The distance down the hill from the top is 150 m and it has a slope of 30.0° What is the speed of the truck down the slope as it hits the sand?

____

____

7. In the last question (Q. 6) the sand has a resistive force of 100 kN against the wheels of the truck which has a mass of 5.50 tonnes. What would be the distance the truck travels in the sand before it stops?

____

____

8. A mother puts her whistling kettle on the gas stove. When steam starts to come out of the spout the loud whistle makes her young son ask what was happening. What would be the correct energy conversions occurring?

A. Kinetic energy → heat energy → potential energy → sound energy
B. Chemical energy → potential energy → heat energy → sound energy
C. Heat energy → kinetic energy → mechanical energy → sound energy
D. Chemical energy → heat energy → kinetic energy → sound energy

9. An athletic physics student of mass 65.0 kg runs up a flight of 52 stairs in a time of 9.20 s. If each stair is 22.0 cm high, what power is the student developing in his legs whilst running?

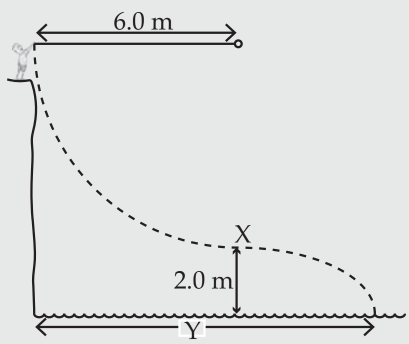
10. A hammer of mass 220 g is moving at speed of 15.0 m s^{-1} when it strikes a nail in the wall which is driven in at a speed of 2.00 m s^{-1}.

a) What is the change in kinetic energy of the hammer?

b) If all the change in KE went in heating up the 30.0 gram nail, calculate the temperature rise of the nail (SHC of iron = 440 J kg^{-1} K^{-1}).

11. A prototype car was found to have a mass of 1500 kg and could accelerate at 6.80 m s^{-2}. During trials it was accelerated for a time of 7.20 s to measure the power output of the engine. From these figures, calculate the average power output of the car over the 7.20 seconds.

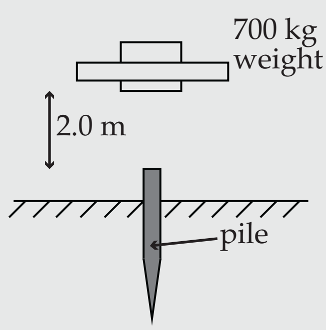
12. Harry decides to swing on a rope attached to a tree branch and into the river. The rope is 6.00 m long and at the point where he lets go he is 2.00 m above the water. From energy considerations, find out



a) What his velocity is at point X,

b) The distance Y he lands in the water from the bank.

13. A pile-driver consists of a 700 kg steel weight which is raised 2.00 m above the pile, then dropped onto it to drive it into the ground.



a) If the pile has a mass of 1200 kg, what velocity will it have immediately after the raised weight has hit it? (assume the pile and weight move down together)

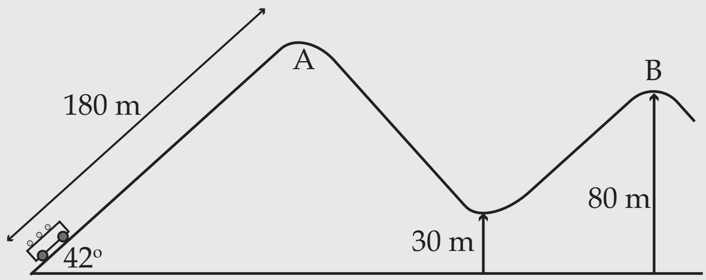
b) If the resistance of the ground on the pile is 30.0 kN how far into the ground does the pile move?

____

c) What work is done by the pile in penetrating the ground?

____

14. A roller coaster is constructed so that in the first ramp the truck is pulled up a slope of 420 for a distance of 180 m. If the truck and the passengers have a mass of 950 kg,



a) What work is done in pulling the truck up the first slope?

____

____

The roller coaster truck is then allowed to fall from the top of the ramp (A) down then up to point B which is 80.0 m from the ground.

b) Find the velocity of the truck at point B if 10% of the potential energy gained at A is converted to heat along the track.

____

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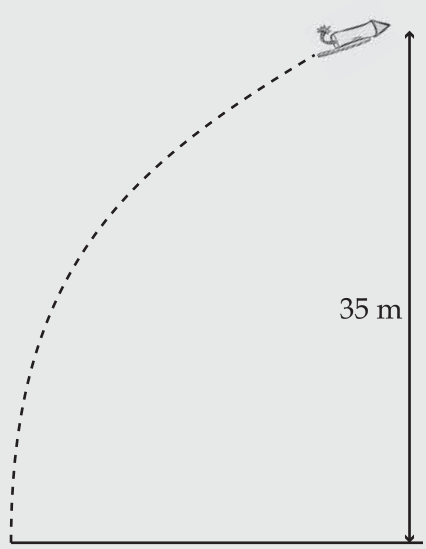
____

____

15. The solid fuel in a particular solid fuel firework rocket has an energy value of 400 J g^{-1}. In reaching its maximum height the 300 g rocket uses its 0.400 g packet of fuel and reaches a vertical height of 35.0 m. What will the speed of the rocket be at its maximum height?



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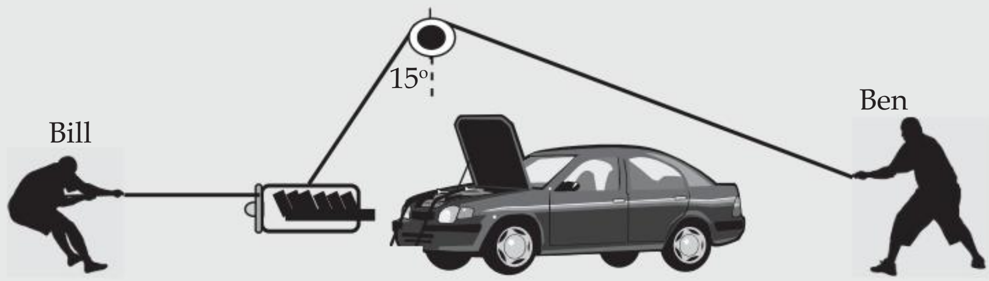
16.



To raise a 550 kg car engine out of the chassis, Ben lifts it with a pulley system while Bill pulls it sideways by another rope so it clears the body. The diagram above shows an instant when Ben's top rope is at an angle of 15.0° to the vertical and Bill's rope is horizontal.

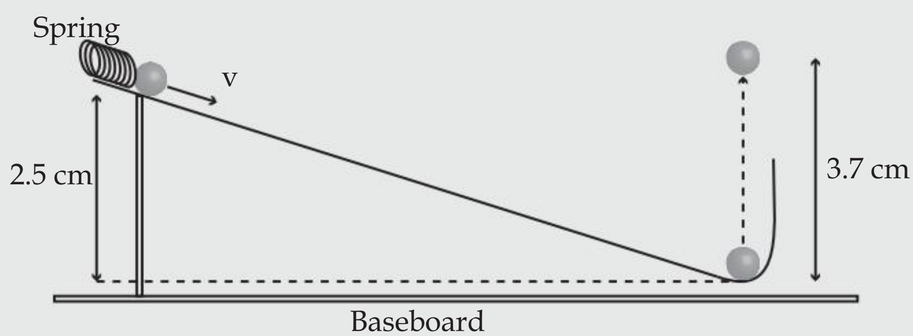
a) If Bill pulls the engine sideways onto the bench through a horizontal distance of 45.0 cm what work has he done? (Assume the angle to vertical remains constant).

____

b) If Bill takes 15.0 seconds to pull the engine, what power was used in his muscles?

____

17. In a pin-ball machine a ball 25.0 cm high is projected down a sloping track with a bend at the end which sends the ball vertically upwards. After the ball is fired down the slope it rises vertically to a height of 3.70 cm above the baseboard.

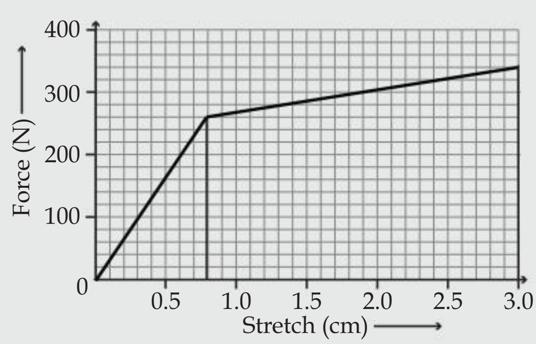


From energy considerations, what speed must the ball have had when it was projected downwards from the spring at the top of the slope?

____

____

18. The graph shows how the tensile force on a safety belt holding a crash-test dummy varies with stretch during a simulated crash. Use the graph to estimate the work done in stretching the belt and hence the energy stored in a crash.



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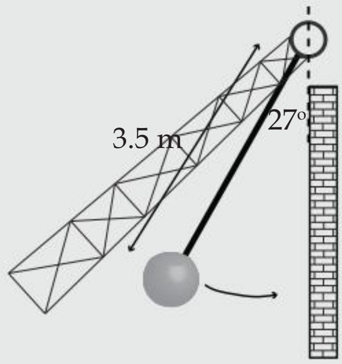
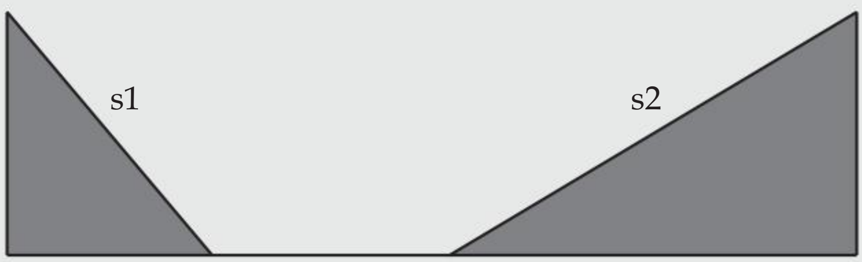
19. An electric motor of rating 23.0 kW is used to raise a lift in a skyscraper 255 m high. If the lift has a mass of 800 kg and it takes 2.00 minutes for the lift to travel from bottom to top, calculate the % efficiency of the electric motor.

20. A 500 kg wrecking ball on a crane is used to smash a wall down. The cable holding the ball is 3.50 m long and it is found that the minimum angle to which the ball must be raised to break the wall is 27.0°.

Calculate the work that must be done to break the wall



21. Two balls, each of 1.00 kg are allowed to roll down different slopes of the same height.



s_1 = 6 m. s_2 = 4 m **PLEASE CHECK.**

L1 = 5.20 m L2 = 2.64 m

Motion Test 1

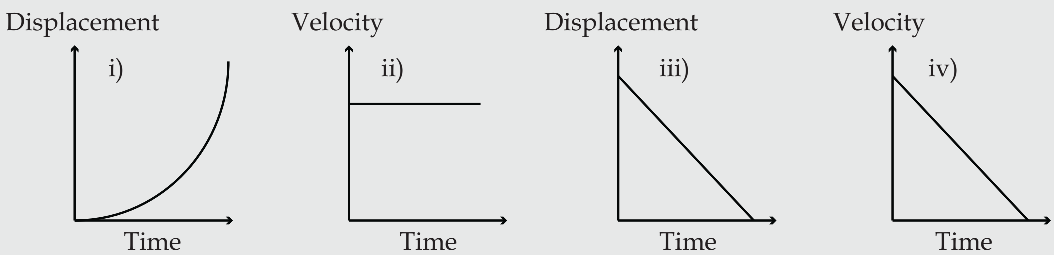
(Take $g = 9.80\ m\ s^{-2}$; $3.60\ km\ h^{-1} = 1.00\ m\ s^{-1}$; Ticker time – 0.02 s per dot)

Section A Multiple Choice **[10 marks]**

1. A man drives his car for 30 minutes on a major road at 70 km h^{-1} and into the country. He then stops for 30 minutes for a tea break then travels North on a country road for 1½ hours at a speed of 110 km h^{-1} to complete his journey. The man's average speed over the whole journey is about:

A. 106 km h^{-1} B. 91 km h^{-1} C. 80 km h^{-1} D. 87 km h^{-1}

2. Which of the following graphs applies for an accelerating object?



A. i), ii), iii) B. i), iv) C. iii), iv) D. i), iii), iv)

3. A man's cap falls off his head onto the ground. Assuming zero air resistance, an estimate of the time before it hits the ground will be about:

A. 0.2 s B. 0.4 s C. 0.6 s D. 0.8 s

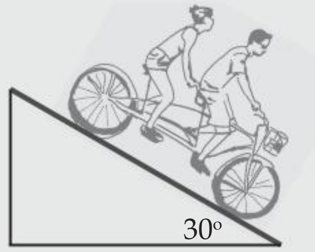
4. A boy leaning out of his top-floor window one day accidentally knocks a flowerpot from the windowsill and he hears the sound of the crash 2.5 s later. The boy can use this time to calculate the height of his windowsill above the ground. What is the approximate height of the windowsill above the ground?

A. 25 m B. 30 m C. 35 m D. 40 m

5. In the last question the boy realizes that in using the v/t calculations for height (h) he has neglected the effect of air resistance and also the time it took for the sound to travel to his ear. A better value for h could be obtained by allowing for the following:

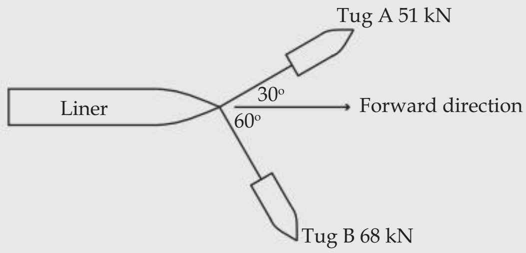
	Allowing for the speed of sound	Allowing for air resistance
A	True time should be shorter than measured, true h would be smaller	True time should be longer than measured, true h would be larger
B	True time should be longer than measured, true h would be smaller	True time should be shorter than measured, true h would be larger
C	True time should be shorter than measured, true h would be smaller	True time should be shorter than measured, true h would be smaller
D	True time should be longer than measured, true h would be larger	True time should be shorter than measured, true h would be smaller

6. Jill and Ben are on their tandem bike and start to accelerate down a ramp with a slope of 30.0° to the horizontal. Gravitational acceleration acts vertically downwards, neglecting friction, the two people on the tandem bicycle will have an acceleration down the hill of about:



A. 9.80 m s^{-2} B. 8.50 m s^{-2} C. 4.90 m s^{-2} D. 5.70 ms^{-2}

7. Two tugs are pulling a large ocean liner out to sea on ropes. Tug A exerts a force of 51.0 kN at an angle of 30.0° to the forward direction and tug B exerts a force of 68.0 kN at angle of 60.0°. The resultant force on the liner due to the tugs is about:



A. 85 kN B. 92 kN C. 119 kN D. 123 kN

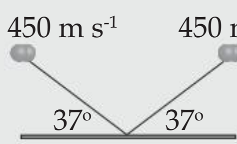
8. Due to the tugs pulling the liner in the last question (Q. 7) the liner will start to move forwards at an angle to the forward direction of about:

A. 53.1° B. 36.8° C. 23.1° D. Zero degrees

9. The catapult launching aid system on an aircraft carrier is a mechanical device that accelerates jet fighters across the deck up to take-off speed in quite a short distance. A jet needs to achieve a take-off speed greater than 198 km h^{-1}. This is achieved with a catapult system which accelerates the jet forwards at a rate of 25.2 m s^{-2}. With these requirements, the minimum distance along the deck needed for a successful take-off would be about:

A. 48 m B. 60 m C. 82 m D. 98 m

10. A molecule of oxygen moving at 450 m s^{-1} strikes the wall of a container at an angle of 370 and rebounds at the same speed.

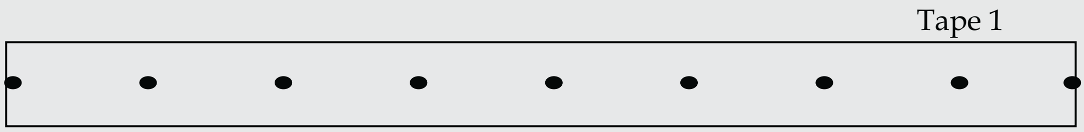


The change in velocity of the molecule is about:

A. 720 m s^{-1} at 0° B. 670 m s^{-1} at 90° C. 540 m s^{-1} at 90° D. Zero

Section B Longer Questions **[Total 40 marks]**

1. The complete ticker tape shown was attached to an object falling from a bench.



a) What can you tell about the motion of this object? [1 mark]

____

b) How long did the object take to fall? [1 mark]

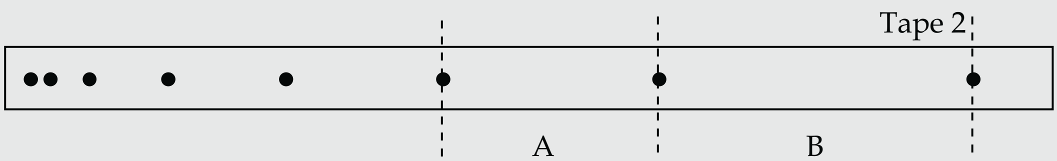
____

c) What was the average speed of the object? [2 marks]

____

____

d) By measuring lengths A and B on tape 2, calculate the velocities of each section



Velocity over length A = _____________ m s^{-1} [1 mark]

Velocity over length B = _____________ m s^{-1} [1 mark]

e) Calculate the acceleration between section A and B below. [4 marks]

____

____

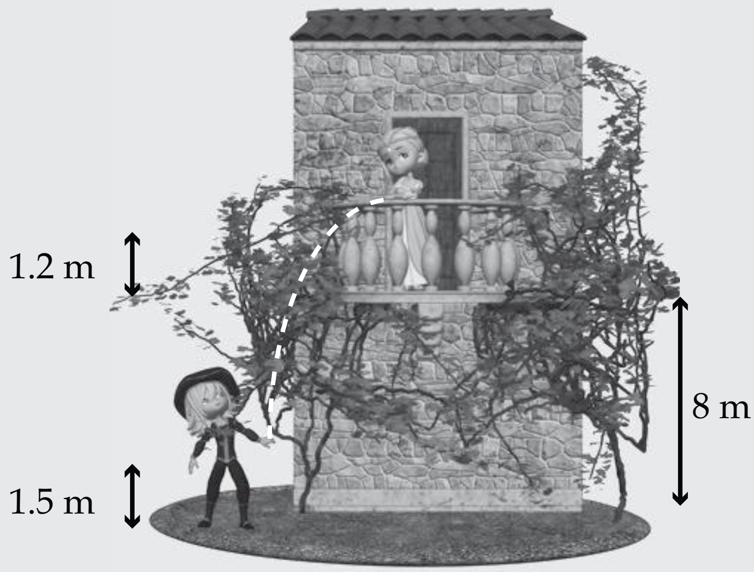
2. Celia can swim at a maximum speed of 2.50 km h^{-1} in still water and wants to swim across a stream which is 30.0 m wide and whose water moves towards the west at a speed of 6.00 km h^{-1}. She heads northwards across the stream at her maximum speed.

a) Draw a vector diagram to calculate her actual resultant velocity and angle of movement across the stream [4 marks]

b) How long does she take to cross to the other bank? [2 marks]

c) What is Celia's displacement from the start when she lands? [2 marks]

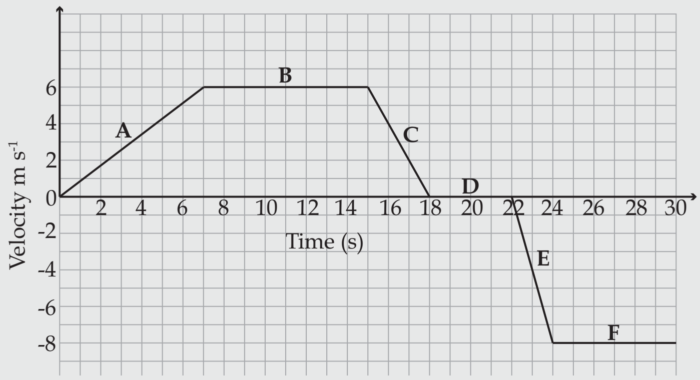
3. Romeo wants to throw a gift up to Juliet who is at her bedroom balcony 8.00 m above on the bottom floor of her house. Romeo throws from his hand 1.50 m above the ground to the horizontal. On his third attempt he just manages to get the gift to go over the parapet of the balcony, which is 1.20 m high.



a) At what speed does he need to throw the gift for it to land on the balcony? [4 marks]

b) If Romeo had thrown the gift at an angle of 75.00° to the ground at 5.00 m s^{-1}, at what speed would the object be moving in a vertical direction? [2 marks]

4. The following graph shows the velocity of a bike rider riding down her street from home over a total time of 30.0 seconds



a) Describe the rider's motion over the following sections:

(i) Section A ______________________________

(ii) Section B ______________________________

(iii) Section D ______________________________

(iv) Section E ______________________________ [2 marks]

b) Calculate the rider's initial acceleration [2 marks]

____

____

c) Calculate the distance the rider moved in section B [2 marks]

____

____

d) Calculate the displacement of the rider from home after 30 seconds. [4 marks]

____

____

5. Jordan stands on a bridge and throws his car keys down at a velocity of 5.00 m s^{-1} to his friend Emma, 25.0 m below.

a) With what velocity do the keys hit the ground? [2 marks]

____

____

b) How long do the keys take to hit the ground? [2 marks]

____

____

c) The key-ring has a car alarm remote controller which will break if it strikes the ground at more than 22.5 m s^{-1}. With what maximum velocity must Jordan throw the keys downwards to Emma if the remote is to remain unbroken? [2 marks]

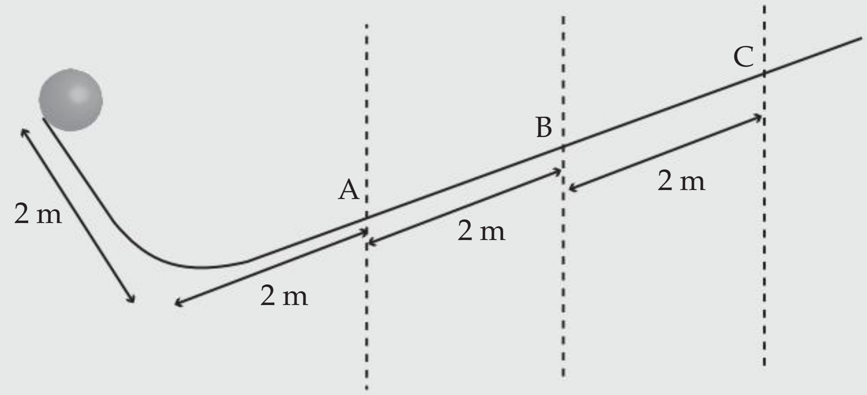
____

____

Motion Test 2

[Total 50 marks]

1.



A heavy iron ball is released from the top of a left-hand ramp so that it moves down and then up the opposite ramp.

a) If no energy is lost to friction, to what maximum position will it rise to points, A, B or C? [1 mark]

____

b) Explain why you gave this answer [2 marks]

____

____

2. Judo players use a "break-fall" to prevent injury when thrown to the ground. A break-fall involves striking the ground with the hand before the body lands.

a) Explain, in terms of physics, how a break-fall can prevent injury [2 marks]

____

____

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b) Explain why a tennis racquet is able to project a ball at a higher speed than a plain wooden bat of the same size and mass [2 marks]

____

____

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3. a) Explain the difference between an elastic and an inelastic collision occurring between two objects [2 marks]

____

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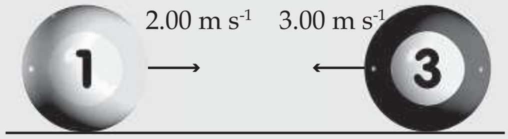
In a game of pool, the red spot ball and yellow spot ball of the same mass collide with the velocities shown in the diagram and carry on moving.



After the collision the red spot ball continues to move in the same direction, but with its velocity reduced to 0.25 m s^{-1}.

b) Calculate the final velocity of the yellow spot ball [3 marks]

____

____

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c) By calculating initial and final kinetic energies, find out if this collision is elastic or inelastic [5 marks]

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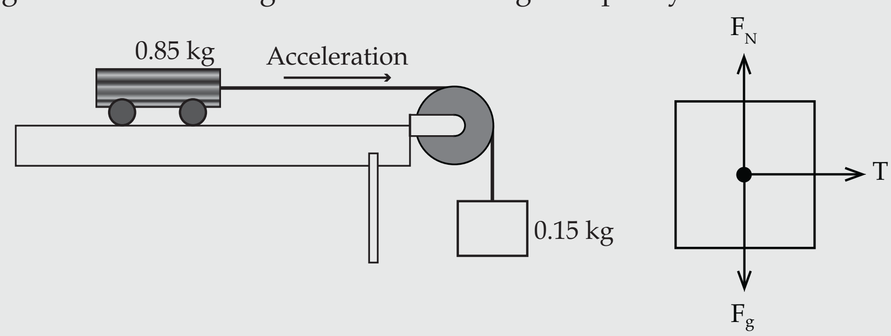
4. A trolley of mass 0.850 kg is accelerated across a frictionless bench by a set of weights of mass 0.150 kg attached to a string on a pulley.



a) In the spaced above draw a free body diagram, showing all the forces on the trolley as it accelerates [3 marks]

b) Calculate the acceleration of the weights and trolley system? [2 marks]

____

____

____

c) Calculate the tension in the string pulling the trolley [2 marks]

____

____

____

____

5. Robin, the weightlifter, is a 120.0 kg muscle-man who likes to train with weights every day. In a competition, Robin lifts an 80.0 kg barbell up onto his chest from the floor.

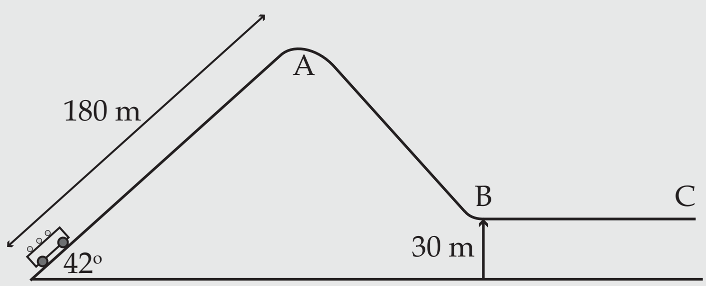
a) What force must Robin's arms exert upwards to hold the barbell on his chest, stationary? [1 mark]

b) When on his chest, the weights are 146 cm above the floor. What potential energy do the weights have in this position? [2 marks]

c) If the lift to his chest took a time of 1.58 s, what power did Robin produce in lifting the weights to his chest? [2 marks]

d) Whilst lifting the 80.0 kg weights up to his chest, the upward force in Robin's arms was 924 N. Calculate the acceleration acting on the weights. [3 marks]

6. A roller coaster is constructed so that in the first ramp the truck is pulled up a slope of 42.0° for a distance of 180 m.



a) If the truck and the passengers have a mass of 950 kg, what work is done in pulling them up the first slope? [3 marks]

b) If the velocity at point A is zero, with what velocity does the truck enter the straight at point B? [3 marks]

c) The truck is now brought to a halt at point C which is 35.0 m from point B. By equating energy and work done, find the force exerted by the brakes in order to stop the truck at C [3 marks]

____

____

____

d) When the truck is lifted up to the top position of the roller coaster a large electric motor is used, rated at 30.0 kW. If the time for the truck to ascend the slope is 44.7 s, calculate the work done lifting the truck in this time [2 marks]

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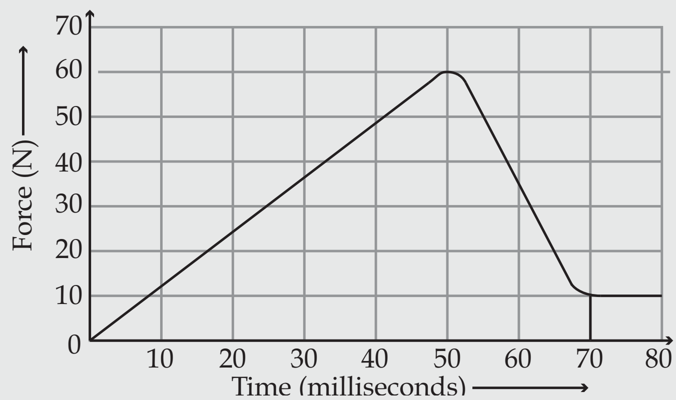
7. The graph below shows a force/time plot for a hockey ball being struck by a stick.



a) From the graph, estimate a value for the impulse given to the ball over the first 70 milliseconds [3 marks]

____

____

____

b) Using your answer to part a) calculate a value for the velocity of the hockey ball, given that its mass is 250 g [2 marks]

____

____

c) The graph above was produced for a wooden stick. A new fibreglass stick has been produced which bends a lot more than the wooden one. Sketch another graph on the same axes (in another colour) to show what the F/t shape would be like for the more flexible stick [2 marks]

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WAVE MOTION

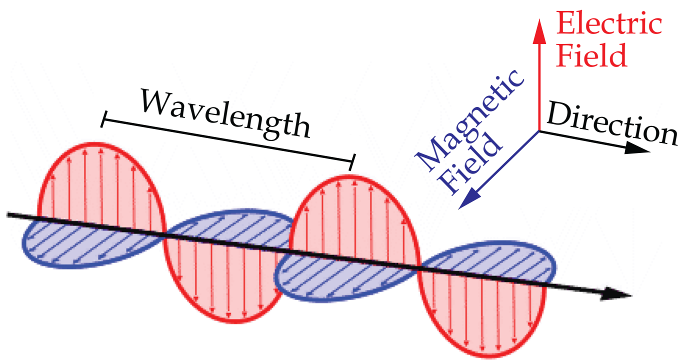
Chapter
5

5.1 Types of Waves

Waves transfer energy from one place to another with no net transfer of matter (not like a bullet which transfers kinetic energy by moving from the gun to the target). Waves can be transmitted through a medium, as with water or sound waves, or by transmission of pure energy, without the need for a medium. Waves that utilise a medium are termed "Mechanical Waves" as they need particles for their transmission.

EMR Waves.

Light is propagated as an electric field and a magnetic field that are at right angles to each other (transverse wave). This enables light to travel through a vacuum where no particles exist to be oscillated. So light cannot be classified as a mechanical wave. It is classified as: non-mechanical, self-propagating, Electro-magnetic, transverse wave.



James Clerk Maxwell was able to show in the mid-1800s that light was an Electro magnetic wave. He determined, through calculus that in a vacuum, the wave speed should be equal to the equation shown below. Try the equation. What do you notice about this value?

$$v = \frac{1}{\sqrt{\varepsilon_0 \mu_0}}$$

μ_0 = permeability of free space
= $4\pi \times 10^{-7}$

ε_0 = permittivity of free space
= 8.85×10^{12}

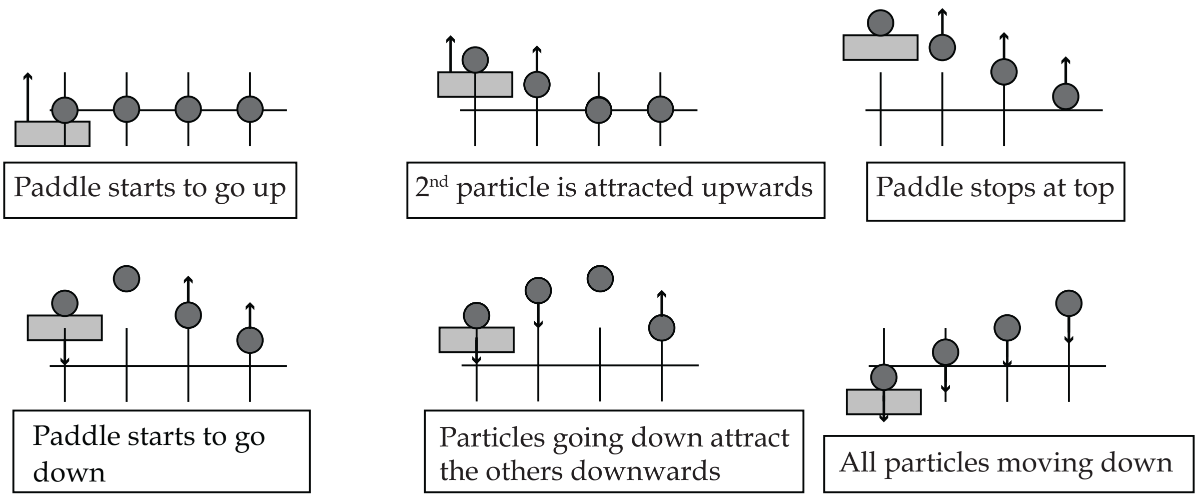
Transverse Waves.

Transverse means "across". With a transverse wave, the particle movement is at right angles to the direction of motion of the wave. An example of transverse waves is the waves that occur on the surface of water.

When one particle of water is displaced from its equilibrium position by, say, a paddle the adjacent particles also move at a later time due to intermolecular attraction. This time delay between particles moving is what makes the wave move outwards, as energy is transferred through a medium. A 'medium' is the matter through which the wave is moving e.g. water, air, rock, etc. All waves are propagated outwards from a point - 'propagation' means growth, or spreading.

Propagation of a transverse wave

Imagine a paddle moving up and down in a pool of water.

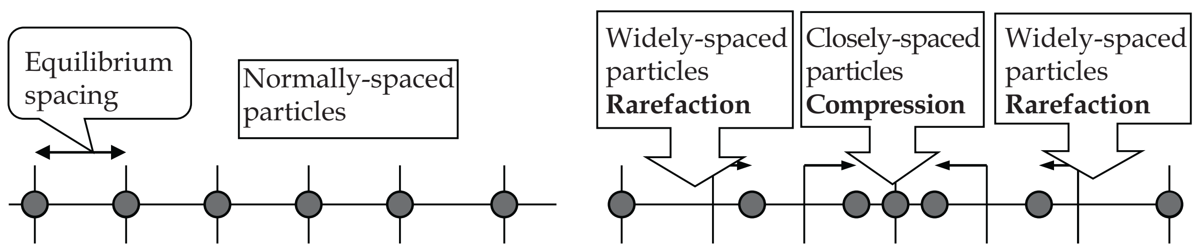


Notice that the motion of each particle is only ever up and down but the delay time makes it seem like something is moving from left to right. The same effect is produced with the Mexican Wave, where sports fans stand up and sit down one after the other after a short delay.

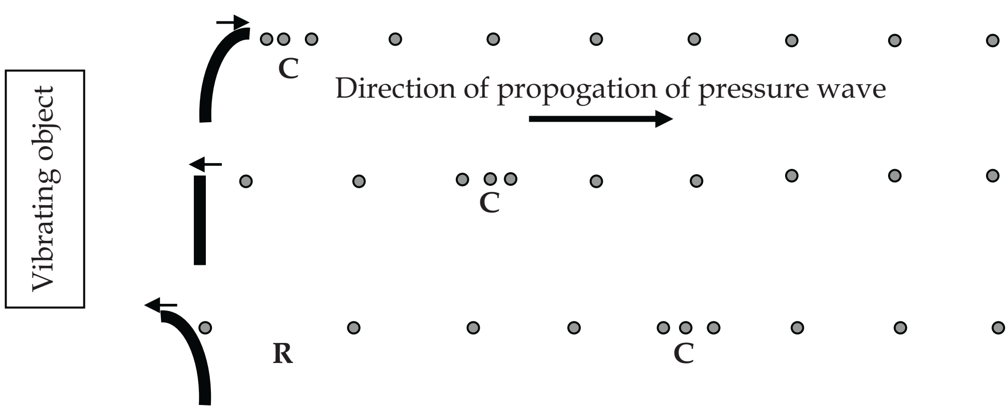
Longitudinal Waves.

With a longitudinal wave, the particle vibration occurs in the same direction of the motion of the wave. Sound waves propagate in a longitudinal manner and not transversely. Particles that are at their position of equilibrium (least energy) are in a region where the air pressure would be normal (1 atmosphere).

When any object vibrates a part of it is moving forwards, compressing the air and then later backwards "stretching it out". When air molecules are pulled away from each other, a low-pressure zone is created, called a Rarefaction. See the illustration overleaf.



Imagine an object is vibrating back and forth, causing air to be compressed (C) and rarefied (R) alternately.



When the pressure wave reaches the eardrum this causes it to move in and out at the same rate as the high and low-pressure pulses arrive i.e. the same frequency as the source.

All that each air particle does is to move to the right first (+ direction) as the compression arrives and then left (negative direction) as the rarefaction arrives. The maximum displacement of a particle that is oscillating is called its Amplitude (A). The time for one complete oscillation is

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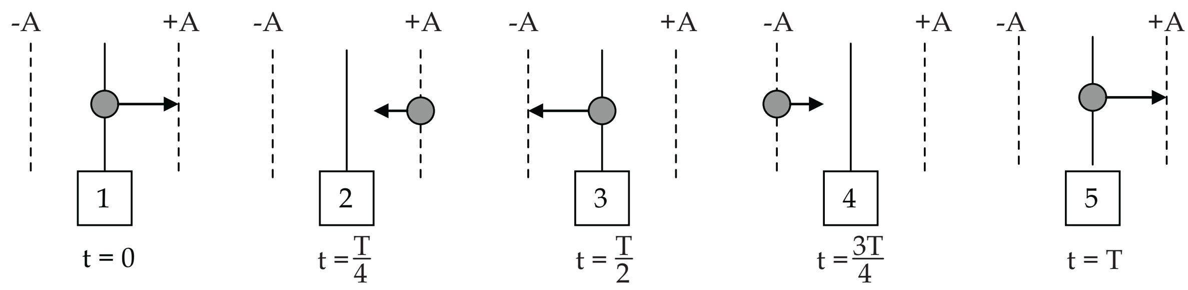
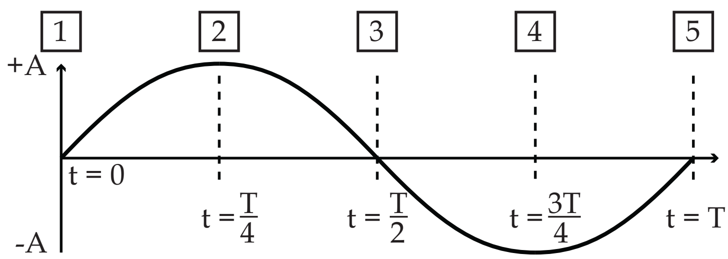
called its Period, T. ¼ of a complete vibration will take a time T/4 and a half will take a time T/2, etc.



After ¼ of the time period the particle is in position 2 above which is its furthest point to the right. The particle passes back through the zero position at ½ T and moves to a position of negative amplitude after ¾ of a time period.

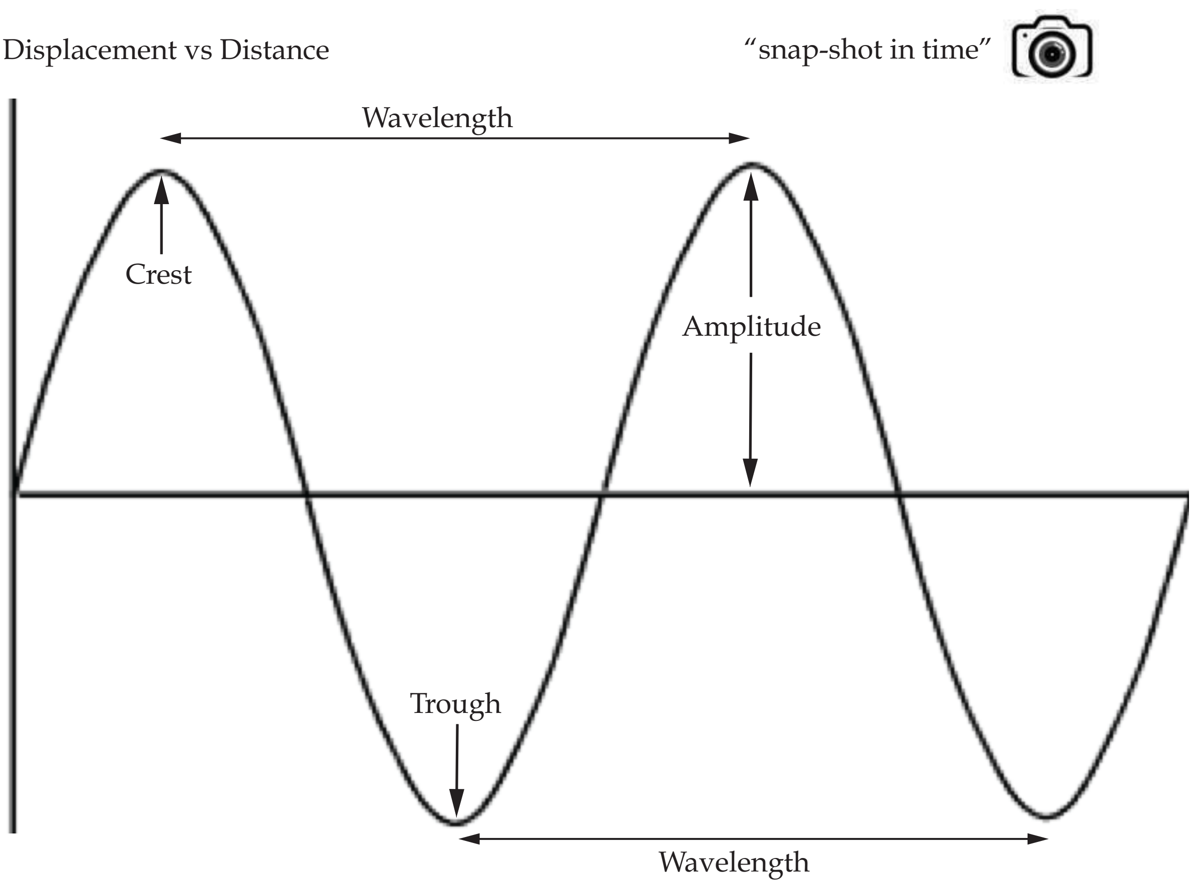
A plot of the horizontal displacement of the particle at various times in its period T is shown below (movement to the right is taken as a positive displacement):



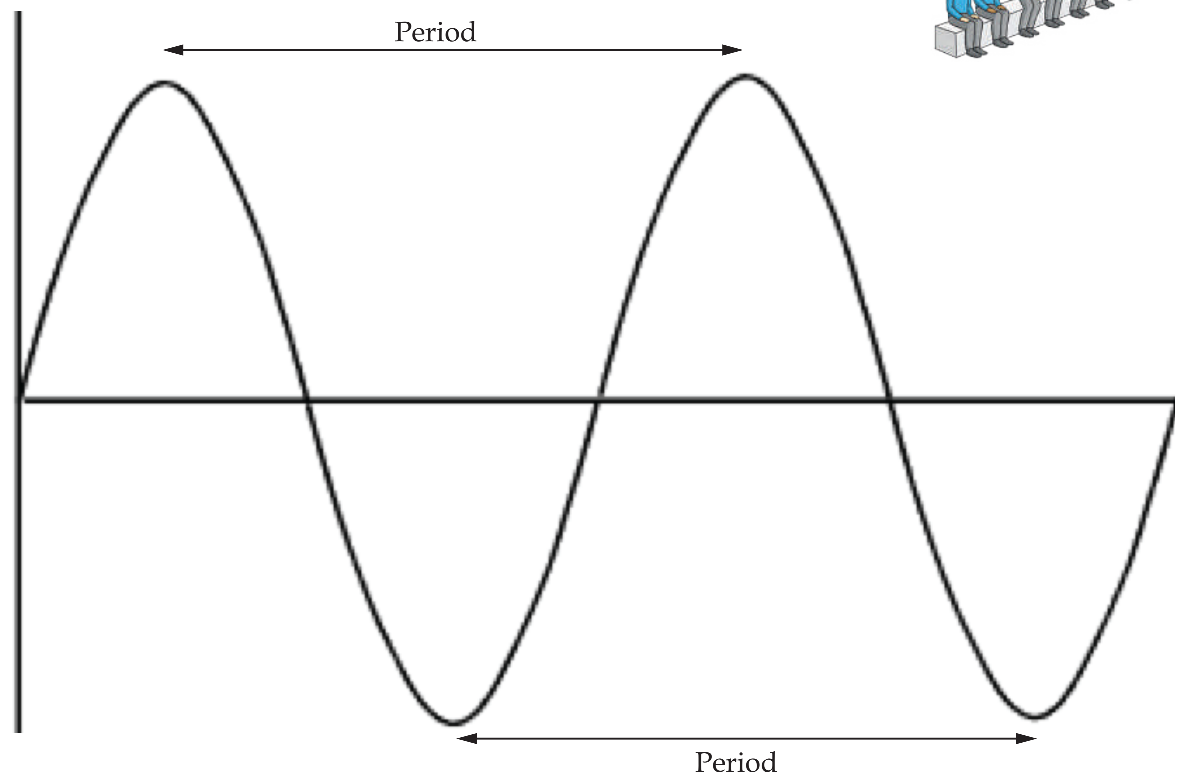
Graphing Wave Motion.

There are two ways to graph transverse wave motion. One is to look at the amplitudes of the particles over a set distance. The length from successive peaks (or successive troughs) will provide you with the wavelength. Consider this type of graph as a snap-shot in time. If you took a picture of a surface water wave, you would see the distance that each wave was apart.

Displacement vs Distance "snap-shot in time"



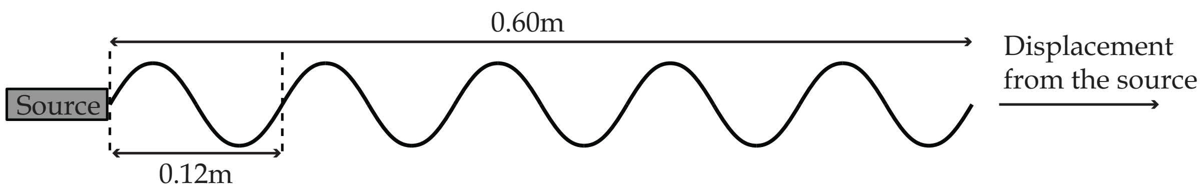
The other is to look at the amplitudes of the particles over a set time. Consider this graph as looking at one individual person in a Mexican Wave and watch their displacement over a set time period. The ‘time’ from successive peaks (or successive troughs) will provide you with the period of the wave.



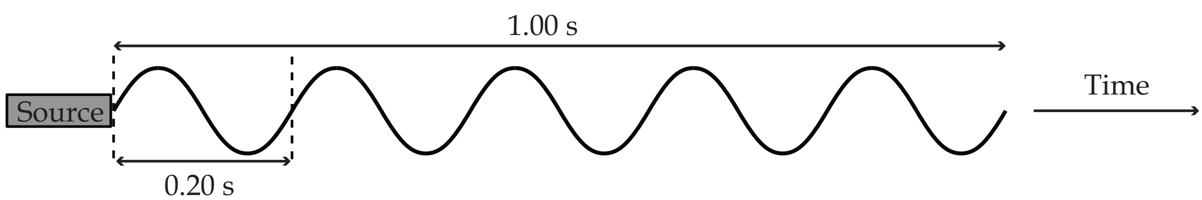
“Focus on one particle”

5.2 The Wave Equation

Below is a diagram of 5 waves moving on a pond at a particular instant. Each wave has a length of 12.0 cm i.e. the wavelength (λ) = 0.120 m. (Time is fixed – like a flash photograph).



The following diagram is the same shape as the one above but this one shows the motion of at a fixed distance from the source of the waves. It shows how wave height varies with time. (Distance from the source is fixed at a particular position).



If these 5 waves were given out by the source in 1 second then the frequency (f) of the source was 5 waves per second or 5 hertz (5 Hz) and so the period (T) for each wave = 0.200 second. Frequency is the number of waves occurring per second, which is 1/0.2 = 5.00 Hz.

$$\text{Frequency} = \frac{1}{\text{Period}} \quad \text{or } f = \frac{1}{T}$$

The velocity of the wave is the distance travelled in a given time,
so v = distance/time = 0.120/0.200 = λ /T or 0.600 m s^{-1}

so $0.6 = 5 \times 0.12 = f\,\lambda$

Hence the most useful formula in sound is $v = f\,\lambda$

This is known as the wave equation and it applies to waves of any kind (sound, light, water waves).

Example 1

a) The speed of sound in air at 25.0 °C and 100 kPa is 346 m s^{-1}. What is the wavelength of a 1384 Hz note being played on a flute in air?

b) If the speed of sound in water is 1500 m s^{-1}, what would be the wavelength of this note in water?

Solution 1(a)

Description	Marks
$v = f\lambda \Rightarrow \lambda = \frac{v}{f}$	1
$= \frac{346}{1384}$	1
= 0.250 m	1
Total	3

Solution 1(b)

Description	Marks
$v = f\lambda \Rightarrow \lambda = \frac{v}{f}$	1
$= \frac{1500}{1384}$	1
= 1.08 m	1
Total	3

5.3 Speed of Sound

The speed of sound can be determined by finding how long the sound wave takes to travel a known distance e.g. A gun is fired from a hill 2.00 km from the gun and a stopwatch started when the smoke from the gun is seen.

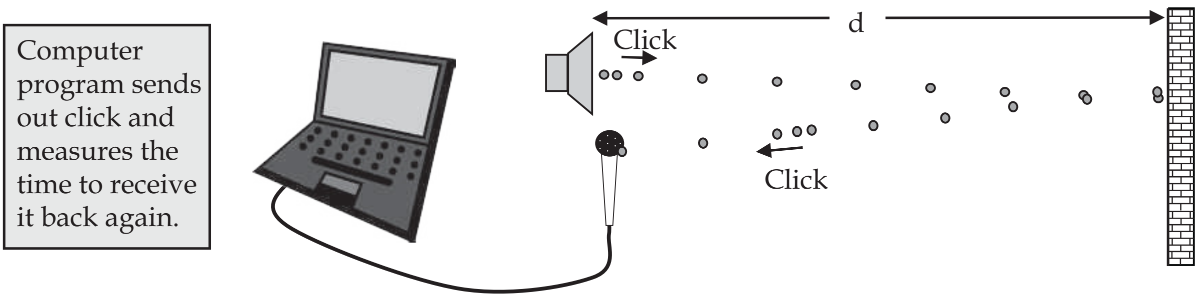
The stopwatch is stopped when the sound is heard. If the time taken is 6.00 s, then $v = d/t = 2000/6 = 333$ m s^{-1}.

This method assumes light travels the 2 km instantly (a fair assumption as the time of travel is actually about 7 μs). This method has a large error due to human judgement and reaction time (about ± 0.5 s)

Echo Method

When sound bounces back from a distant object (e.g. shouting at a mountain) we hear a reflection of the sound some time later, due to the time taken for the sound to hit the mountain and then travel back again. We could estimate how far away the mountain is by assuming the speed of sound and counting the time for the echo to return.

A more accurate method of finding the speed of sound in the laboratory uses a computer program to measure the time between when a "click" is emitted from a speaker and when the echo of the click is received back through a microphone after bouncing back from a wall. The set-up is shown below.

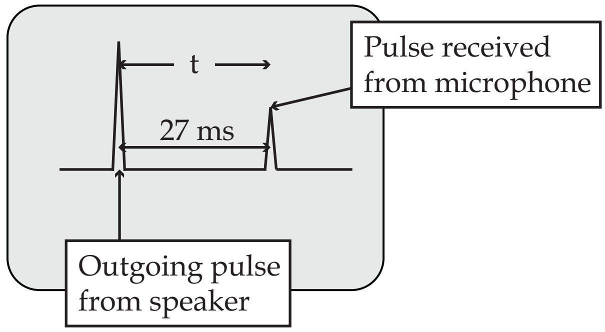


The program gives a computer trace, shown on the right.

Suppose d = 4.50 m and the time delay t between the click and its echo returning measured on the computer is 27.0 milliseconds.

The velocity of sound v = 2d/t

$$v = \frac{2 \times 4.50}{27.0 \times 10^{-3}} = 333 \text{ m s}^{-1}$$



Note that sound travels faster in liquids than in gases, and even faster in solids. This is due to the greater intermolecular forces prevalent in liquids and solids compared with gases. This causes the effect of the movement of particles on adjacent particles to occur more quickly.

Example 2

Two girls decide to try to find the speed of sound in steel as a school project. For this they experiment with a 700 m length of disused railway line nearby. One girl strikes the rail 700 m away with a hammer while the other girl measures the time delay between the two sounds she hears with an accurate stopwatch.

a) Why does the second girl hear two sounds?

b) The two girls repeat the experiment 5 times for accuracy and the time differences they record are: 1.82 s; 1.91 s; 1.90 s; 1.85 s; 1.87 s.

Assuming that the speed of sound in air was 346 m s^{-1} on the day, calculate the speed of sound in the steel rail.

Solution 2(a)

Description	Marks
One sound wave will travel through the air, one through the rail at a faster speed to arrive first	1
so two sounds will be heard	1
Total	2

Solution 2(b)

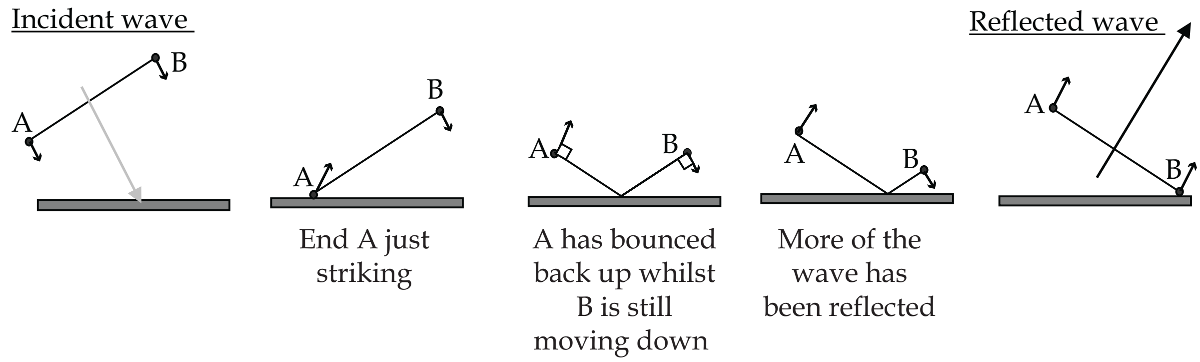
Description	Marks
t = d/v so average time delay = $t_{air} - t_{steel}$ value = 1.87 s	1
t_{air} = 700/346 = 2.023 s So 2.023 – t_{steel} = 1.87	1
So t_{steel} = 0.153 s and v_{steel} = 700/0.153	1
= 4.57×10^3 m s^{-1}	1
Total	4

5.4 Reflection of Waves

Looking at waves on water gives an insight into how other waves, such as sound or light waves, behave when they strike a barrier.

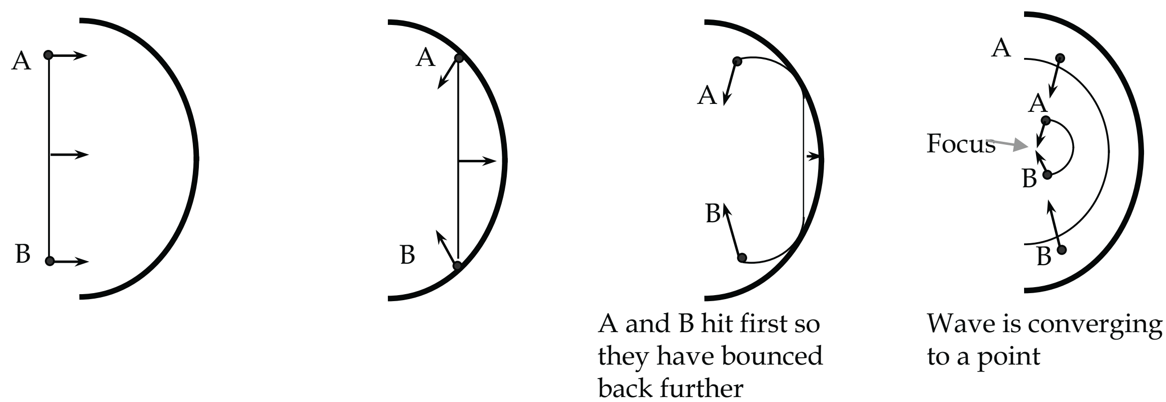
Reflection from a surface is explained by the difference in time that each part of the wave strikes the surface and bounces back. End A hits first and bounces back before end B has reached the barrier.

Concave mirror explanation



If light or sound wave strikes a concave mirror, it comes to a focus after it is reflected from the curved surface.

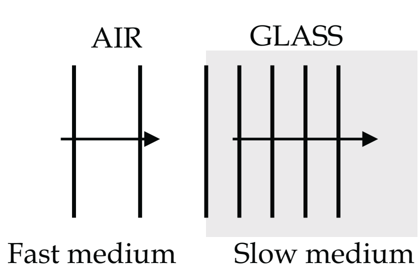
Again the wave model predicts actual observations found in the lab. A point focus is where all the wave energy is concentrated into a tiny area. A concave reflector can be used to focus sound or light.

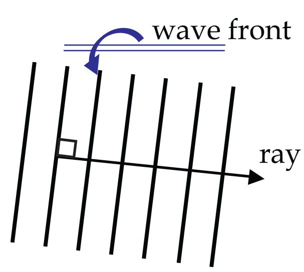


5.5 Wave Model for Refraction

When light strikes another medium (with a different wavespeed) at an angle it changes direction (bends) due to one part of the wave travelling at a different speed to the other part. This change of direction of a wave when it moves into a different medium is known as Refraction and is caused by a change in velocity moving from one medium to another (see the illustration overleaf). Imagine light waves travelling from air into glass, where they slow down, the wavelength is decreased but the direction and frequency of the wave remain the same.

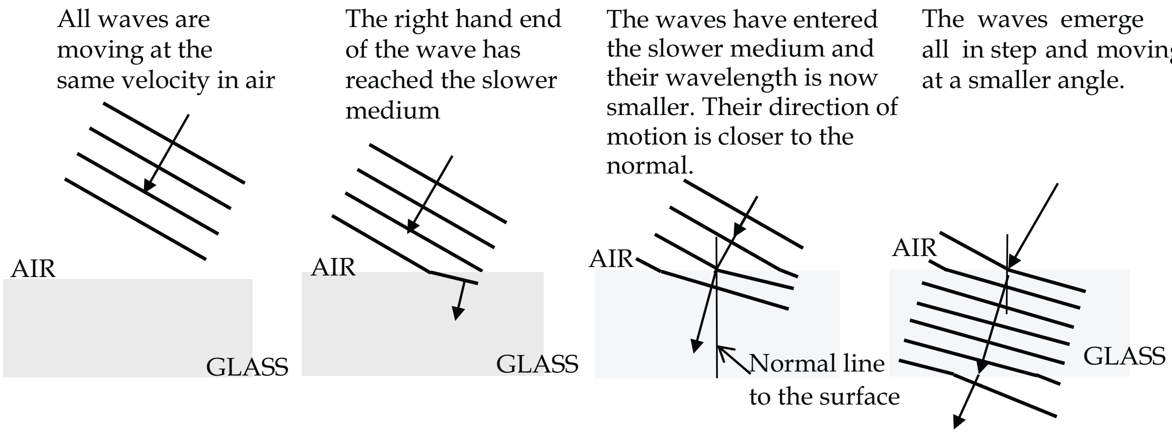
Wavefronts represent regions of the medium where the particles have the same displacement/ pressure. The ray represents the direction that they wavefront is travelling and is drawn perpendicular to the wavefront.





However, if the wave strikes the interface between the air and the glass at an angle, then the end of the wave that strikes the glass first will move at a slower speed while the other end is still moving fast. This causes the wave-front to change direction. This situation is similar to a row of soldiers when they want to go round a corner – the soldier on the inside moves slowly while the outside soldier moves faster as his path is longer.

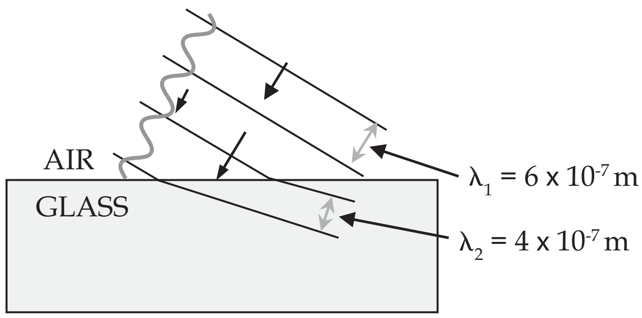
Waves moving from a fast to a slower medium will be bent towards the normal of the surface:



According to the wave model, if a light wave goes into a slower medium (e.g. air to glass) the direction will change so the ray bends towards the normal to the surface and its wavelength decreases but the frequency always remains the same.

The diagram here shows an example of how the wavelength would change as light with a wavelength of 6.00×10^{-7} m goes into glass and slows down. $v = f\lambda$ so wavelength would get smaller in the ratio of the two velocities.

The speed of light in air is 3.00×10^{8} m s^{-1} and in glass about 2.00×10^{8} m s^{-1} so $\lambda_2 = 4.00 \times 10^{-7}$ m.



Snell's Law of refraction

Waves have a different speed in different materials (media). The ratio of speed in medium 1 to the speed in medium 2 is called the Refractive Index (n). In the case above n = 1.5

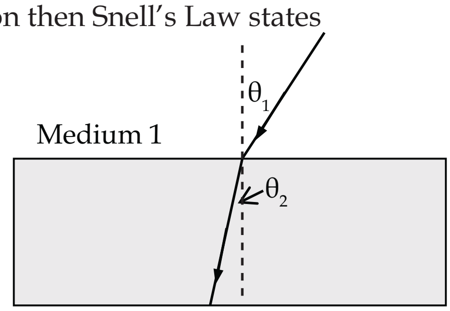
Snell's Law links the angle at which the ray of light strikes the surface of a medium (angle of incidence) to the angle it makes inside the medium (angle of refraction).

If θ_1 is the angle of incidence and θ_2 is the angle of refraction then Snell's Law states

$$n = \frac{\sin\theta_1}{\sin\theta_2}$$

So if θ_1 is 30.0° and θ_2 is 19.5° then

$$n = \frac{\sin 30.0}{\sin 19.5} = 150$$



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Example 3

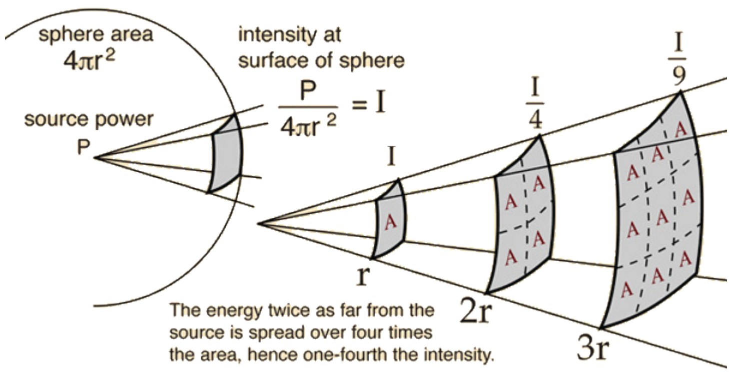
A light ray strikes the surface of a swimming pool at an angle of 41.0°. If the refractive index of water is 1.33, calculate the angle of refraction of the light ray in the water.

Solution 3

Description	**Marks**
$133 = \frac{\sin 41}{\sin\theta_2}$	1
so $\theta_2 = \frac{\sin 41}{1.33} = 0.4933$	1
$\theta_2 = \sin^{-1}(0.4933) = 29.6°$	1
Total	3

5.6 Sound Intensity

Sound spreads from its source in all directions i.e. in a sphere so that, as the wave gets further from the source, the energy becomes spread over a larger and larger area. The power of a sound wave per square metre is called its Intensity (I).



The area of a sphere of radius R is given by $4\pi R^2$ so, at 1 metre from the source, the Intensity would be: $I = \frac{P}{4\pi R^2} = \frac{P}{4\pi}$ but at 2 m from the source intensity would be: $I = \frac{P}{4\pi R^2} = \frac{P}{16\pi}$ which is 4 times smaller, not 2 times smaller.

Hence, if a person stands twice as far away from a sound they will hear the sound with a quarter of the intensity. Intensity and distance are therefore related by an Inverse Square Law, the same as an electric field is related to the charge and gravitational fields related to matter. Intensity is measured in watts per square metre (W m^{-2}).

Example 4

A starter gun cartridge explodes emitting a sound power of 1.20 watts. Calculate:

a) the Intensity of sound at the ear of the starter official which is 1.50 m away

b) the sound intensity at the ear of a runner who is positioned 36.0 m away from the gun.

Solution 4(a)

Description	Marks
$I = \frac{P}{4\pi r^2}$	1
$I = \frac{1.2}{4\pi 1.5^2}$	1
$= 0.042\ W\ m^{-2}$	1
Total	3

Solution 4(b)

Description	Marks
$I = \frac{P}{4\pi r^2}$ At 36 m away	1
$I = \frac{1.2}{4\pi 36^2}$	1
$= 7.37 \times 10^{-5}\ W\ m^{-2}$	1
Total	3

Given the power is a constant, the equation can be rearranged to:

$$I_1 = \frac{P}{4\pi r_1^2},\ I_2 = \frac{P}{4\pi r_2^2} \qquad \frac{P}{4\pi} = I_1.r_1^2 = I_2.\ r_2^2$$

So $I_1 r_1^2 = I_2 r_2^2$

Example 5

The intensity of sound from a rather vocal magpie is measured at a distance of 15.0 m to be $5.00 \times 10^{-6}\ W\ m^{-2}$. Calculate the sound intensity that would be measured at a distance of 7.50 m from the magpie.

Solution 5

Description	Marks
$I_1 r_1^2 = I_2 r_2^2$	1
$5.00 \times 10^{-6}(15.0^2) = I_2\ (7.50^2)$ $I_2 = \frac{5.00 \times 10^{-6}(15.0^2)}{7.50^2}$	1
$= 20.0 \times 10^{-6}\ W\ m^{-2}$	1
Total	3

Absorption

A measure of the fraction of sound energy absorbed by a 1 metre thickness of material is called its absorption coefficient (symbol β). Soft materials, such as foam, have large values of β e.g.

If you covered a wall with a 1 m thickness of soft foam it would absorb about 60% of the sound energy i.e. β = 0.6. This means that only 40% of the sound intensity would be reflected.

After the sound of intensity 200 mW has reflected off all 4 walls the reflected intensity would therefore be only 0.4 × 0.4 × 0.4 × 0.4 = 0.026 or 2.6% of the original sound intensity remaining.

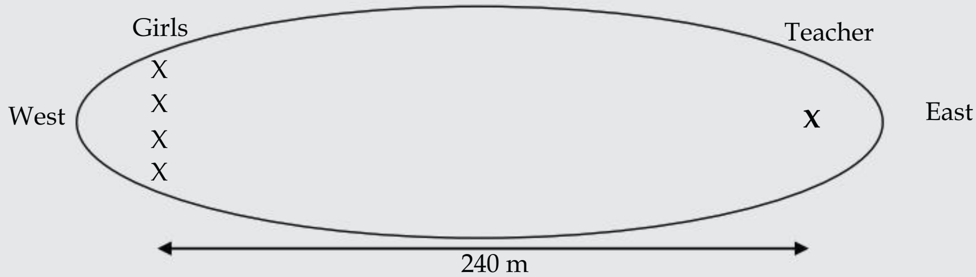
On the other hand, if the walls were tiles (β = 0.2) then, after 4 reflections, there would still be about 40% of the intensity remaining. This is why areas such as swimming pools and large halls echo so much, which adds to the problem of noise pollution.

Noise Pollution can come from machinery, music, people or aircraft and can cause a loss of hearing if the intensity of sound exceeds a value of about 0.01 W m^{-2} for a few minutes, but constant intensities less than this occurring over a whole day can also damage the ear (e.g. a gardener mowing all day). There are regulations regarding silencing of vehicles and industrial machinery, as well as mandatory ear-protectors for operators. One local council regulation for shops that emit sound (music, announcements, etc.) is that the intensity must not exceed 3×10^{-6} W m^{-2} (65 dB) at a distance of 1 metre from the shop-front.

Apart from using sound-absorbent materials to reduce noise pollution, other systems such as dampers, reflecting baffles, and noise cancellers are used nowadays. Rubber mounts on electric and petrol engines act as dampers for transmitted vibrations and reflectors are used on freeway barriers to deflect the traffic noise away from residents. Noise cancellers produce a sound which is that same frequency but out of phase with the noise waves to generate destructive interference (e.g. noise-cancelling headphones)

Sound Waves Quiz

1. In a class experiment to find the speed of sound a starting pistol was fired by the teacher while some girls measured the time between seeing the smoke and hearing the bang at the end of the oval.



The timings were then repeated with the teacher and the girls exchanging their positions, still maintaining the 240 m separation. The class results are shown in the table:

Exp No.	Direction of travel	Time (s)
1	East to west	0.685
2	East to west	0.690
3	East to west	0.688
4	West to east	0.708
5	West to east	0.705
6	West to east	0.698

From these results what would be the most accurate value for the speed of sound on the oval?

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2. In Question 1 the teacher pointed out that the speed of sound from East to West was different to that from West to East because of a wind blowing on the day. From the results above find an approximate value for the wind speed.

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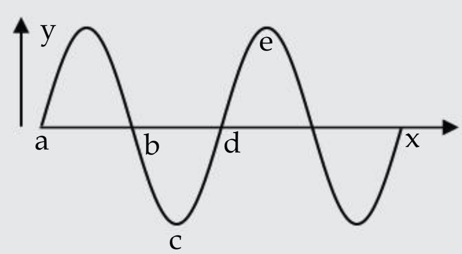
3. The graph opposite shows a plot of horizontal displacement of air particles in a sound wave at a particular instant. y is the displacement from the zero position and x is the horizontal distance from the source. Which points on the graph show air particles that are π radians (180^0) out of phase?



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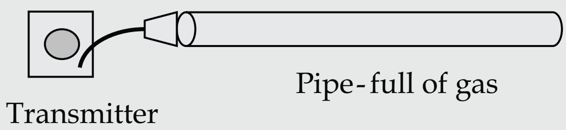
4. Waves are formed by the Kreepy Krauly on the surface of a pool so that 25 waves are produced in 5.00 seconds covering a distance of 10.0m. For these waves find the:

   a) Speed b) Frequency c) Wavelength.

5. The speed of sound in a certain gas is related to the Celsius temperature (T) of the gas by the formula: $v = 405 + 0.085T$

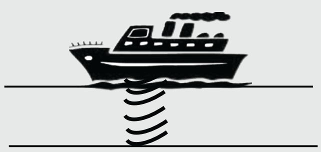
   Calculate the speed of sound in this gas at a temperature of 25.0 °C.

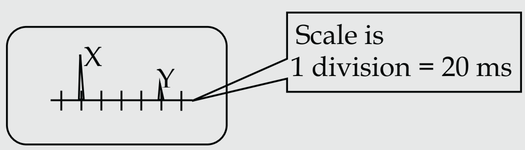
6. An ultrasonic sound wave is sent from one end of a 150 m long open pipe filled with the same gas referred to in Q. 5 at a temperature of 51.0 °C so it hits the other end of the pipe and rebounds back to the transmitter.



   Find the time taken under these conditions, for the wave to travel to the end of the pipe and back again.

7.

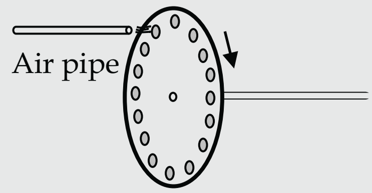




   A yacht sends an ultrasonic sonar pulse from a transmitter on its keel downwards towards the seabed. The outgoing pulse (X) and the reflected pulse (Y) are shown on a CRO screen, as displayed on the screen. The speed of sound in seawater was 1520 m s^{-1}.

   If the time scale on the screen is 1 horizontal division = 20 milliseconds, calculate the depth of the water from the bottom of the boat.

8. A siren is made by blowing air at a high pressure through holes in a rotating steel disc. The disc shown is of diameter of 62.0 cm, has 200 holes in its outer edge and rotates at a rate of 1500 revolutions per minute. Calculate the frequency of the sound emitted from the siren.



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9. A musical instrument produces sound waves with a wavelength of 60.0 cm on a cold day when the speed of sound is 310 m s^{-1}. On the next day it is very warm and the speed of sound has changed to 360 m s^{-1}. What is the new wavelength produced, if the same note is played?

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10. Electromagnetic waves (e.g. light) and sound waves are similar in some respects whilst different in other ways. Below are some comparison statements about these waves:

i) They both travel slower in a more dense medium

ii) Only one of these can be diffracted around objects

iii) Both transfer energy spherically outwards from the source

iv) Only one of these can be polarised

v) Both can show interference effects

Which of these statements is/are true?

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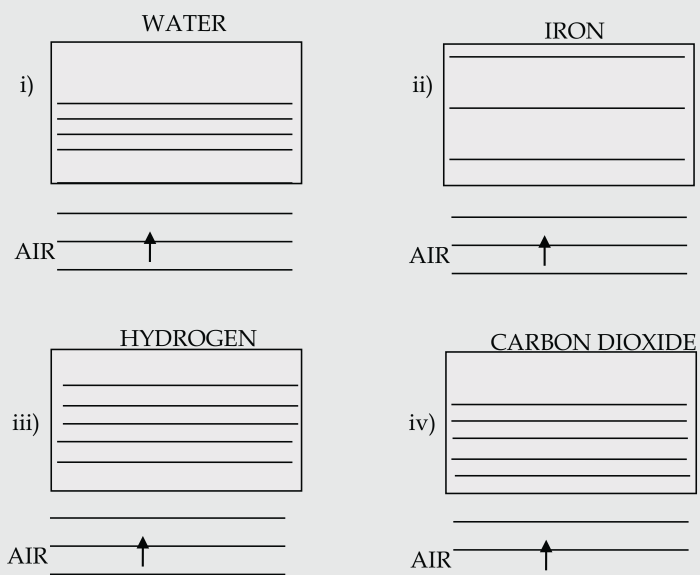
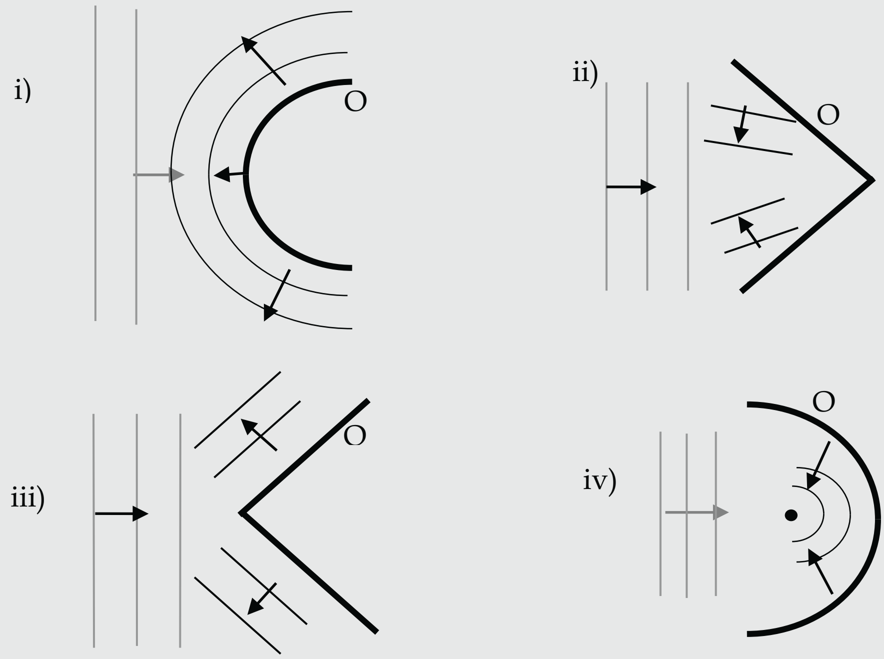
11. Compared to their speed in air sound waves travel faster in light gases (e.g. helium) and solids.



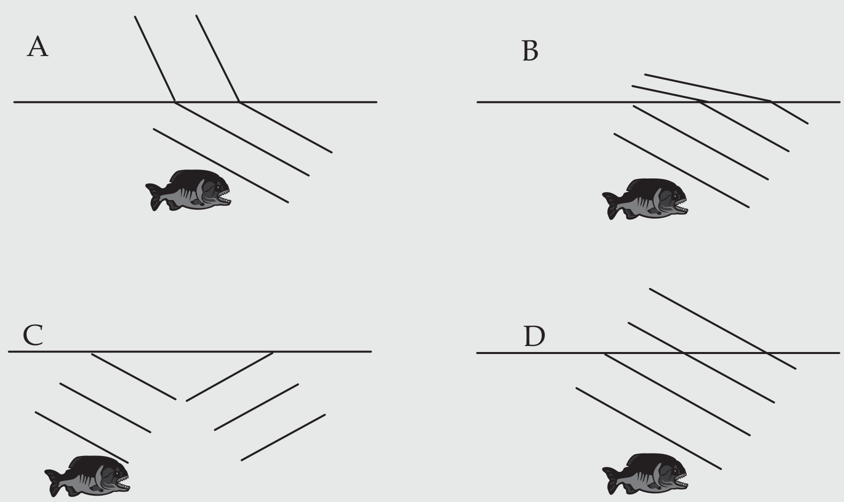
Which of the preceding wave diagrams correctly represent the way the wavelength of sound waves change when travelling from air into another medium?

12. Plane water waves in a ripple tank are reflected from different-shaped objects (**O**) in the water:



Which one of the diagrams above shows the correctly reflected waves?

13. Some fish are able to emit loud pulses of sound under water that can sometimes be heard above the surface. Which one of the diagrams below shows sound waves emitted by a fish correctly striking the surface?



14. A band is playing on a stage and a girl in the audience experiences sound with an intensity of 3.40×10^{-4} W m^{-2} when she is 55.5 m from the stage.

a) Calculate the sound power emitted by the band.

b) What would the sound intensity be for a man standing 10.0 m from the stage?

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15. The velocity v of a wave down a guitar string is given by the formula: $v = \sqrt{\frac{T}{m}}$

Where T = tension in the string and m = mass per metre of the string in kg m^{-1}
The top E string on a guitar has a total mass of 0.208 g and is stretched to a tension of 226 N.
The total length of the string is 62.8 cm.
What is the velocity of the wave down this string?

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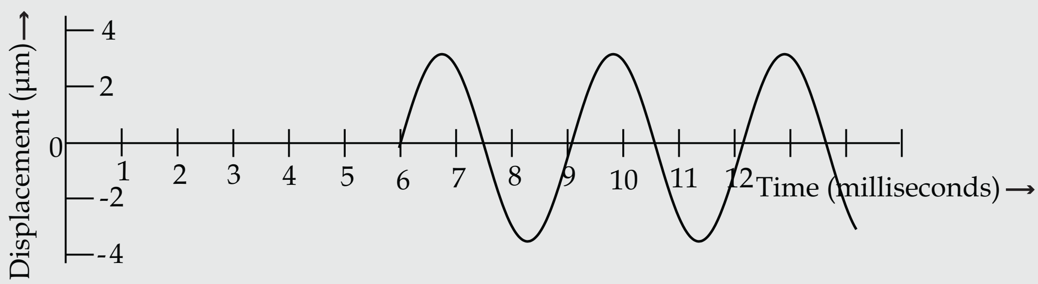
16. A sound wave is produced by a source placed at a distance of 192 cm from a receiver at time t = zero. A displacement/time graph of the air particles is shown below.



Find the speed and wavelength of the wave

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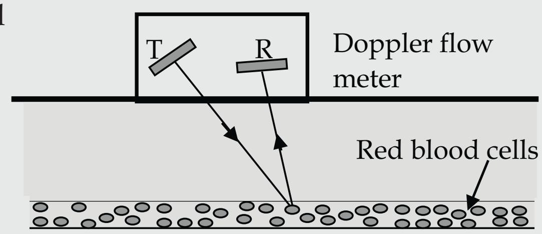
17. The Doppler Flow Meter allows the speed of flow of blood to be calculated by the change in frequency produced between a transmitted ultrasonic wave and the one received back by reflection from red blood cells. The transmitter T sends waves out to the moving blood cell which is received back by the receiver R.



The equation for the reflected wave frequency from a blood cell moving away from the transmitter is:

$$f_r = f\left(\frac{1}{1 + \frac{v_b}{v}}\right)$$

f_r = reflected frequency f = transmitted frequency
v = velocity of sound in the body = 1480 m s^{-1} v_b = velocity of blood flow

In one measurement an ultrasonic wave of exactly 5.0000 MHz was transmitted and a wave of frequency 4.9993 MHz was received back.

Use this equation to find the blood flow velocity for this patient.

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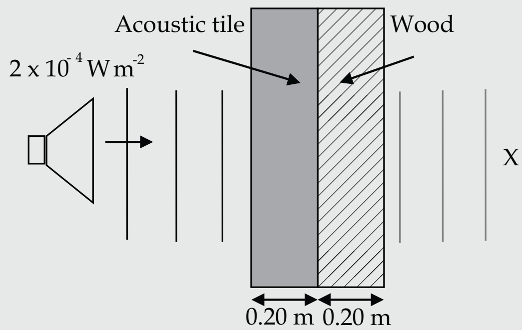
18. Different materials absorb sound to different extents. Some values of β for different materials are shown below in the table

Material	β at 500 Hz
Air	0
Curtain	$0.50\ m^{-1}$
Acoustic tile	$0.55\ m^{-1}$
Brick	$0.03\ m^{-1}$
Timber	$0.08\ m^{-1}$



A 500 Hz sound wave of intensity 2.0×10^{-4} W m^{-2} strikes the wall of a small recording studio and some of the sound is transmitted to the outside.
Using the figures supplied, what will be the approximate sound intensity heard at position X?

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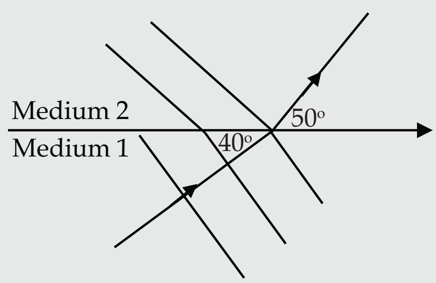
19.



Sound waves travel from medium 1 to medium 2 and are refracted from an angle of 40° to the interface to an angle of 50°, as shown. Calculate the refractive index of sound from medium 1 to medium 2.

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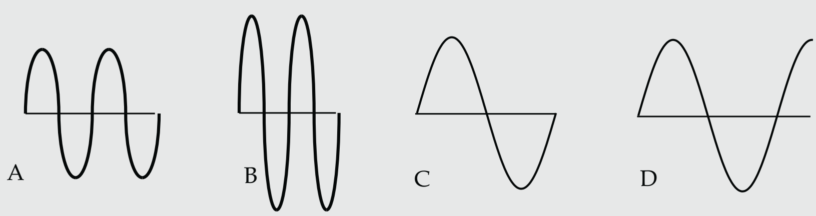
20.



Which wave pattern represents the highest pitched, loudest note?

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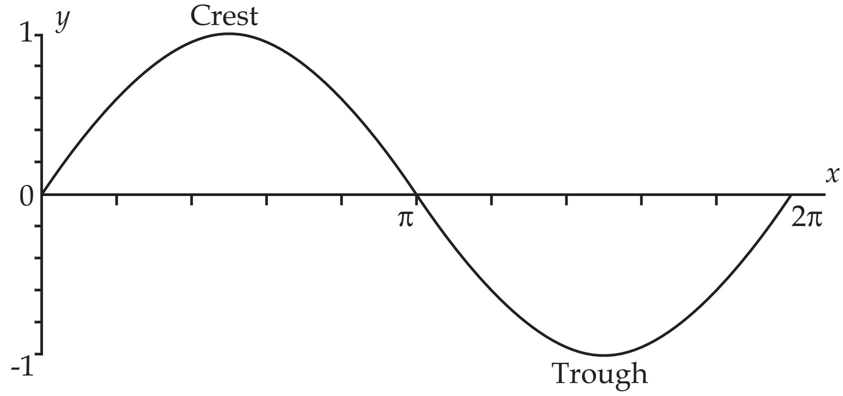
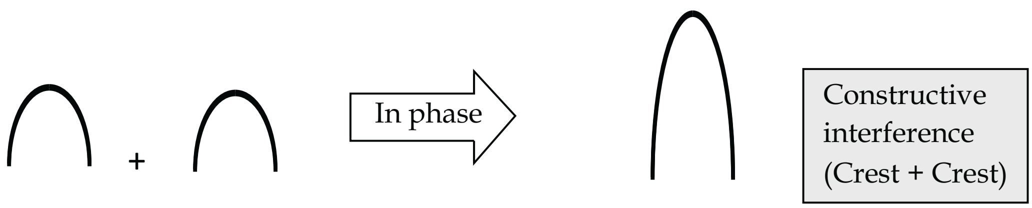
5.7 Interference of Waves

Where one wave meets another, the energy can either add (if the waves are in phase) or subtract (if the 2 waves are out of phase). The word 'phase' refers to the equivalent angle shown by the sine wave at that time. One wave adding to another is known as Superposition.

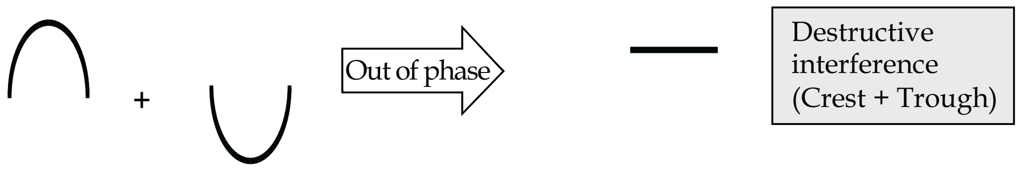


In phase



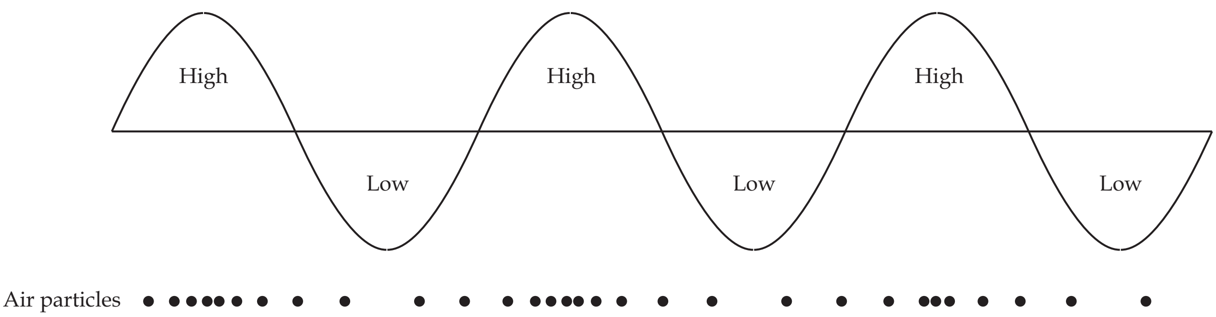
Two wave crests at the same phase angle (both starting at zero degrees) arriving at a point will combine to give a resultant wave of twice the amplitude

Out of phase



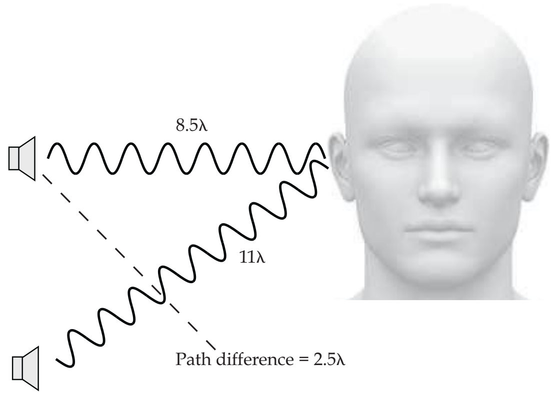
A wave crest and a wave trough arriving at a point will combine to give a resultant wave of zero amplitude. These 2 waves are 180° (or π radians) out of phase.

Representation of a longitudinal pressure wave as a sine wave.



The crest of the sine wave represents the position of maximum pressure i.e. where the air molecules are bunched together. The low pressure area is where the air particles are spaced furthest apart.

With sound waves coming from two different sources, there can be positions where the two waves overlap and the sound intensity is twice the amplitude or even zero (see the diagram overleaf). One wave has travelled a different distance to the other and therefore contains a different number of waves: If the Path Difference is equal to a whole number of waves, then there will be constructive interference – a loud sound. If the Path Difference is an odd number of half waves ($\lambda/2$, $3\lambda/2$, $5\lambda/2$, etc) then the two waves will cancel out and there will be zero sound.

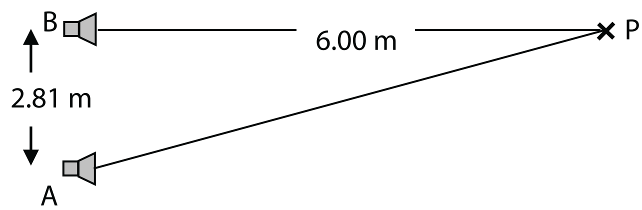


The number of waves from the top speaker to the listener is 8½, whereas the number of waves from the bottom speaker is 11 whole waves.

The Path Difference between the top and bottom speakers to the listener is 11 - 8½ which is 2½ waves or 5λ/2. Hence the waves will cancel and destructive interference will occur – there will be no audible sound at that point.

Example 56 Consider a stereo sound system where 2 in-phase speakers (A and B) are emitting the same note of frequency 1384 Hz. The speakers are 2.81 m apart and a boy stands at a point P, 6 m directly in front of one speaker.

Will the boy hear a loud or soft sound, due to the speakers at point P?



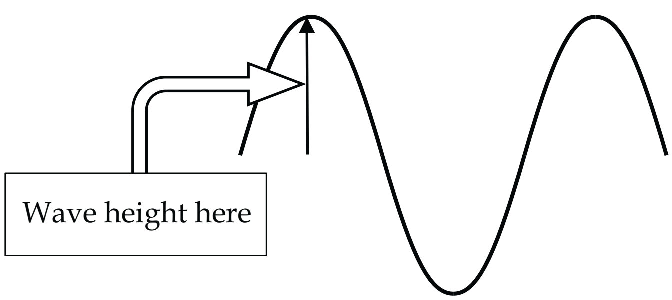
Solution 6

Description	Marks
λ = v/f = 346/1384 = 0.25 m	1
Distance $AP^2 = 2.81^2 + 6.00^2$ So AP = 6.625 m	1
Distance BP has 6/0.25 complete waves = 24 waves	1
Distance AP has 6.625/0.25 complete waves = 26.5 λ	1
Total	4

The difference in path length AP – BP represents 2.5 wavelengths, so the waves arriving from A and B are out of phase and point P is a nodal point (soft sound).

CDS and DVDs

In this age of digital signals, sine wave heights from music can be converted into binary numbers by a computer and then these numbers are burned onto a plastic disc by a laser as holes. Computers can only read a zero or a 1, so all numbers, sounds, colours and words have to be converted into Binary Code.



e.g. suppose a voltage level in a wave at a point was 179 mV, then the computer would have to convert this wave height to 8-bit binary as follows:

The Least Significant Bit (LSB) is furthest to the right as will be a 1, as the number is odd. The

8^{th} bit on the left is called the Most Significant Bit (MSB) will be $2^8 = 128$. The number contains the following factors:

$2^7 = \mathbf{128}$ (MSB)	1 of these	
$2^6 = 64$	0 of these	
$2^5 = \mathbf{32}$	1 of these	
$2^4 = \mathbf{16}$	1 of these	128 + 32 + 16 + 2 + 1 = 179
$2^3 = 8$	0 of these	
$2^2 = 4$	0 of these	
$2^1 = \mathbf{2}$	1 of these	
$2^0 = \mathbf{1}$	1 of these	

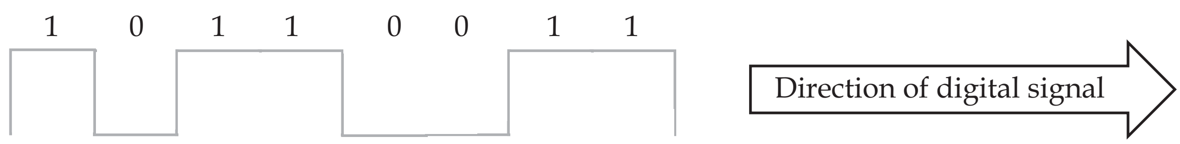
Bit 8	Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1
128s	64s	32s	16s	8s	4s	2s	Units
1	0	1	1	0	0	1	1

So the binary number 10110011 is read by the computer as representing 179 mV. (Read from left to right)

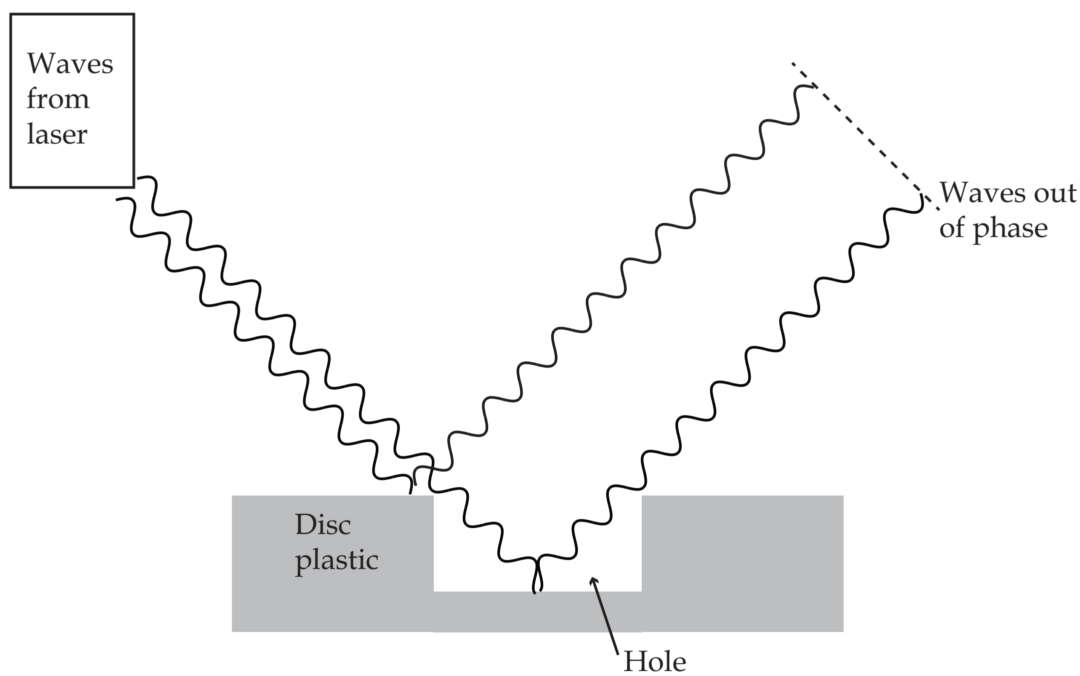
The sine wave from a piece of music is scanned very quickly by the computer and the wave heights converted to binary code, which can be sent along a wire or transmitted by radio waves to a receiver.

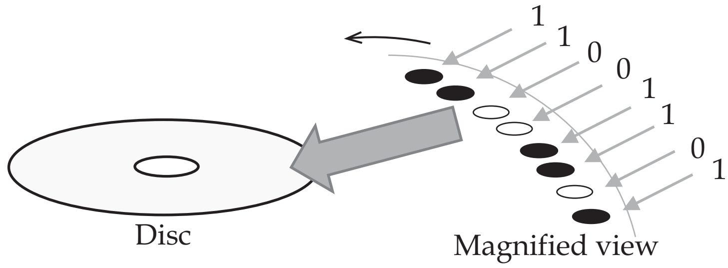
The digital wave would look like this:

This binary number can be burnt into the CD so that a '1' is a hole and a 'zero' is 'no hole'.



To retrieve the digital information a laser is shone onto the disc. Where the light reflects back off the top layer of plastic a '0' is registered and where the hole is, the light has travelled and extra half wavelength and so the light comes back out of phase to destructively interfere. The lack of reflected light is registered as a '1' by the light detector.





<u>**Ultrasonic Waves**</u>

The human ear is able to detect sound waves from a frequency of about 20 Hz to about 20 kHz, depending on the age of the listener, but people tend to lose sensitivity to the higher and lower ends of the sound spectrum as they get older. Some animals, like bats and dolphins, use ultrasonic sound waves to communicate and detect other animals (moths, fish, etc). Waves with such a small wavelength, like ultrasonic waves tend to travel straighter and not to be deflected around objects, which allows these animals to locate prey more accurately. Newer cars have ultrasonic emitters in the front and rear bumpers to sense how close the car is to an object in front or behind it – a hazard-warning device which measures the time taken for the sound to be reflected from another car to calculate distance. By using a specified ultrasound frequency, the received sound would not be confused with other sounds in the environment that might be being emitted.

Example 7

A bat senses its prey by emitting an ultrasonic note from its nose that bounces off the cave wall and leaves a “sound shadow” where an insect is present. This will only be accurate if the sound wavelength emitted roughly equals the size of the prey in front of it. If the bat can just detect a moth with a wingspan of 5.0 mm, what frequency note is the bat emitting?

Solution 7

If the object is smaller than the wavelength of the sound then the wave will disperse around the object and there will be no “shadow”. So λ needs to be smaller than 5.0 mm.

If the speed of sound is 346 m s^{-1} then the frequency of sound is:

Description	Marks
$f = v/\lambda$	1
$= 346/5 \times 10^{-3}$	1
$= 69.3$ kHz	1
Total	3

<u>**Ultrasound Scans**</u>

Sound can be used to probe the interior of the body, instead of using X-rays which are more dangerous.

Ultrasound scans are commonly used with pregnant women to visualise the foetus, or with athletes with damaged knees to find imperfections. These scans use the fact that ultrasound is reflected by layers of tissue of different densities beneath the skin to generate an image of the interior structures. The time difference between the reflected waves is used by a computer to produce a fairly sharp image.

5.8 Resonance

<u>**Free Vibrations**</u>

Occur when an object is displaced from its equilibrium point and then left to vibrate by itself. When a tuning fork is struck, the prongs vibrate about their mean position. The elastic restoring force strongly pull the prongs back and forth. We say that the tuning fork vibrates at its **natural frequency** which is the frequency of its free vibration.

Forced Vibrations

Occur when one vibrating object makes another object vibrate. If a tuning fork is connected to a wooden box and then struck, the wooden box is caused to vibrate with the same frequency. As the box has a larger vibrating area than the tuning fork, they displace a greater volume of air and produce a louder sound. Guitars and drum bodies are an example of forced vibrations.

Resonance

Resonance occurs when the driving frequency matches the natural frequency of the object. This causes the amplitude of the vibration to increase very quickly, often resulting in the object being damaged. If you listen to the bottle, you can hear "white noise" which is a mixture of all the different frequencies occurring in the bottle.

If you blow across the mouth of a bottle, the air in the bottle is made to vibrate and you hear a note. The frequency of this note is determined by the dimension of the bottle. The sound results from the free vibrations of the air in the bottle.

When you blow across the top of the bottle, you are providing waves of many different frequencies to the air column inside the bottle. However, waves of one particular frequency, the natural frequency or resonant frequency, transfer energy very efficiently and set up a standing wave in the bottle.

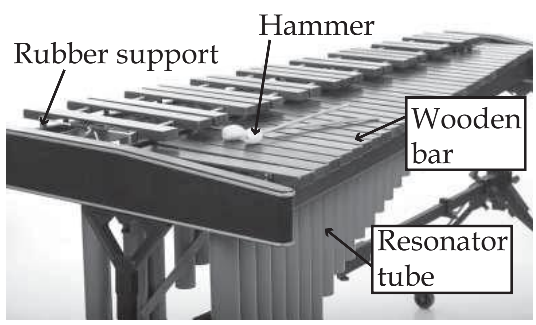
It is said that if an opera singer sings the same note as the natural frequency of a wine glass loud enough, then the glass can resonate to such an extent that the glass can shatter.

Soldiers are always made to stop marching in step with each other when passing over a bridge in case it causes resonance to occur in the bridge structure and it starts swinging wildly.

Sometimes resonance is useful to enhance the loudness of a musical note. For example, a Marimba is an instrument where the player strikes wooden bars with a small hammer to produce a note.

In a Marimba the sound produced in striking a wooden bar is very soft but underneath the bars there are tubes, tuned to the natural frequency of that particular bar so that resonance occurs in the tubes, making the instrument sound much louder.

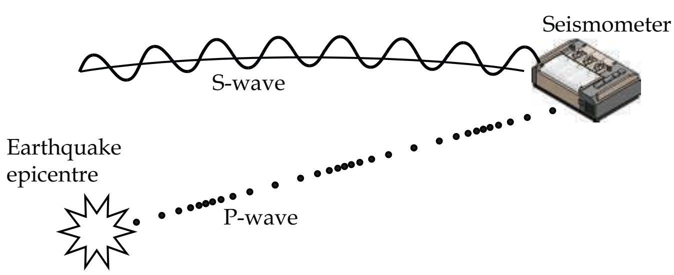
Marimba



Microwave ovens work by an oscillator emitting the resonant frequency of water molecules to heat the water up. At frequencies of microwaves (around 10^9 Hz) water molecules resonate and, in vibrating, produce heat.

5.9 Seismic Waves

Waves transmitted through the Earth are called Seismic waves and are of two types: P and S waves. P–waves are longitudinal and can travel through solid and liquid parts of the Earth, whereas S–waves are transverse waves and can only travel through solids, such as rocks. Both S and P–waves waves are generated when an earthquake occurs and travel at different speeds to be detected by a seismometer, which is an instrument that can record the arrival of each wave electronically.



When an earthquake occurs beneath the surface of the Earth the P–wave travels in a straight line towards the seismometer while the S-waves travel at a slower speed along the Earth's surface and arrive some time later. The seismometer records the time difference between these two waves and from this difference the position of the earthquake can be calculated.

Example 8

Results of seismic recordings: Speed of S-wave = 6.00 km s^{-1} Speed of P-wave = 12.0 km s^{-1}

Time difference between the arrival of the waves = 120 s.

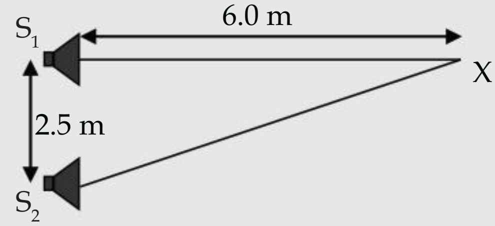
How far away is the earthquake epicentre?

Solution 8

Description	**Marks**
Time for the S-wave to travel distance d is given by $t_s = \frac{d}{6}$ Time for the P-wave to travel distance d is given by $t_p = \frac{d}{12}$	1
Time delay is given by $120 = t_s - t_p = \frac{d}{6} - \frac{d}{12}$	1
$120 = \frac{2d}{12} - \frac{d}{12} = \frac{d}{12}$	1
Hence d = 12 × 120 = 1440 m	1
Total	4

Interference Quiz

1. A pair of stereo speakers S_1 and S_2 separated by a distance of 2.50 m are emitting a constant note of 680 Hz. A person stands 6.00 m from one of the speakers at X, as shown.



Which of the following statements about this situation is correct? (Take v = 340 m s^{-1})

A. The sound at X is soft because the wave from S_1 is out of phase with the wave from S_2

B. A very loud sound is heard at X because the path difference between S_2 and S_1 is a whole number of half wavelengths

C. There is a very low intensity of sound at X because interference between one wave and the other produces a displacement antinode

D. There is a high sound intensity at X because distance $S_2X - S_1X$ equals a whole number of Wavelengths

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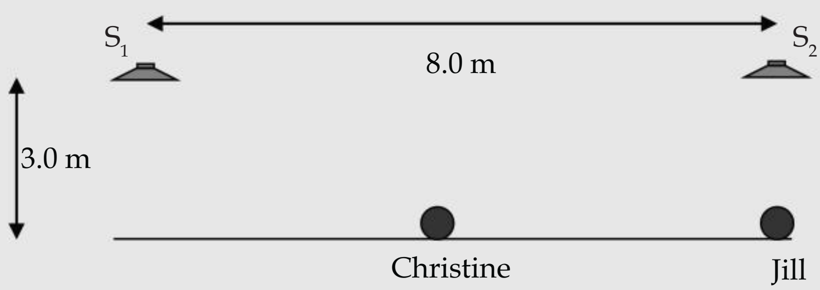
2.



A rock band has its bass bins (speakers) placed 8.00 m apart on stage. Christine sits exactly in the middle of the front row 3.00 m from the line of speakers and in this position perceives a very loud interference maximum at a frequency of 162 Hz. Jill sits at the end of the row but she experiences a very soft sound.

Find the wavelength of the sound and how many other interference maxima there are between the two girls, not counting those where Christine and Jill are? (Velocity of sound v = 346 m s^{-1})

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3. Which of the following classification of waves is correct?

	Longitudinal	Transverse
A	Water waves, sound	Electromagnetic, X-rays
B	Seismic P waves, ultrasonic	Violin string, water ripples
C	Flute waves, red light	β waves, blue light
D	Seismic S waves, γ waves	Guitar string, UV waves

4. Below is a table showing experimental results of the highest audible frequency that humans can hear for different ages:

Age (y)	Highest Audible Frequency (Hz)
3 – 23	20,000
34	16,100
46	12,000
55	8,000
67	3,900

What pattern is evident from the data in this table?

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5. The reverberation time for a room is given by Sabine's Equation: $T = \frac{V}{6.25K}$

V = volume of the room (m^3)
β = absorption coefficient of the wall material (β = 0.55 for acoustic tiling)
A = area of the walls
K = β × A

A rectangular recording studio measures 8.00 m long by 4.00 m wide by 2.50 m high and is covered completely with acoustic tiles. What will be the reverberation time for the studio?

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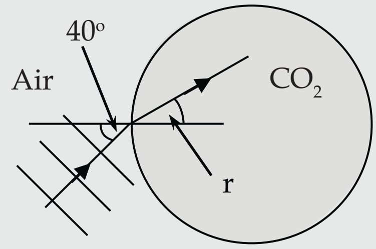
6. The speed of sound in air at 20 °C is quoted as 344 m s^{-1} and 266 m s^{-1} in carbon dioxide. A sound wave is directed at a balloon filled with CO_2, striking the outer surface at an angle of 40.0° to the normal.

Using Snell's Law determine the direction of the sound wave as it moves inside the balloon (angle r to the normal).



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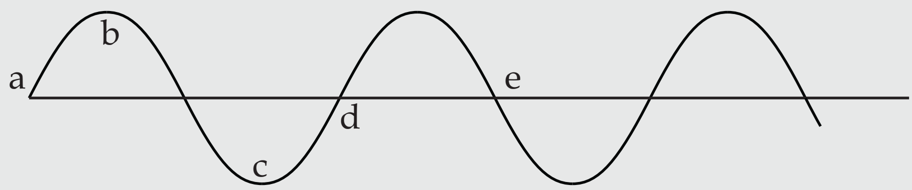
7.



The diagram above shows a transverse water wave at one instant when it is travelling to the right. In the next fraction of a second particles a – e will move as the wave passes.

Which of the diagrams below shows the correct movement for each particle in the next fraction of a second?

A.	↑ a	← b	→ c	↓ d
B.	↓ b	↓ c	← d	→ e
C.	↑ c	↓ d	↑ e	a↓
D.	↓ d	↓ e	↓ a	↓ b

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8. A truck passes a toy shop which has toy aeroplanes hanging by strings from the ceiling, each with a different length. The shop owner notices that, as the truck passes, one of the toy 'planes swings wildly while the others only move slightly. Explain why the toy 'planes behave differently.

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9. The frequency of an ultrasound transmitter is set so that it can detect small objects of less than a millimetre in diameter. It has been found that the most accurate detection comes when the emitted wavelength is around the size of the smallest object to be detected. If the speed of sound in the body is 1.52×10^3 m s^{-1}, estimate the lowest frequency needed for the ultrasound machine.

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10. Explain how noise-cancelling headphones work.

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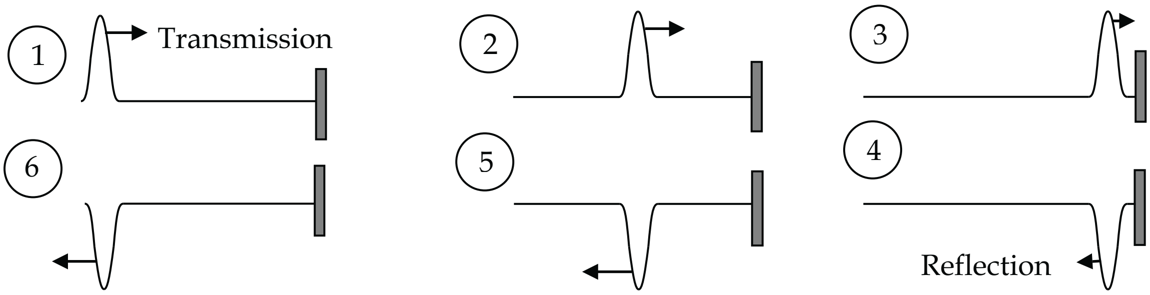
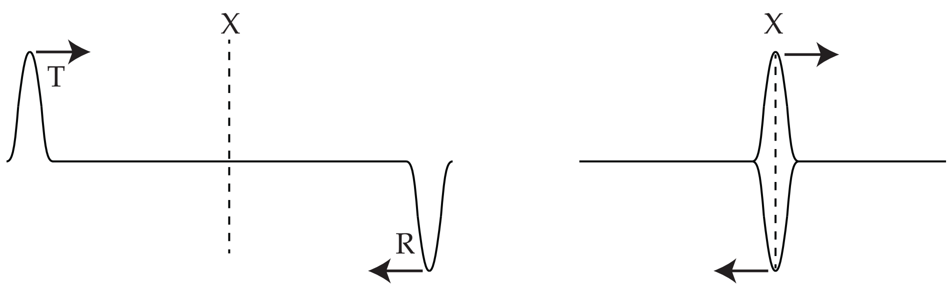
5.10 Standing (stationary) Waves

Imagine a transverse wave pulse being sent along a rope attached to the wall. The tension acts through the rope, meaning that in front of the pulse the Tension acts downwards, returning the rope back to its equilibrium after the pulse has passed. When the pulse approaches the wall, the downwards tension inverts the pulse such that it is reflected from the wall so that a crest becomes a trough on reflection i.e. 180° phase change.

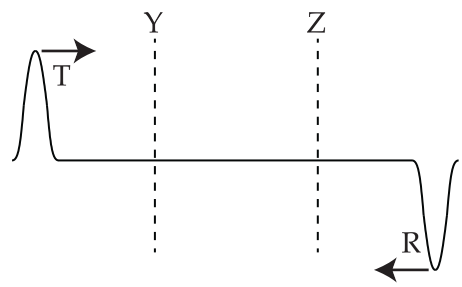


If the left hand side of the rope is constantly moved up and down to produce progressive waves then the incident waves (left to right) can interfere with the reflected waves (right to left). This interference between a wave and its reflection produces a standing wave along the rope where.



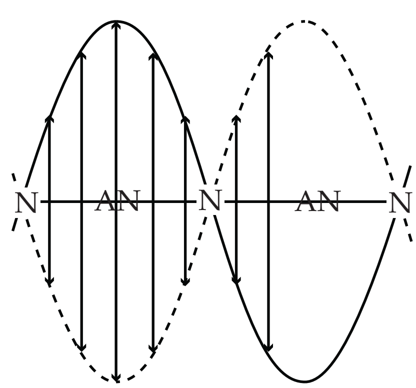
Point X is equidistant from the T wave and the R wave, so both waves reach X at the same time. Hence the rope is being pulled up by the transmitted wave and pulled down by the reflected wave at the same time. This leads to destructive interference and no net displacement of the wave or zero amplitude. This region is referred to as a 'node' or 'N'.

There will also be positions, (e.g. point Y) where the outgoing wave pulls the rope up to a maximum and immediately afterwards the reflected wave arrives to pull it downwards so a maximum amplitude of vibration is produced at that point. This position of maximum amplitude is referred to as an 'antinode' or 'AN'.



This interference produces an Antinode at Y and another at point Z where the R wave pulls the string downwards first before the T wave reaches it.

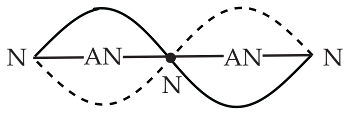
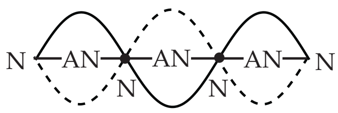
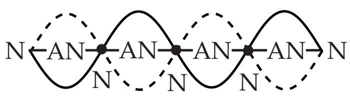
The overall result of the two waves interfering is a Standing Wave – where there nodes and antinodes are in the same position and no movement appears to occur from left or right. The parts of the string just move up and down with different amplitudes.



The simplest standing wave that can be produced on a string is called the Fundamental. Both ends are fixed and so must be nodes, with one antinode in the centre. This means that the length of the string must equal $\lambda/2$ ($\lambda = 2L$) so the fundamental frequency $f_1 = v/2L$ and is also known as the first harmonic (simplest vibration mode).

The next mode of vibration for a string is where another node is formed in the middle of the string, so $L = \lambda$ and $f_2 = v/L$. Therefore this frequency (called the second harmonic) is given by: $f_2 = 2f_1$. This frequency, f_2, is also called the "first overtone".

The next harmonic that can occur is called the "third harmonic" (or the second overtone), which is 3 times the fundamental frequency ($3f_1$).

Diagram	**Name**		**λ(n)**	**f(n)**
	Fundamental frequency	1st Harmonic	$\lambda(1) = \frac{2L}{1}$	$f(1) = \frac{1v}{2L}$
	1st overtone	2nd Harmonic	$\lambda(2) = \frac{2L}{2}$	$f(2) = \frac{2v}{2L}$ or $2 \times f_1$
	2nd overtone	3rd Harmonic	$\lambda(3) = \frac{2L}{3}$	$f(3) = \frac{3v}{2L}$ or $3 \times f_1$
	3rd overtone	4th Harmonic	$\lambda(4) = \frac{2L}{4}$	$f(4) = \frac{4v}{2L}$ or $4 \times f_1$

In summary

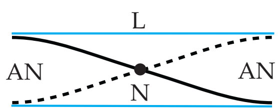
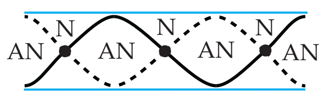
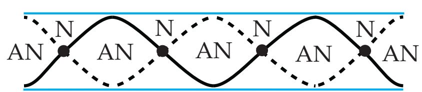
$\lambda(n) = \frac{2L}{n}$ $\qquad$ $f(n) = \frac{nv}{2L}$

5.11 Standing Waves in Pipes

Harmonics are produced when certain frequencies allow areas of repeating interference (caused by superposition of pressure waves reflecting through a pipe). Waves in a pipe travel as plane waves as they continually reflect off the inner walls of the pipe.

Harmonics in open pipes

As a compression wave reaches the end of an open pipe, it is no longer confined and rapidly expands into the air leaving behind a low pressure rarefaction that travels back down the pipe (the compression is reflected as a rarefaction, returning out of phase by $\frac{\lambda}{2}$). When the rarefaction reaches the end of an open pipe, the higher pressure outside the pipe rapidly expands into the rarefaction and travels back down the pipe as a compression wave. In this way, the standing wave is similar to that found in a string and has the same equation relating frequency, length and wave speed. The standing wave formed in a pipe has its maximum air displacement (a particle antinode) at the open end. In terms of pressure, this means there is a pressure node at the open end of the pipe (the rarefaction and compression are working together to cause maximum particle displacement).

Diagram	**Name**		**λ(n)**	**f(n)**
	Fundamental frequency	1st Harmonic n = 1	$\lambda(1) = \frac{2L}{1}$	$f(1) = \frac{1v}{2L}$
	1st overtone	2nd Harmonic n = 2	$\lambda(2) = \frac{2L}{2}$	$f(2) = \frac{2v}{2L}$ or $2 \times f_1$
	2nd overtone	3rd Harmonic n = 3	$\lambda(3) = \frac{2L}{3}$	$f(3) = \frac{3v}{2L}$ or $3 \times f_1$
	3rd overtone	4th Harmonic n = 4	$\lambda(4) = \frac{2L}{4}$	$f(4) = \frac{4v}{2L}$ or $4 \times f_1$

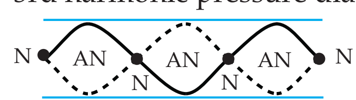
In summary

$\lambda(n) = \frac{2L}{n}$ $\qquad f(n) = \frac{nv}{2L}$

Note: the pressure diagram is the opposite compared to a particle displacement diagram:

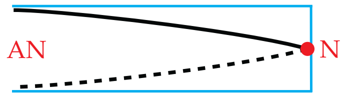
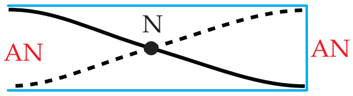
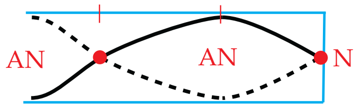
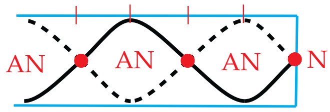
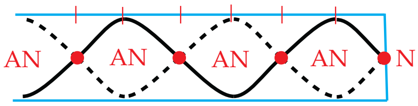
3rd harmonic particle diagram

3rd harmonic pressure diagram



Harmonics in closed pipes.

When one end of a pipe is closed, a pressure antinode (displacement node) occurs at the closed end as the particles cannot move into the wall of the closed end. When a compression wave strikes the closed end of a pipe, it is reflected as a compression with no phase change. The standing wave formed in the pipe must have maximum air displacement (a displacement antinode) at the open end. In terms of pressure, this means there is a pressure node at the open end of the pipe (the rarefaction and compression are working together to cause maximum particle displacement) and a pressure antinode at the closed end (the rarefactions and pressure waves are working against each other) to produce zero particle displacement.

Diagram	Name		λ(n)	f(n)
	Fundamental frequency	1st Harmonic n = 1	$\lambda(1) = \frac{4L}{1}$	$f(1) = \frac{1v}{4L}$
	Note: it is not possible to have a particle antinode at the closed end of the pipe. This means that even integer harmonics (2, 4, 6, etc) are not able to be established in the pipe. Only the odd integer harmonics can occur (1, 3, 5, 7, etc).			
	1st overtone	3rd Harmonic n = 3	$\lambda(3) = \frac{4L}{3}$	$f(3) = \frac{3v}{4L}$ or $3 \times f_1$
	2nd overtone	5th Harmonic n = 5	$\lambda(5) = \frac{4L}{5}$	$f(5) = \frac{5v}{4L}$ or $5 \times f_1$
	3rd overtone	7th Harmonic n = 7	$\lambda(7) = \frac{4L}{7}$	$f(7) = \frac{7v}{4L}$ or $7 \times f_1$

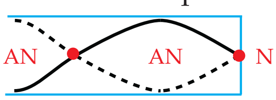
In summary:

$\lambda(n) = \frac{4L}{n}$ $\qquad f(n) = \frac{nv}{4L}$ $\qquad$ Note: only odd integer harmonics can be established.

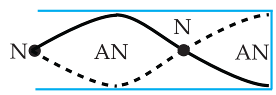
Note: the pressure diagram is the opposite compared to a particle displacement diagram:

i.e.

3rd harmonic particle diagram

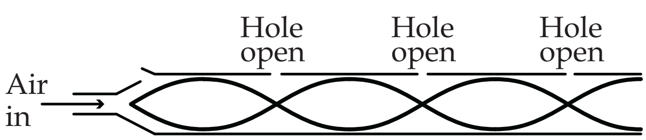


3rd harmonic pressure diagram



All musical instruments operate using standing waves in the string or pipe. Wind instruments are either open or closed pipes, with lengths corresponding to fixed harmonics. Pipe lengths can be altered continuously with instruments such as trombones but with trumpets different lengths of pipe are placed into the airflow by pressing valves down.

With other wind instruments nodes are produced by uncovering holes along the pipe and hence producing different frequencies.



When a hole is uncovered the pressure inside must equal the pressure outside i.e. a pressure node, or a displacement antinode.

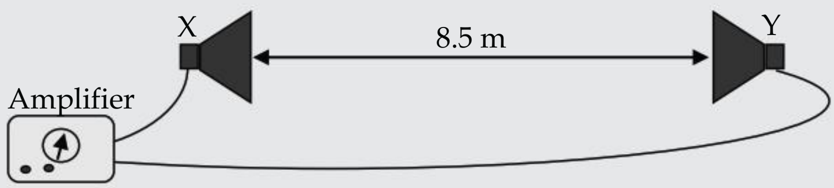
Note: Blowing harder in a wind instrument is a way of producing a higher harmonic e.g. an octave rise in the note.

Standing Waves Quiz

1. What are the conditions for a standing wave to be generated?

2. A boy blows across his plastic pen top to produce a standing wave, which has a fundamental frequency of 2200 Hz. If the speed of sound in air on that day was 346 m s^{-1}, what length must the pen top be?

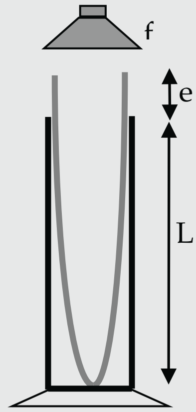
3.



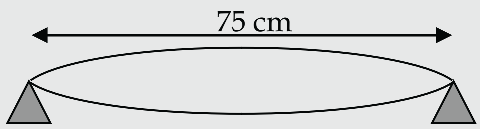
Two loudspeakers X and Y are connected in phase to the same amplifier emitting a continuous sine wave. The speakers are facing each other in a room and separated by a distance of 8.50 m. A woman walking between the speakers notices that between X and Y there are 17 points where the sound is extremely soft due to interference between the two waves. What must be the wavelength of the transverse wave being emitted?

4. The distance from the outer ear to the tympanic membrane (eardrum) is about 2.50 cm. This can be considered a closed pipe capable of resonating at a fundamental frequency and "amplifying" a particular frequency of sound. Use a value of 346 m s^{-1} as the velocity of sound to find the resonant frequency of the ear canal.

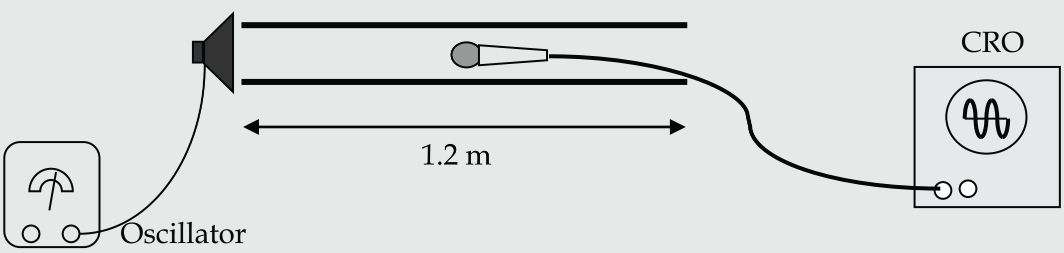
5. The loudspeaker shown above the tube has a very low frequency signal fed into it that is gradually increased until resonance occurs. The frequency is increased several times more, obtaining two other values of resonant frequencies. The wave actually starts outside the tube at a distance e, called the 'end correction' If the speed of sound is 360 m s^{-1}, L is 90.0 cm and e is 2.00 cm, what are the next two frequencies above the fundamental at which resonance will occur?



6. A guitar string is 75.0 cm long between the bridge and the nut, shown vibrating in its fundamental mode. If the speed of a transverse wave in this string is 850 m s^{-1}, at what frequency will the string vibrate in its third harmonic?

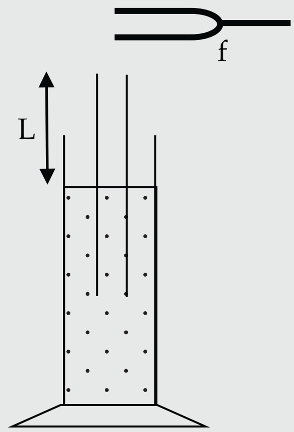


7.



A loudspeaker is placed facing into a 1.20 m long plastic pipe and is connected to a 1300 Hz oscillator. A microphone is attached to a wooden rod and pushed inside the pipe. The cable from the microphone is attached to a cathode ray oscilloscope (CRO) to measure its output.
Using this apparatus it was found that a point where the loudest sound occurred was exactly half way down the tube. The rod was gradually withdrawn and another loud point was found 13.0 cm from the first position. Calculate a value for the speed of sound on that day.

8. In an experiment mentioned a 256 Hz tuning fork was held above the tube to achieve resonance when L was equal to 33.4 cm.



Calculate from this single measurement a value for the velocity of sound.

9. The third overtone of an open organ pipe is found to have the same pitch as the second overtone of a different, closed, organ pipe. What is the ratio of the fundamental frequencies of the open pipe to the closed pipe?

10. A wind instrument is blown softly and produces a note of 875 Hz. When blown more strongly the instrument produces a note of 1.75 kHz. The speed of sound on that day was 346 m s^{-1}.

Which of the following is true?

A. The instrument acts as a closed pipe and is about 39 cm long

B. The instrument acts as an open pipe and is about 20 cm long

C. The instrument acts as a closed pipe and is about 17 cm long

D. The instrument acts as an open pipe and is about 42 cm long

INVESTIGATIONS

Chapter 6

6.1 Investigations

This section of physics has been introduced for the new National Curriculum.

Apart from performing the usual directed experiments, where the teacher tells you what to do, you will be expected to think up, organise and conduct an experiment or investigation of your own. These kinds of experiments are called Open-Ended because the method you use is open to your own imagination and originality. However, the way the investigation is performed and measurements taken must be rigorous and use good scientific methods (see later). You will also be expected to find ways of reducing the errors to a minimum.

For example, suppose you wanted to test the strengths of different types of dinner plates. Dropping each one to see which broke easiest would obviously be a very poor experimental design due to the lack of control of variables and the errors involved with the technique. You will be expected to critique your own experimental designs and modify them to lower the variability and increase the accuracy of data.

<u>The meanings of terms used in this chapter</u>

Open-ended investigation: Students design an experiment to solve a problem where there is no single, correct way of doing it.

Variables: Any factor in an experiment which can be altered.

Independent variable: A factor which is deliberately changed to see its effect.

Dependent variable: A factor which is not changed by the experimenter but is measured to judge the effect that the independent variable has on it.

Control variables: Other factors which affect the result, but must be controlled (kept constant), in a Fair Test.

A control: An experimental set-up where variables have not been changed - used to compare results with those where the independent variable has been changed.

A Fair Test: An experiment where results are compared in a scientific way. Only one variable is changed deliberately by the experimenter to see its effect.

Operational definition: A statement of how the dependent variable will be defined and measured numerically.

Critical thinking: Analytical thinking skills used to criticise and make sense of methods and results.

Creative thinking: Creative thinking involves generating alternative or original ideas for solving problems.

Rule of many: A way of increasing the accuracy or reliability of measurements by taking many readings and finding their average.

Accuracy: of a measured value refers to how close a measurement is to the correct value. The uncertainty in a measurement is an estimate of the amount by which the measurement result may differ from this value.

Precision: of measured values refers to how close the agreement is between repeated measurements. The precision of a measuring tool is related to the size of its measurement increments. The smaller the measurement increment, the more precise the tool. Decimal places express the precision of a measuring tool.

In Individual measurements, uncertainty refers to the number of decimal places in the measurement.

In a set of measurements, uncertainty refers to the variation in this set. Uncertainty = $\frac{\text{range}}{\text{n}}$

Validity: Valid results are ones which truly reflect what the investigation was set up to find out. All experiments should have high validity. Valid data is both accurate and precise.

Reliability: is the overall consistency of a measure. A measure is said to have a high reliability if it produces similar results under consistent conditions.

Repetition: Repeating the same experiment several times, using the same conditions and averaging results increases the reliability of the results.

Conclusions: statement of what the results have indicated. A valid hypothesis should be able to be *supported* or *refuted* based on the results (providing the results are valid themselves!).

Evaluation: Constructive criticism of the experimental methods used, with suggestions of how improvements could be made.

Good quality Investigations

Open investigations will be graded on performance of the following aspects:

- Ability to generate ideas - scanning for possible investigations, problem-solving, creative thinking.
- Depth of planning - thinking ahead, modifying procedures and equipment.
- Efficiency in conducting procedures - using methods that minimise errors, using equipment efficiently.
- Depth of interpretation of results - analysing trends, generating possible explanations.
- Effectiveness in evaluating outcomes – using critical thinking and self evaluation; identifying sources of error and possible amendments to the experiment to improve its validity.
- Quality of communication - using good verbal, written and graphical skills.

6.2 Generating ideas

It is quite difficult to think of novel and interesting ideas for open-ended investigations. Remember, the problem focus needs to involve a real-world context and not simply experiments that confirm what we already know, such as "Finding the value of g", or "Proving Ohm's Law", or "Showing that Q = mcΔt".

If you choose an investigation covering an area of interest of your own then you are more likely to be successful, focused and tenacious in the project when things go wrong.

You could begin by brainstorming for ideas from the following real-world focus areas:

- My kitchen
- My garden
- My school
- My sport
- My hobby
- My transport
- My clothing

Examples of some possible investigations here could be:

- How efficient is a microwave oven? (kitchen)
- How does air temperature change effect the temperature change of a pool? (garden)
  Or
  How does the depth of a pool effect the rate of temperature change? (garden)
- Which is the best pen? (school)
- Investigating the bounce of a squash ball (sport)
- Are fishing line breaking strains correct? (hobby)
- Investigating gear ratios on a bicycle (transport)
- How flameproof are nightdresses? (clothing)

In each of the possible investigations above the **aim** needs to be determined together with Operational Definitions of terms such as "best" and "most efficient" because what is regarded as "best" for one person may not be best in a different context.

For example the operational definition of best pen could vary from "The longest lasting pen" to the "One with the most friction on its grip" or the one with "The most visible or quickest drying ink". It is up to the investigator to define "best" at the outset.

Now complete the Quiz on page ???

6.3 Hypothesising

A hypothesis is an informed guess about what the outcome of an experiment might be. A hypothesis aims to predict a cause and effect using the scientific method. It is allowed to be a simple "if… then…" statement.

i.e. "*If the intensity of light incident on a metal plate increases, the voltage will increase in a direct proportion.*"

It can also aim to predict a correlation i.e. "*The voltage across a metal plate will be directly proportional to the intensity of light incident upon it.*"

Or it can remain completely open ended: "*To determine the relationship, if any, of the voltage across a metal plate and the intensity of light incident upon it.*"

In all cases, the independent variable and the dependent variable must be stated.

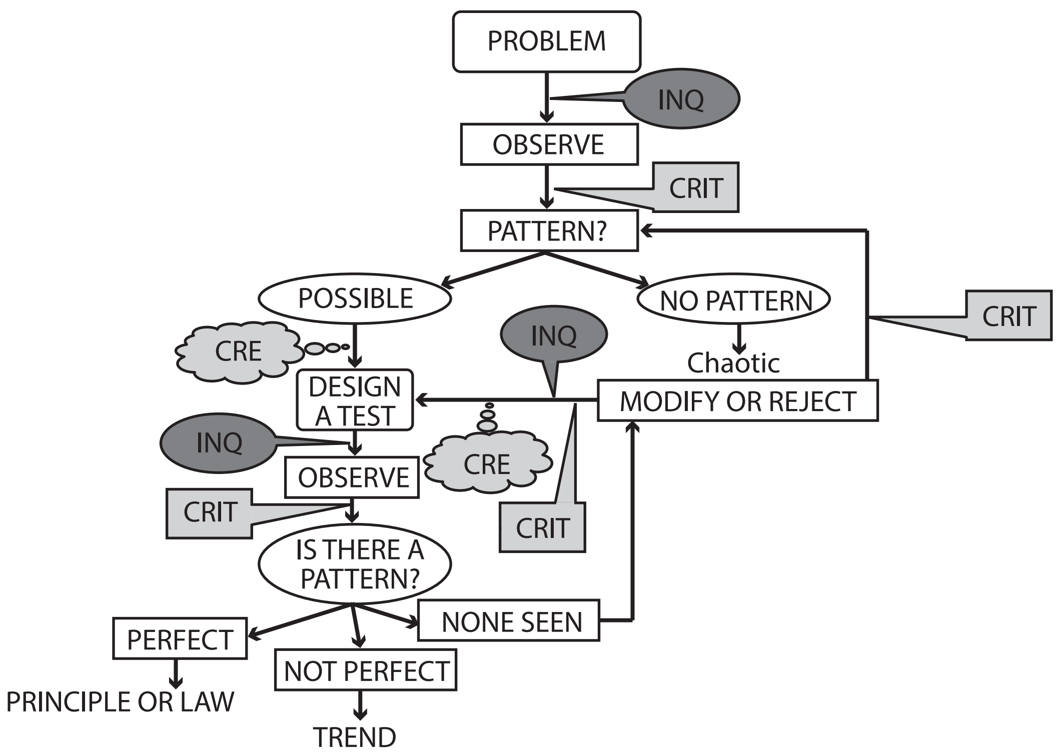
It is scientifically incorrect to state that a hypothesis has been proven correct as it would theoretically take an infinite number of trials (e.g. we cannot prove that CO_2 causes global warming). Scientists hedge their bets and say that a hypothesis has been supported (it is likely) or refuted – "… it is highly unlikely that…" etc.

Now complete the Quiz on page ???

6.4 Planning Investigations

Any investigation starts with a question or a problem that needs solving. Through careful observations a pattern may be suggested, this forms the basis of the investigation.

Example: "My clothes pegs decay after months outside but I have noticed the red ones seem to weaken in a shorter time. I wonder if the red ones are weaker and if it is the sun that is making them decay".



The test that is designed will need to see whether the sun is the cause of the decay and whether red pegs are more susceptible. If the tests are fair tests (rigorous), where all variables are controlled, then the investigation may show a pattern in data to support the hypothesis.

Good experimenters are able to use three different types of thinking: Inquiry thinking, critical thinking and creative thinking. The chart above shows the scientific method for investigations and the points in it where these thinking styles are used.

These three types of thinking are used at different stages of the investigation:

Inquiry Thinking requires skills of research and how to access related background information.

For Creative Thinking, different ideas and methods are brainstormed without any decisions being made.

Critical Thinking is the mode used to analyse and make decisions on which would be the best methodology.

If no pattern is apparent after analysing the data, then it may be that the tests used were faulty. Sometimes this may not be discovered until after the experimenter has become involved and gained experience with the apparatus and data. Methods may then have to be modified to allow greater accuracy and reliability.

6.5 Preliminary Testing

It is important, before making a hypothesis or committing yourself to a particular experimental design, to "get a feel" for variables and the equipment involved. For instance, you cannot make an hypothesis about which soap powder is best unless you know something about the ingredients of each one being tested, how much they cost, etc. You might plan to put one teaspoon-full of powder in each bowl to wash clothes but a preliminary experiment might then show that you actually might need one cup-full to make any significant difference in cleanliness.

Preliminary experiments allow you to get the values of variables for an investigation approximately correct which can save time later.

Now complete the Quiz on page ???

6.6 Controlling Variables

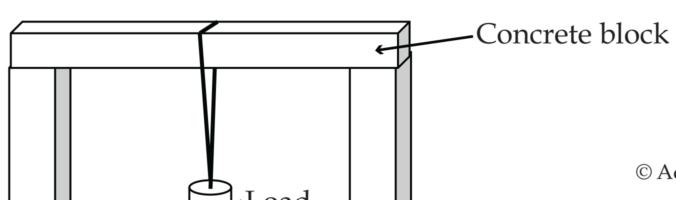
Variables are factors in an experiment that can be changed. The factor that you deliberately change is called the Independent Variable and the factor that you measure to see how it was affected in called the Dependent Variable. To see what effect the independent variable has on the dependent variable all other factors must be controlled e.g. if we want to see which fabric stretches the most we must control the size of each fabric so each has the same length and width and then, perhaps hang weights on each and measure the stretch. The independent variable would be the one we change (e.g. the fabric type) and the dependent variable is the one we measure (the amount of stretch).

A Student's Example Investigation

Problem: Does the addition of fibreglass to concrete make it stronger?

This is an open-ended experiment as there is no set way of doing it in the book. My operational definition of "strong" will be the greatest weight (in newtons) a concrete block can hold without breaking. The independent variable here is "amount of fibreglass added" and a control will be used where an identical concrete block will be tested which has no fibreglass content. The dependent variable will be the amount of load placed on the block to make it break.

Possible set-up:



Other variables controlled are:

- Proportions of sand, cement dust and water for the mix
- Setting time and temperature
- Dimensions of the block
- Spacing of the supports
- Positioning of the load

Hypothesis

I know that some concrete used for building has other materials added to make it stronger (e.g. steel) so I hypothesise that the more fibreglass that is added the stronger the concrete will be.

The amount of fibreglass in the mix is the independent variable as it is the one we vary and the average amount of weight needed to break the blocks is the dependent variable.

Using creative thinking I have come up with 3 possible designs which I will criticise using my critical thinking

Possible experimental design	Criticisms
Drop a weight onto the block and measure the height needed to break it.	It fractures slightly every time and would give varying results
Push up onto it with a hydraulic jack until it breaks.	Good control of variables but how will I know how much force has been applied?
Load up block as above and measure the maximum load withstood.	How do I judge the exact point of fracture?

A Fair Test set up for my chosen design would be:

- Use a common mould to make all the samples of concrete
- Use a constant mix of sand, cement and water for all blocks (research what a normal mix is)
- Experimental blocks contain a standard amount of fibreglass
- When set, each block is placed on the supports in the same position and a small load is added in the middle
- Weight is continually added until the block breaks and the load falls (my operational definition of "broken"). Weight added to break the block is the dependent variable.
- To increase the reliability of results 5 repetitions of loading for the experimental and Control blocks are carried out.

<u>Results</u> – loads (average in newtons) added until blocks broke

Control (N) (no fibreglass added)	**Experimental (N)** (With fibreglass added)
5.6	**6.3**
6.1	**7.0**
5.9	**7.5**
6.0	**5.6**
5.8	**8.0**

<u>Conclusions</u> (using critical thinking)

The addition of fibreglass seems to have increased the strength of the concrete as the average load supported by the blocks with no fibreglass was 5.88 N but with the fibreglass in the blocks supported an average load of 6.88 N – a 17% increase.

However there is a large variance in the readings for the Experimental blocks (range: 5.6 – 8.0) which indicates far less reliability in the results and hence more difficulty in being able to predict the breaking load of fibreglass-reinforced concrete blocks.

My method of testing the beam strength seems to have validity as it reflects the way concrete would be actually loaded when used in buildings.

Now complete the Quiz on page ???

6.7 The Rule of Many

In any investigation it is important to obtain the most accurate values within the limits of the measuring instruments.

If a set of scales only measures to 1 gram and we try to weigh one lolly on it of about 3 grams we could be as much as 1 gram out. This represents an uncertainty, of 1/3, or 33% in the mass of the lolly. We can increase the accuracy of our measurement by weighing lots of lollies, instead of just one. 10 lollies will weigh about 30 grams - again with an error of 1 gram. 1 in 30 only represents an error of 3.3% - using the same apparatus.

The procedure of combining lots together for measurement to increase accuracy is called the rule of many.

Now complete the Quiz on page ???

6.8 Analysing Data and Drawing Conclusions

After doing an accurate science investigation you will need to look at the results and use your critical thinking skills to “make sense of them” i.e. discover what the pattern is that links the dependent variable to the independent variable. If a pattern is very accurately known then it can be expressed as a mathematical equation (a ‘Law’) and in a graph all points will lie close to a line e.g. a graph of the volume of milk against how much it weighs. If there is some unpredictability then the points on the graph will lie around the trend line but will not follow an exact pattern e.g. the weights of people versus their heights.

Now complete the Quiz on page ???

6.9 Evaluating Experiments

Evaluation involves the highest order of thinking levels as it requires analytical and critical thinking mode to make criticisms and judgements of experimental designs. To do this, students must understand good techniques of investigation and think effectively about the control of variables. Good physics students should also be able to evaluate experiments in other subject areas, such as chemistry or biology, where the Scientific Method applies equally well.

To redesign an investigation the creative thinking mode must also be used

Now complete the Quiz on page ???

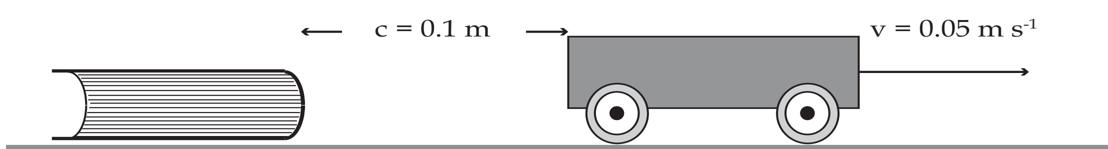
6.10 Processing Data

It is far easier to draw a line of best fit in physics than to estimate where a curve of best fit should be drawn through a set of data points. Many relationships in physics are linear e.g.

- The distance travelled in 1 minute at constant speed versus the speed of an object
- The stretch of a spring versus the weight on it
- The weight of an object versus its mass

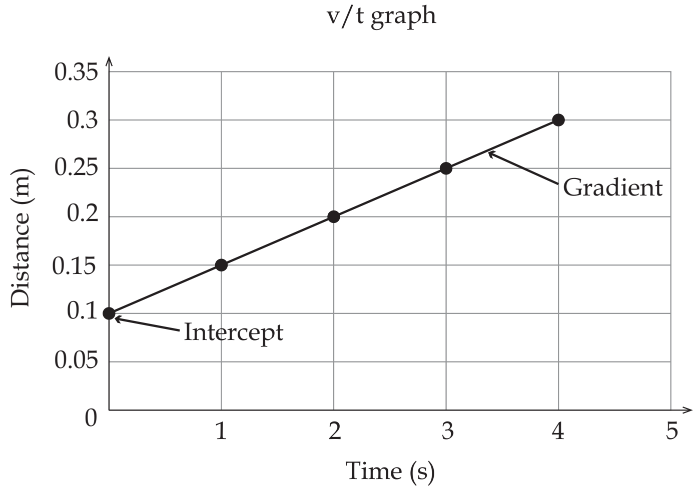
For all of these above the mathematical relationship is in the form of **$y = mx + c$.**

In the example below a trolley starts 0.1 m from a book and increases this distance by 0.05 m every second



The distance of the trolley from the book will vary as shown in the following table.

Distance (m)	Time (s)
0.10	0
0.15	1
0.20	2
0.25	3
0.30	4



For the graph:
y = distance travelled and
x = time.
m will equal the gradient of the line (speed) and c will be the distance of the object from the assigned zero position (the book edge).

To calculate the gradient of a straight line graph we use the formula $\text{gradient} = \frac{\text{rise}}{\text{run}}$

For accuracy, the triangle we use to calculate gradient must be large. i.e. two adjacent points on the graph will be inaccurate!

Suitable points would be point A and B shown above. So the gradient of the line would be:

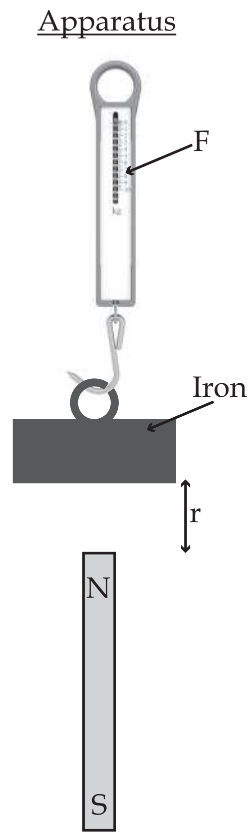
$$\text{gradient} = \frac{y_B - y_A}{x_B - x_A} = \frac{0.3 - 0.1}{4 - 0} = 0.05 \text{ m s}^{-1}$$

The data used in the example above are similar to those seen in maths books, where they have been generated from an equation: distance = 0.05t + 0.10

However, when data are measured, as with physics experiments (rather than found from an equation) the points will not lie directly on the line due to inaccuracies in making the measurements (ruler or stopwatch).

Many relationships in the Universe do not conform to a linear relationship:

- The height of a person versus their weight
- The brightness of a lamp versus the current flowing
- The force on an iron bar versus its distance from a magnet.



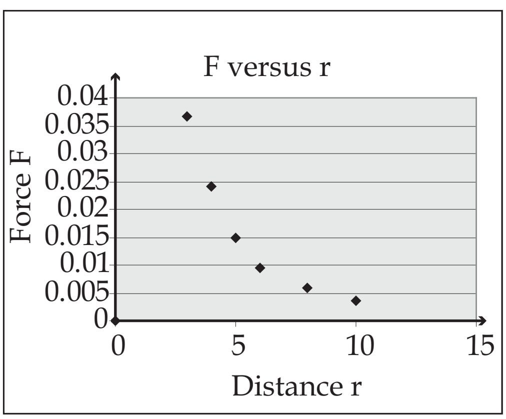
This last magnetic example involves the Inverse Square Law where force (F) should be inversely proportional to the distance from the magnet (r) according to the relationship:

$$F_m = \frac{k}{r^2}$$

i.e if the distance away increases by a factor of 2 then the force is reduced by a factor of 2^2 (4 times less)

Here are some results obtained from an investigation of magnetic force at different positions:

r (cm)	F (N)
0	0
3	0.0367
4	0.0242
5	0.0150
6	0.0096
8	0.0059
10	0.0035



978-1-74098-173-6

If we plot a graph of F versus r we will obtain a set of points that fit to a hyperbolic graph, where it would be difficult to draw a line of best fit.

However, we can change this to be a straight line graph (graph straightening) by plotting a different set of variables.

If the equation could instead be written as $F_m = k \cdot \frac{1}{r^2}$, this would now be in the form y = mx + c. From the equation, the gradient becomes the constant k and there is no expected y intercept.

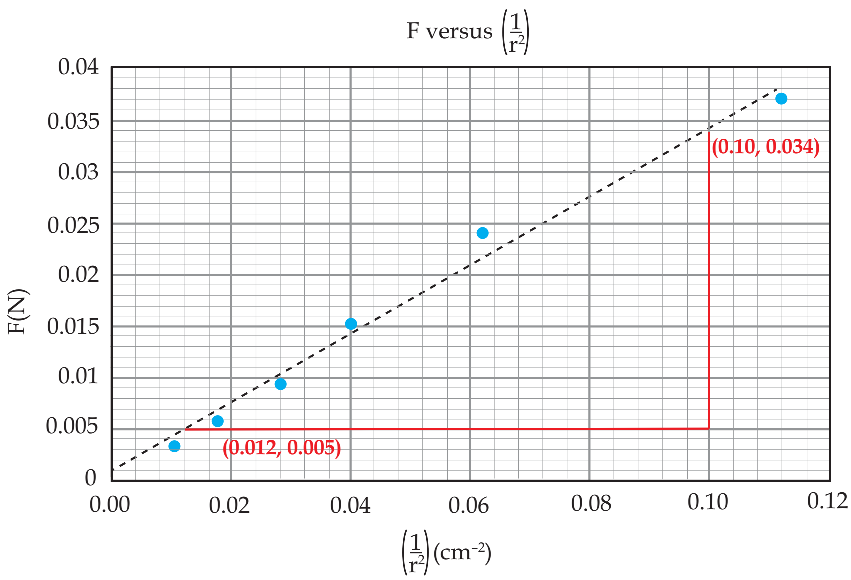
This will give a straight line of best fit.

The data must now be manipulated (inversing the square of r) and providing it in a new column.

Below is the linearised graph of F versus $\frac{1}{r^2}$

*Note: the measurements of r and F are expressed to the same decimal place as they were measured with the same ruler and newton meter. $1/r^2$ is expressed to the same significant figures as r as it is a multiplication/division/power of r.

r(cm)	$1/r^2$ (cm^{-2})	F(N)
3.0	0.11	0.0367
4.0	0.063	0.0242
5.0	0.040	0.0150
6.0	0.028	0.0096
8.0	0.016	0.0059
10.0	0.0100	0.0035



No effort should be made to force the line of best fit through the origin. When drawing the gradient lines, the triangle should occupy at least half of the line of best fit.

The gradient is therefore $m = \frac{y_2 - y_1}{x_2 - x_1} = \frac{0.034 - 0.005}{0.10 - 0.012} = \frac{0.029}{0.088} = 0.33 \text{ N cm}^{-1}$

Recall that the y and x axis have units, so the gradient must also have the units of the y axis divided by the x axis.

6.11 Uncertainy estimation from measurements

No instrument can measure a quantity to an infinite resolution. All measurements are limited by the instrument you are using. If the finest markings on a ruler are separated by 1 mm, you could make careful measurements to within 0.5 mm, but probably no better. To make more precise measurements you would need to use a piece of equipment with a much higher resolution e.g. a micrometer or vernier callipers.

So a ruler with 1 mm divisions will have an uncertainty of 0.5 mm in each reading

The position of the arrow could be written as: 62.7 ± 0.5 mm
or 6.27 ± 0.05 cm
or 0.0627 ± 0.0005 m

> The error/uncertainty value needs to be expressed to the decimal place of the measurement. It does not follow sig fig rules.

Note: When using a ruler (generally with mm intervals) we would tend to round the final digit to the nearest millimetre and give the position of the arrow as 63 mm or 6.3 cm. This is incorrect – you should always give your measurement to one significant figure more than the scale on the measuring device suggests (it is ok for that digit to be zero, if the scale is difficult to resolve). Your estimate to one degree of precision higher than the scale will be covered by the uncertainty.

<u>Calculations and Significant Figures</u>

The following two rules are used to determine the number of significant figures in the answer to a calculation.

Rule 1: When multiplying or dividing numbers

- Identify the number that is given to the least number of significant figures. Round the answer to the same number of significant figures.

Rule 2: When adding or subtracting numbers

- Identify the number with the least number of decimal places. Round the answer to the same number of decimal places.

Eg: $0.0104 \times 0.0\underline{23} = 0.0002392$ which must be rounded to 2 sig fig

$= 0.00024$

$= 2.4 \times 10^{-4}$

$105.55 - 34.\underline{2} = 71.35$ which must be rounded to 1 decimal place

$= 71.4$

$= 7.14 \times 10^{2}$

<u>Combination of uncertainties</u>

There are 3 simple rules which can be followed for each type of calculation.

Rule 1. When adding or subtracting data, add the absolute uncertainties.

Rule 2. When multiplying or dividing data, add the percentage uncertainties.

Rule 3. When raising data to the nth power, multiply the percentage uncertainty by n

Rule 1 example:

A length is measured be 13.42 ± 0.05 cm. A second length is measured to 8.03 ± 0.05 cm. What is the difference between the two lengths?

13.42 – 8.03 = 5.39 cm (2 decimal places)

Uncertainty = 0.05 + 0.05 = 0.10

difference in length = 5.39 ± 0.10 cm

= $(5.39 \pm 0.10) \times 10^{-2}$ m

> The answer must be given to the least number of decimal places.
>
> The uncertainty is written so that it varies in the last digit (5.39 ± 0.1 would be **incorrect**)

Rule 2 example:

The temperature of (0.30 ± 0.02) kg of water is raised by (5.5 ± 0.5)°C. Determine the amount of energy transferred to the water and the error in this amount.

Q = mcΔT

= 0.30 × 4180 × 5.5 Note: the specific heat is a given value, not measured.

= 6897

= 6900 J kg^{-1} K^{-1} (2 sig fig)

Total percentage uncertainty = %unc(m) + %unc(ΔT)

= (0.02/0.30) × 100 + (0.5/5.5) × 100

= 6.67% + 9.09%

= 16.6%

Q = 6900 ± (16.7/100)6900

= 6900 ± 1152 Note: error must be rounded to the same place value, ie 100s.

Q = 6900 ± 1100 J kg^{-1} K^{-1}

Rule 3 example:

The energy stored in a spring is given by: $E_k = ½kx^2$ where k is the spring constant and x the distance the spring is stretched (from equilibrium). For a particular spring k = (544.0 ± 3.0) Nm^{-1} and x = (0.120 ± 0.010) m. Determine the energy stored in the spring.

$E = \frac{1}{2}kx^2$

=(1/2)(544.0)$(0.120)^2$

= 3.9168

= 3.92 J (3 sig fig)

Total percentage uncertainty = %unc(k) + 2 × %unc(x)

= (3.0/544.0) × 100 + 2 × (0.010/0.120) × 100

= 0.511 + 2 × 16.7

= 33.9%

E = 3.92 ± (33.9/100)3.92

= 3.92 ± 1.3288

= 3.92 ± 1.33 J

Note: uncertainty values must always be quoted so that the uncertainty is in the final digit of the measured or calculated value. In a measured value (in an experiment), this should fall out naturally if the measurement is made correctly, but in a calculation, the value may need to be rounded.

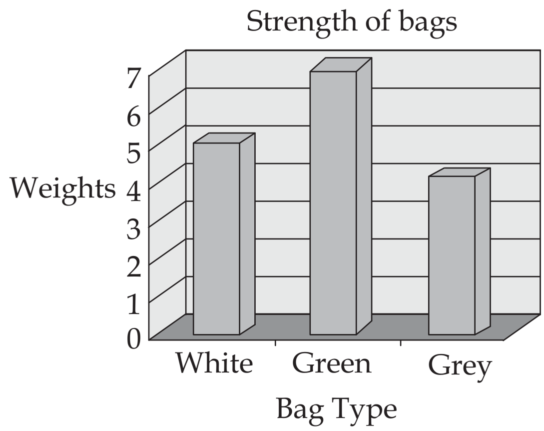
6.12 Graph plotting

It is fairly easy to plot graphs on graphics calculators from a set of tables giving values for the independent and dependent variables. However using software such as Microsoft Excel is much better as it is more visual, easier to manipulate and graphs produced can easily be cut and pasted into an experimental write-up.

<u>**Graph Types**</u>

a) Bar Graphs

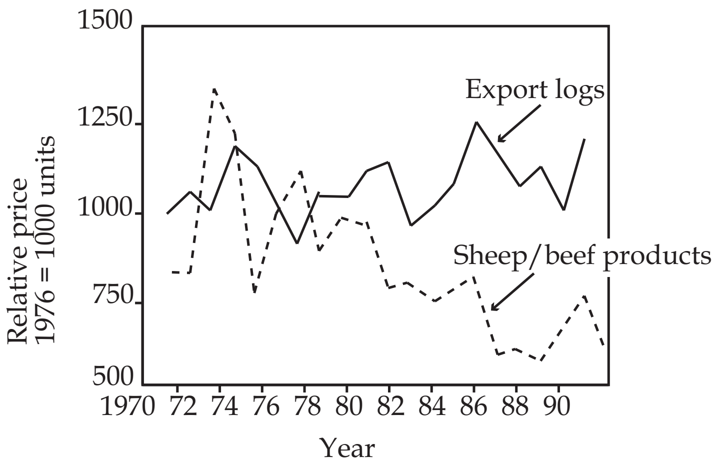
Bar graphs are rarely used in physics as they merely display variables that are discrete or non-continuous data.



e.g. Type of plastic and its strength – the different types of plastic have no relation to each other and are therefore stand-alone variables.

b) Point-to point graphs

These graphs are rarely used in physics as they have no equation linking one point to the next, although they may show a general trend overall.

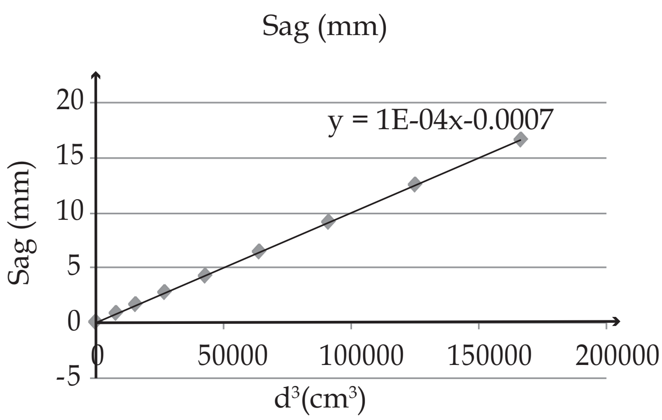


e.g. Weather patterns or economics data.

The 'export logs' graph shows a general trend upwards but the lines between points cannot really be trusted!

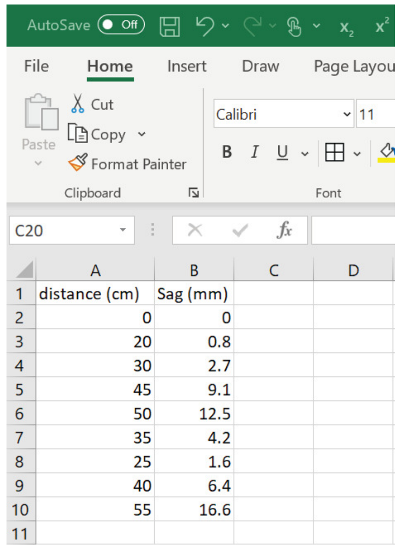
c) Line of best fit

In physics we are really involved with finding the overall equation that governs the system. But, as we have seen, experimental data has some uncertainty. Hence by drawing an estimated line through the points we are assuming that this line follows a valid equation describing the system. If we have as many points on one side of the line as the other then this is a way of averaging out the errors. The more points there are the more certain we can be that is the correct one.



If you have a set of data that you want to plot and draw a line of best fit through, then follow the steps below.

Open a new Excel spread sheet and type in your independent (x) values in column A and dependent values in column B.



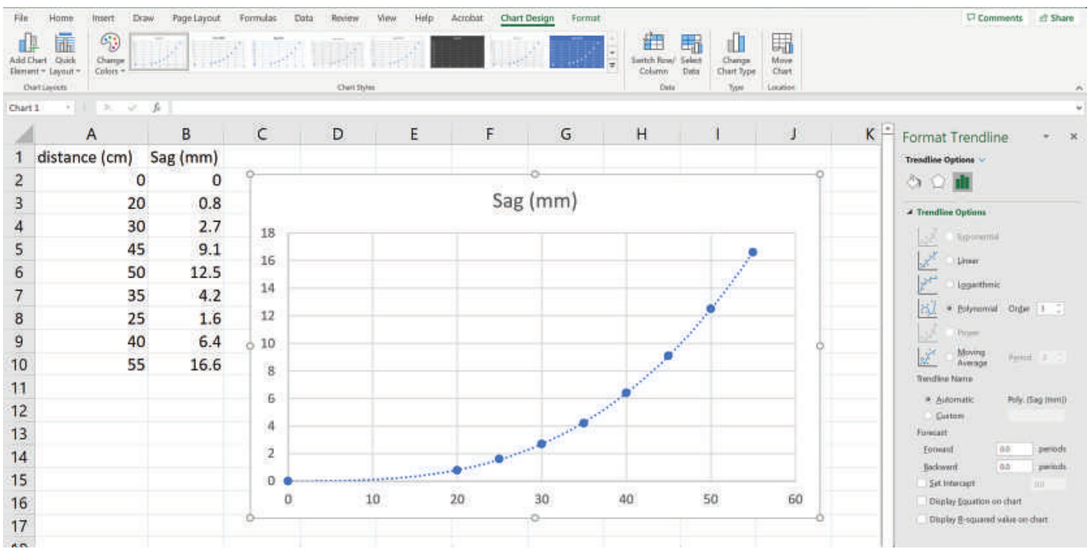
Highlight both columns A and B by clicking and dragging, including the column headings ("Distance" and "Sag"), then click on the "Insert" tab at the top. Click on the box for XY Scatter Graphs. The graph of the data in the table will plot automatically.

Right click onto one of the points of the graph and an option box will appear with an option of "add trend-line".

If you click on this it will draw the line of best fit for you, but the prompts ask for the kind of graph you want:

The options for types of graphs are:

Exponential
Linear
Polynomial *order?* ☐
Power
Moving average



If the graph looks linear then clicking on the 'linear' box will draw in the line of best fit but if it is obviously curved like the one shown above then by choosing 'polynomial' the graph will be drawn according to what power polynomial is required.

By clicking a '2' in the order box will choose an x^2 graph or order '3' will plot a cubic graph of y versus x^3.

By trying each order in turn and then seeing which graph fits the points best, the equation of the line can be estimated by clicking in the box at the bottom of this window where it prompts "Display equation on graph".

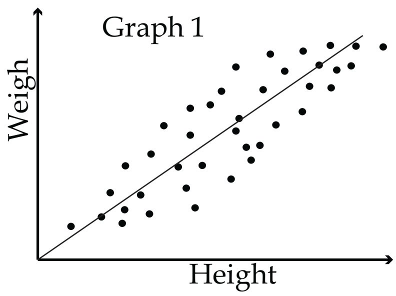
6.13 Testing Data

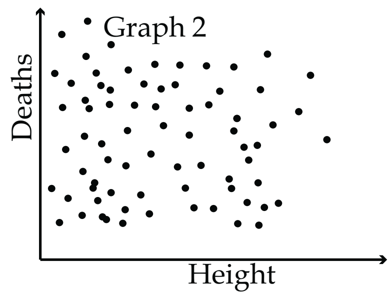
If we suspect there is a relationship between two variables there is a simple statistical measure that tells us the likelihood that the variables are co-related. This is known as the regression squared co-efficient or R^2 value. R^2 is a statistical measure of fit that indicates how much variation of a dependent variable is explained by the independent variable(s) in a regression model.

The R-squared value R^2 is always between 0 and 1 inclusive.

Correlation	R^2 Value
Perfect positive	1
Very strong positive	>0.95
Strong positive	0.9
Weak positive	0.6
No association	<0.2
Weak negative	–0.6
Strong negative	–0.9
Very strong negative	<–0.95
Perfect negative	–1

For instance, taller people are generally heavier but there are skinny tall people and plump short people which individually go against the trend. The graph of weight versus height would be like graph 1 below. Although there is a large variance, a linear trend-line could be drawn with an associated R^2 value.





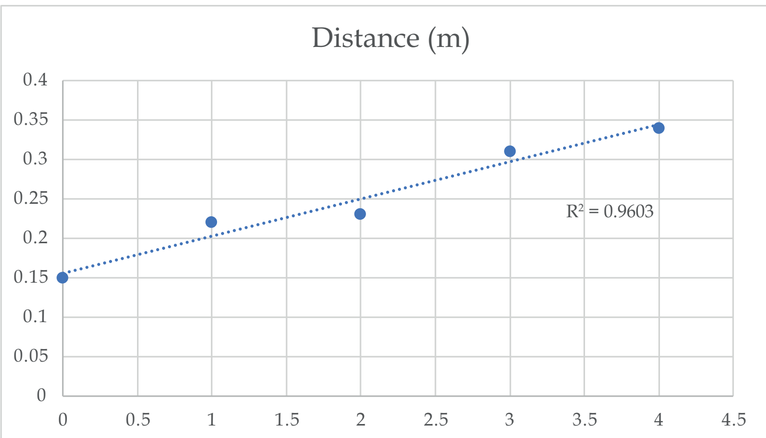
R^2 = 0.8 = less than strong positive correlation

R^2 = 0.1 = No correlation

In physics, a meaningful correlation can be drawn if the R^2 value is above 0.9. The higher the R^2 value, the more confidant you can be about the relationship between the variables and your conclusion drawn as to the outcome of your hypothesis.

Looking at the data from a trolley similar to the experiment in section 6.10, we can test to see how confident we are that distance is linked with time.

Time (s)	Distance (m)
0	0.15
1	0.22
2	0.23
3	0.31
4	0.34



In this case an R^2 value of 0.96 is a very strong positive correlation. The conclusion is that we are quite confident that there exists a relationship between distance and time.

The link between number of deaths on the road and people's height may be totally random, in which case a graph like graph 2 might be found with a very low R^2 value.

Now complete the Quiz on page ???

Aims Quiz

In each of the following investigations scenarios decide on **two possible aims** there might be for the experimenter.

1. A paint technologist used several different kinds of coloured paint and painted each one onto a concrete wall. The technologist came back every 2 months and observed the painted areas with a hand lens.

(i) ____________________

(ii) ____________________

2. A clothing technologist used an old cinema for an experiment on coloured cycling shirts, which involved 30 people sitting along a row of seats and a boy on the stage wearing each shirt in turn. The cinema lights were gradually dimmed and the 30 people wrote down results on sheets of paper, which were later collected in.

(i) ____________________

(ii) ____________________

3. An Infrared camera allows us to see hot and cold areas of an object – hot shows up as red on the picture and cold shows up as blue. The Electric Power Company uses an Infrared camera to take pictures of high voltage pylons and the insulators holding the cables.

(i) ____________________

(ii) ____________________

4. A timber company has produced a new weatherboard, which is coated with polystyrene and tests it by making a model cottage from this board in a field. Four similar model cottages stand next to this one, each made of a different type of weatherboard. In each one is a digital thermometer linked to a computer for recording the temperatures at regular intervals over a period of one week.

(i) ____________________

(ii) ____________________

5. A cosmetics company uses human hair to test its range of shampoos. It does this by washing a bundle of hair with a different product, drying it and then pulling a brush through it 1000 times.

(i) ____________________

(ii) ____________________

Hypothesis Quiz

For the investigation set-ups below give a reasonable hypothesis and state the logic behind each.

1. A building company has produced a new weatherboard, which is coated with expanded polystyrene and tests the product by making a model cottage in a field from the weatherboard. Four similar cottages stand next to this one, each made from different types of weatherboard. In each is a digital thermometer linked to a computer for recording the temperatures at regular intervals over a period of one week.

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2. Emily has been asked by her mother to try out the 3 different hairdryers to see which she should use. The Remington hairdryer sells for $150, the Electrolux sells for $85 and LG sells for $27. Emily tries to design a Fair Test for each hairdryer and sets up an experiment using each hairdryer on her doll's hair.

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3. In a physics experiment on radioactivity a scientist is investigating the absorbing properties of metal sheets of different thicknesses. He sets a gamma ray source in front of a Geiger counter and places each metal sheet in front of the Geiger tube and takes readings on the counter.

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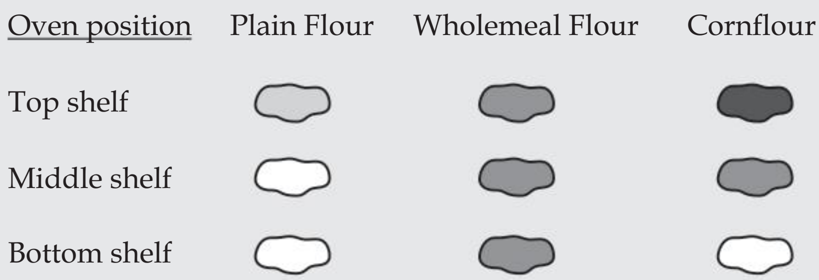
4. Anton wants to find out how absorbent different kinds of papers are for mopping up water spills. For this he places a sheet of each paper over a water spill for a given time and then measures the gain in weight of the papers. Paper A is newspaper, paper B is writing paper, paper C is brown wrapping paper and paper D is the same paper that banknotes are made from.

5. Suzie is testing out different wet-suit materials to see which is warmest. She wraps a bottle of hot water in a layer of each of the materials and measures the water temperatures after 1 hour. Material 1 is white and 3 mm thick, material 2 is black and 5 mm thick, material 3 is white and 6 mm thick and material 4 is black and 3 mm thick.

Preliminary Testing Quiz

1. David is investigating the difference in temperature of different places in an oven. For this he wants to use the "amount of browning" of some balls of dough to indicate the hottest places, but he is not sure what type of flour would be best. He sets up a preliminary experiment using 3 different types of flour and 3 different positions in the oven. Here are the browning results from his preliminary tests:



What useful information has this preliminary test given David about flour type and oven position for planning his full investigation?

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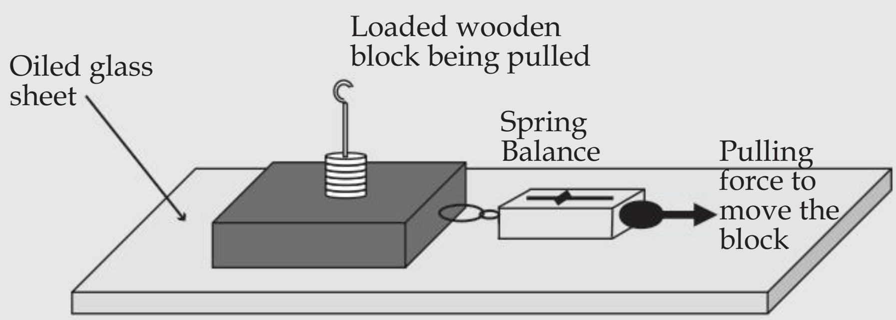
2. Tamara's science project measured the frictional force on a metal plate pulled over a glass slab with 3 different types of oil placed between the 2 surfaces.



Tamara sets up a preliminary experiment using the equipment, shown above so she can get an idea of what sized weight would be best to use on top of the wooden block. The pulling forces needed to move the block for the different oils and different weights are shown below (all in newtons)

Load	**Oil 1**	**Oil 2**	**Oil 3**
0 grams	2.5	2.4	2.6
100 grams	4.2	4.3	4.5
200 grams	5.6	5.8	5.9
300 grams	7.1	7.8	8.3

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a) From these results what weight would be best to use when she does the full investigation? Why?

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b) Which of these oils seems to be the 'best' from the preliminary tests? Explain your choice.

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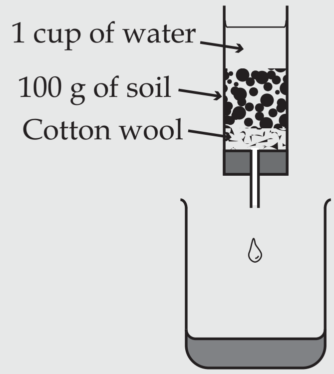
3. Harry was going to set up an investigation of the water retention of different soils around Perth as he had heard that a lot of water just runs through the soil. For his preliminary experiment Harry set up a tube-full of each soil and poured a measured amount of water into the tube.



What Harry wanted to estimate from this preliminary experiment was the time needed for drainage that would give a good variation between the soils. The volumes of water passing through the tube for each soil in different times are shown in Harry's results table below.

Collection Time	Soil 1	Soil 2	Soil 3
5 Minutes	4 mL	74 mL	8 mL
10 Minutes	39 mL	75 mL	11 mL
20 Minutes	60 mL	75 mL	12 mL
60 Minutes	75 mL	75 mL	12 mL

a) What collection time should Harry use to judge the degree of drainage for each soil?

____

b) What are the preliminary results for the relative water retention abilities for each soil? (Rank the soils from best retention to least).

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4. Cindy wanted to try out an experiment on the rusting of iron for a possible Science Talent Search project but she had no idea how long to leave her samples of iron in the water. She set up a preliminary experiment with iron nails in salt water, each nail being treated in a different way to see how well it prevented rusting. Part of her investigation logbook is shown below.

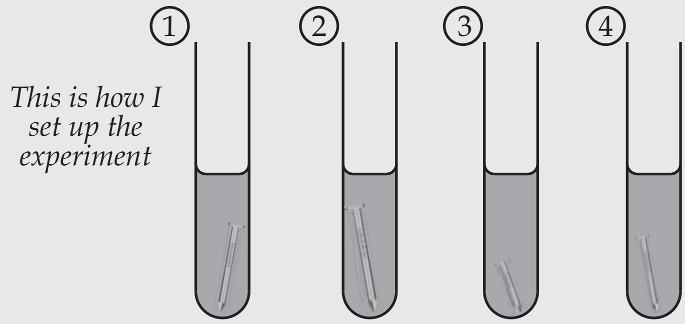
I weighed all of the nails beforehand and treated them in the following way:

Exp 1 The nail weighed 6.71 grams and was covered in oil

Exp 2 The nail weighed 9.13 grams and was covered in zinc-based paint

Exp 3 The nail weighed 3.95 grams and was covered in special white paint

Exp 4 The nail weighed 5.50 grams and was left as it was, had no treatment



I reweighed all the nails periodically over a number of days of sitting in the salty water and here are the results of the **weight losses** for each nail.

No. of days	Experiment 1	Experiment 2	Experiment 3	Experiment 4
1	0.62 g	0.11 g	0.22 g	0.70 g
5	0.81 g	0.15 g	0.29 g	1.32 g
20	0.85 g	0.18 g	0.30 g	2.65 g
50	0.85 g	0.18 g	0.30 g	5.50 g

a) How many days should Cindy leave the nails in the salty water to allow a good comparison of the amounts of rusting when she does the full investigation?

b) Cindy's friend Bill says that these experimental results cannot be used as a Fair Test because all the nails have a different mass. Is Bill right? If not, what mathematical calculations could be used in the comparison?

c) From your calculations, which treatment seems to be the best one in preventing rust from the preliminary experiment? (show calculations)

5. For a physics investigation, John and Josh wanted to experiment with different types of paper to see which would be best for wrapping heavy items in a hardware shop. The boys only had 2 types of spring balances to work with – one read up to 5 newtons and the other 10 newtons. For their preliminary experiments they needed to find the best thickness of paper to use in the accurate experiment so they each set up their own test rig to measure breaking forces.

John's test rig is shown below.

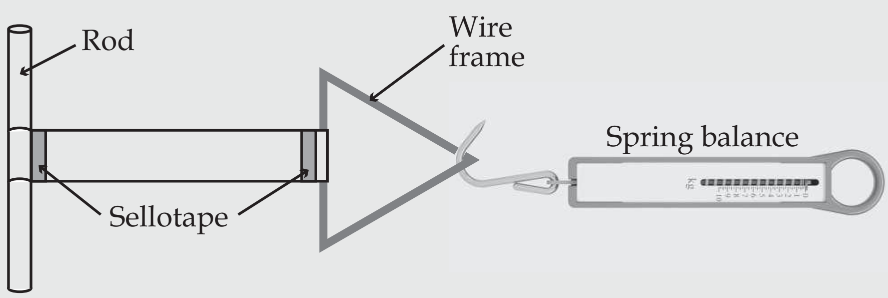
<u>John's test results</u>

Thickness	**5 cm**			**2 cm**			**0.5 cm**		
Paper	Trial1	Trial2	Trial3	Trial1	Trial2	Trial3	Trial1	Trial2	Trial3
Type A	10	4	8	8	6	2	1	1	1
Type B	7	3	9	7	4	7	1	1	1
Type C	N	N	N	10	5	10	1	1	1

(The letter 'N' in the table indicates that the paper did not break)

Josh used a different test rig, shown below.

<u>Josh's test results</u>



Thickness	**5 cm**			**2 cm**			**0.5 cm**		
Paper	Trial1	Trial2	Trial3	Trial1	Trial2	Trial3	Trial1	Trial2	Trial3
Type A	10	9	10	6	6	5	1	1	1
Type B	N	N	N	7	6	7	1	1	1
Type C	N	N	N	8	6	7	1	1	1

Consider the two different experimental designs and the results produced to answer the following questions:

a) Which seems to be the best experimental design, and why?

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b) Comment on the **variance** shown in the results of John and Josh's investigations (see "meanings of terms" if you do not understand the meaning of "variance")

c) From these preliminary results, what thickness of paper should be taken in the accurate investigation to make the best comparison between the different papers? Explain your choice.

d) Which paper seems to be the strongest? Explain.

Variable Control Quiz

1. A student wanted to find out "Which brand of socks keeps feet warmest". He set up an experiment where bottles of hot water were put inside each sock and the temperatures observed over a period of time.

   a) Write down the names of the Dependent and Independent Variables.

   Independent ______________________________

   Dependent ______________________________

   b) Say how you could control the main variables to produce a Fair Test.

   ____

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   c) On what measurement will the judgment of the "best" socks be made?

   ____

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2. "The more coats of paint there are, the better the rust protection".

   How could a Fair Test situation be set up to investigate this statement?

   a) Give a title for the Dependent Variable and say how it might be judged in the most accurate way.

   ____

   ____

   ____

   b) List the other main variables in this Fair Test and say how each could be controlled.

   ____

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3. Concrete is made from a mixture of sand, cement dust, gravel and water - but "Which mix gives the greatest strength?"

   Consider the problem and how a Fair Test could be set up for different mixes of concrete.

a) Give the title of the Dependent Variable and a possible way of judging this accurately (you may need a diagram).

b) List the Independent Variables in the Fair Test and say how each could be controlled.

4. "Which brand of tissue absorbs most water?"

a) Name the Dependent and independent variables in this investigation.

b) How could you set up a Fair Test situation for this investigation, which allowed for the fact that all the tissues used are of different sizes?

5. "Which contains the most chemical energy – candle wax or kerosene?"

Design a Fair Test that you could use to find the answer to this question.

a) Sketch a labelled diagram of the apparatus you would use below.

b) Say how you would control all the main variables for the Fair Test.

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c) Say what the Independent and Dependent variables are for this investigation.

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Rule of Many Quiz

1. One ball-bearing from a box has a mass of less than 1 g. How could you use kitchen scales with a smallest reading of 10 g to obtain a fairly accurate measure of a ball bearing's mass?

2. A tap is dripping in your house and you have a measuring jug that only measures to the nearest 100 mL.

   a) How could you find the volume of one drop of water?

   b) If one drop of water was found to have a volume of 0.62 mL, how much water would be wasted from your shower in a year if it drips 22 times in a minute? (Show your calculations)

3. A student wants to estimate the time period of an indicator light on a car which is less than one second. Explain how the student could obtain an accurate estimate with a stopwatch only reading to the nearest second.

4. Explain how you could find an accurate answer for the thickness of one page of this book using only a ruler in your bag. Write down your answer for thickness.

5. Explain how you could estimate the total length of line that can be drawn with a pen without using it until it runs out.

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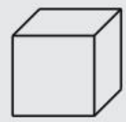
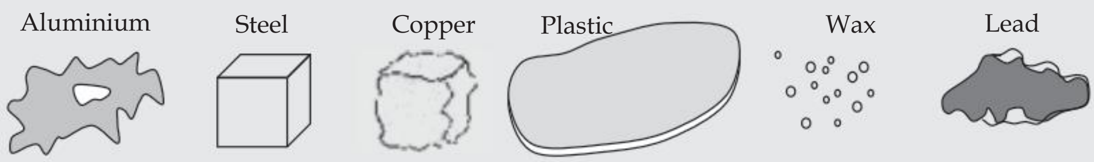
Analysing Data Quiz

1. Ken comes from Indonesia and is interested in finding out the temperatures of fires used in cooking in his village as a science project. He has planned to do this by using cubes of different materials placed in the fire and seeing which ones melt and which ones do not. Using his inquiry skills Ken has looked up the melting points of the blocks he is going to use and has put them into a table:

Material	Melting Point (in °C)
Aluminium	660
Steel	1540
Copper	1084
Plastic	159
Wax	82
Lead	327



Before heating, all the blocks of materials looked like the one above, and after heating, like the ones below



Write your conclusions about the likely temperature of the fire, with reasons.

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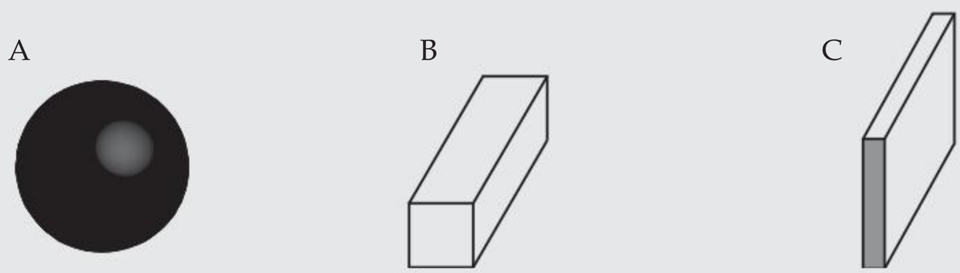
2. In her physics project, Anna investigated the temperature drop when different shaped containers were filled with boiling water and left to cool for 30 minutes. Some of the containers were painted black and some were white, but all had the same internal volume to be filled with water. The shapes are shown below.

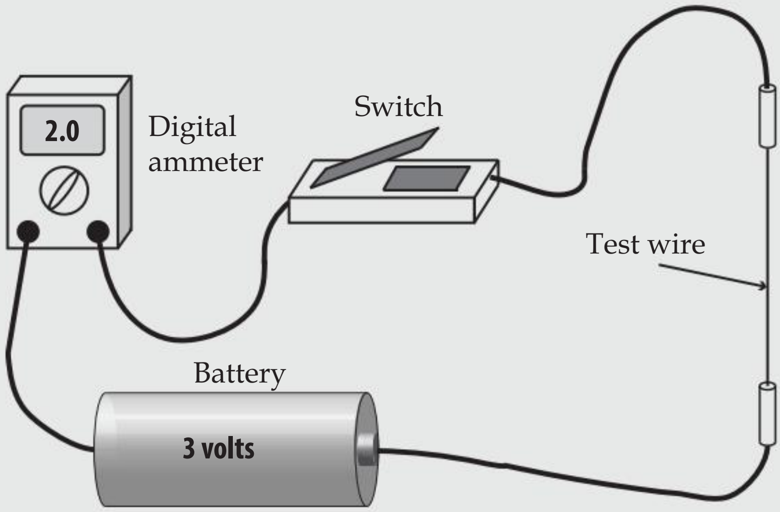


Anna's results are shown below for the 30 minutes cooling period:

Colour	Shape	Temperature Drop (°C)
White	A	5
White	B	15
White	C	40
Black	A	35
Black	B	54
Black	C	60

Write your conclusions from the data shown in the table.

3. Tim has decided to do a physics project on electricity and has set up a circuit with a 3 volt battery, some iron wire and an electric current measurer (ammeter).



Tim wants to find out how the current through a wire depends on its diameter and length. In his investigation he clamped test wires with two different diameters and two different lengths in the position shown on the diagram. His results table is shown below.

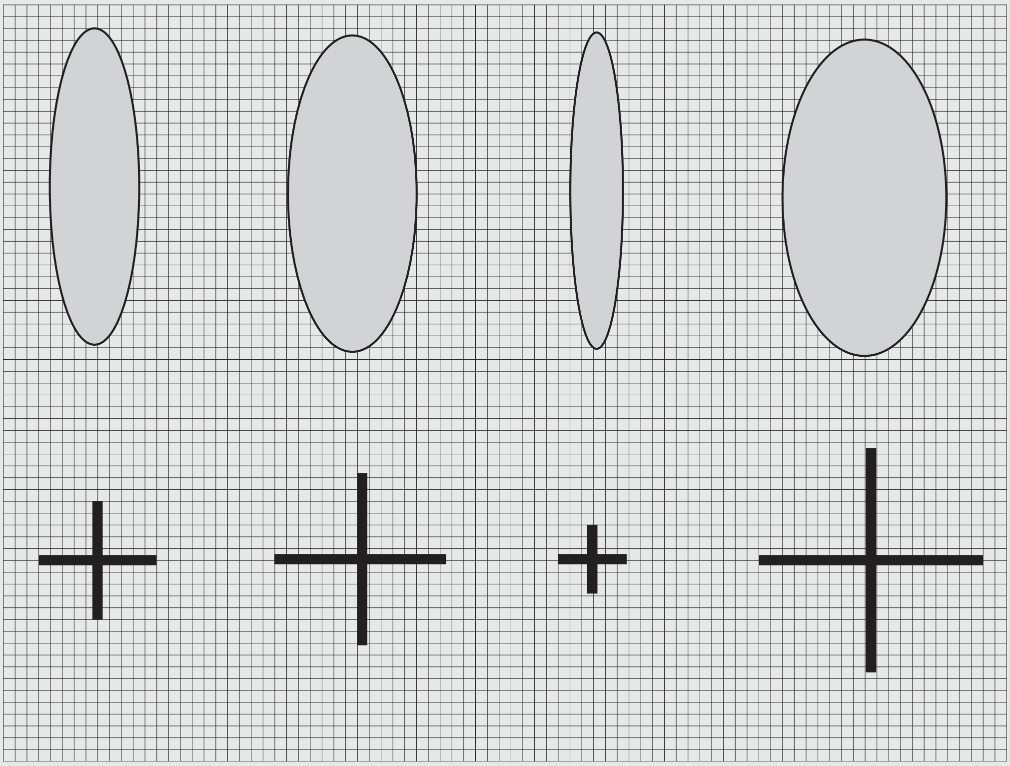
Diameter (mm)	Length (cm)	Current (amp)
0.1	10	0.51
0.2	10	1.99
0.2	5	4.13
0.1	5	1.09

a) What conclusions could Tim reach about how the length of a wire affects the current flowing?

b) How does the diameter of the wire affect the current flowing? Is this a simple relationship?

c) Tim's friend Sarah thinks that the current may be directly related to the **area** of the wire, rather than the diameter. Do some calculations to see whether this hypothesis is supported.

4. For her Science Talent Search project Jane investigated the way different shaped lenses magnify the drawing of a cross on paper. She made an accurate, scale drawing of each lens and the image produced by each one. Part of Jane's project diary is produced below. Each small square represents 1 millimetre.



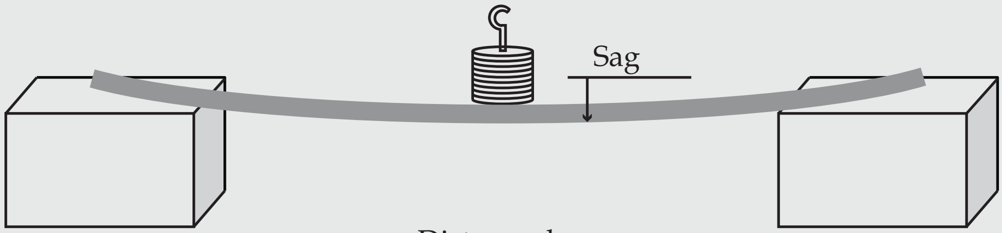
For each lens of different curvature the size of the image in the lens is shown below it. Make measurements using the graph paper divisions and fill in the table below with these measurements.

Width of Lens				
Size of Image				

a) From the table of results what pattern can you see?

b) Can you write a mathematical relationship between the dependent and independent variables (i.e. an equation)?

5. Samantha always wanted to be an engineer, like her mum and was particularly interested in bridge design. For her physics project, she made up a model wooden bridge held at both ends on wooden blocks as supports.



She put 100 gram weights on the bridge to represent the cars and measured how much the bridge sagged in the middle, keeping d constant. This gave her an idea of how a real bridge would behave.

Load (grams)	Sag (mm)
0	0
100	4
200	9
300	12
400	15
500	20

Samantha's table of results is shown above. Use this to plot a graph of Sag (y) against Load (x) on an Excel spreadsheet.

a) What kind of graph is produced by this plot? What pattern is shown by the results i.e. how is the sag related to the load?

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b) In another investigation, Samantha kept the load the same and moved the wooden blocks further apart and measured the sag again. The results of this investigation are shown in Table 2.

Use this to plot a graph of Sag (y) against Distance d (x) on an Excel spreadsheet.

Distance d(cm)	Sag (mm)
20	0.8
30	2.7
45	9.1
50	12.5
35	4.2
25	1.6
40	6.4
55	16.6

Sketch the shape of the graph in the box above.

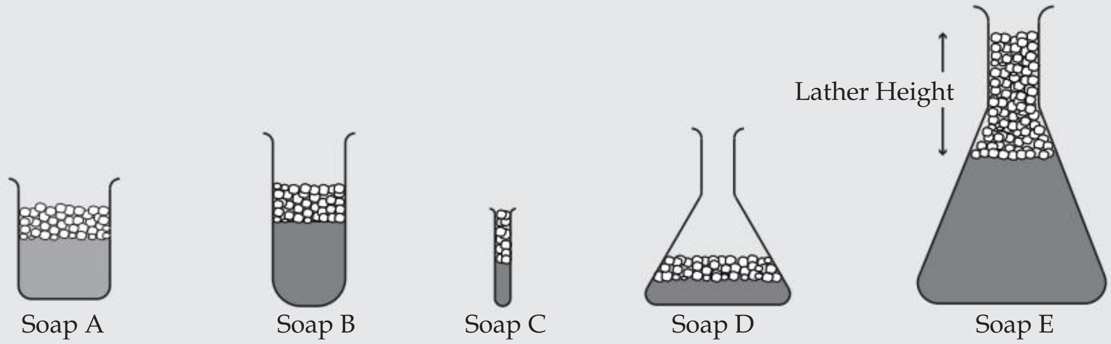
c) What pattern is shown by the results i.e. how is the sag related to the distance apart of the supports?

d) Write the equation for the curve from Excel plot.

e) What other variables might affect the sag for these model bridges?

Evaluating Investigations Quiz

1. The diagrams below show the results of a simple experiment that compares how well different soaps can produce lather.



Here is a sample of Jessica's investigation report:

For this experiment dirty glassware from a laboratory was chosen and some water added. A piece of each different soap was then dropped into the water and shaken up to form a lather (small bubbles). The height of each lather was measured to find which kind of soap was best (Soap E was judged to be best).

Discuss and evaluate this experiment, giving your criticisms of the experimental design and variable controls. Say how the investigation could be improved.

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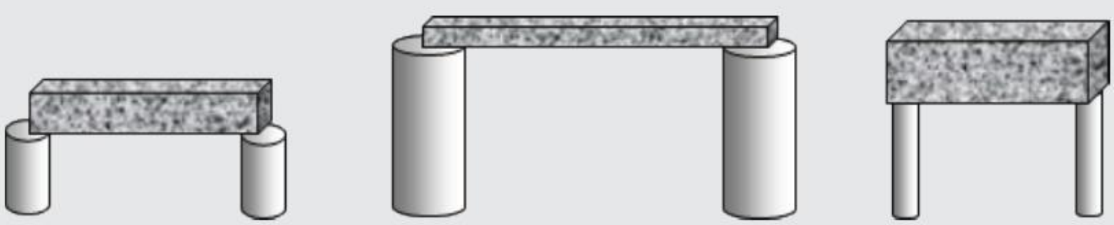
2. The diagram below shows a testing method used to find the strengths of 3 different types of concrete mixes. Concrete is made of sand, cement dust, aggregate (small pebbles) and water.



The method used for testing the strength of each block was to hit each one with a sledge hammer and to note how many hammer blows it took to break them.

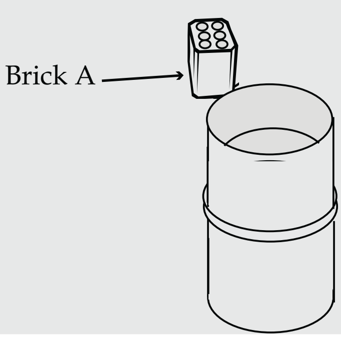
a) Evaluate this method as a fair test for the strength of concrete and write your criticisms.

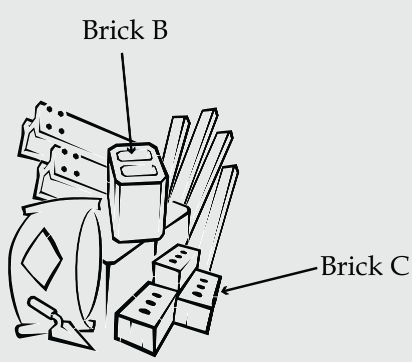
b) Identify and list the most important variables that you think would need to be controlled for a good test of different concrete mixes.

c) Make a sketch of a test rig that could find the braking force of a concrete block in a more scientific way.

d) How would you use the Rule of Many in this investigation?

3. Jarrad's dad is a builder and so Jarrad wanted to investigate the water absorption of different types of bricks for his physics project. In his experiments he half-filled a 200 litre oil drum with water and marked the water level on the side. He then put one type of brick into the water for 5 minutes and then marked the new water level (it went down as the brick absorbed water). In his maths lesson, he found out that the volume of water absorbed would be $\pi \times r^2 \times h$, where h is the drop in water level and r is the radius of the drum.





Jarrad's results were: Water absorbed by brick A = 620 mL
Water absorbed by brick B = 1870 mL
Water absorbed by brick C = 1590 mL

He concluded from these results that brick B was made of the most absorbent type of material.

a) Discuss Jarrad's method of investigation, mentioning good and bad points

b) Are there any points that could be improved with his method of measuring the amount of water absorption?

c) How could Jarrad have allowed for the fact that the bricks were of different sizes (no cutting allowed)

4. For her HASS project Tanya was investigating the safety records of different cars and found some statistics on road deaths from one of the states in Australia. She drew up a table to show all these results.

Car Model	Road Deaths
Volvo 770	132
Kia Menta	549
GM Mini	813
Porsche 811	42
Skoda Sisco	85

Tanya made a conclusion that the Porsche 811 was the safest car to drive.

a) Discuss the quality of Tanya's design for discovering the safest car.

b) What variables are there that need to be allowed for in comparisons like these?

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c) How would the Rule of many be applied in this investigation?

d) The Porsche 811 was only introduced into Australia in 2001. How could you allow for this in a comparison where data was collected over a different number of years?

e) Tanya suspects that the personality and sex of a person buying a high performance car like the Porsche might be different from that of a person buying a Skoda. How could this be allowed for in an investigation, if socio-economic details were available on record?

5. <u>Plastic Bag Investigation</u>

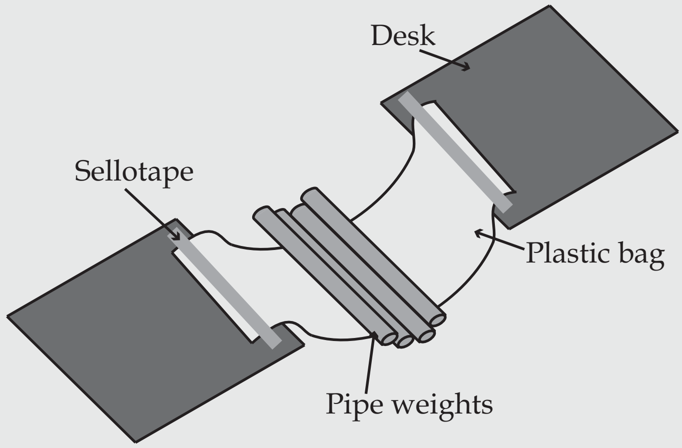
The following two investigations were performed by two different students. You need to evaluate the quality of their experimental designs and conclusions

i) <u>Jeffrey's Investigation.</u>

<u>*Planning*</u>

We are going to see how strong 3 different types of plastic bags are by putting weights on them. We will keep the length of each bag being tested the same.We predict that the green bag will be stronger because it is coloured green like a shopping bag.

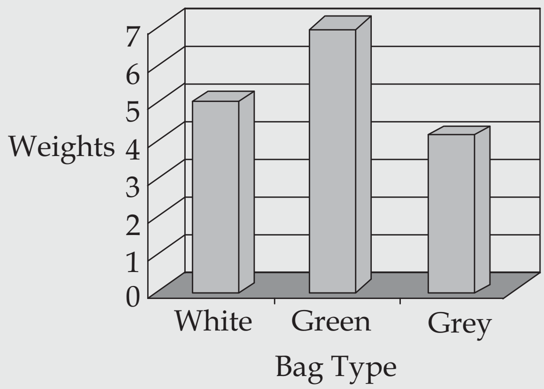
<u>Diagram</u>



We used lengths of pipe for weights but made sure they didn't fall on anyone's feet.

Table of weight to break bag

White bag	5 weights
Green bag	7 weights
Grey bag	4 weights



Conclusions

The green bag material was the strongest and the white bag was the weakest. The prediction was correct which proves the colour made it the strongest plastic.

ii) Karen's Investigation

Planning

I believe there are 4 major independent variables affecting the strength of a strip of plastic bag: length, width, thickness and type of plastic. If we want to see how the plastic type affects the strength we must keep all the other variables the same. My hypothesis is that the green plastic will be stronger because it feels the thickest.

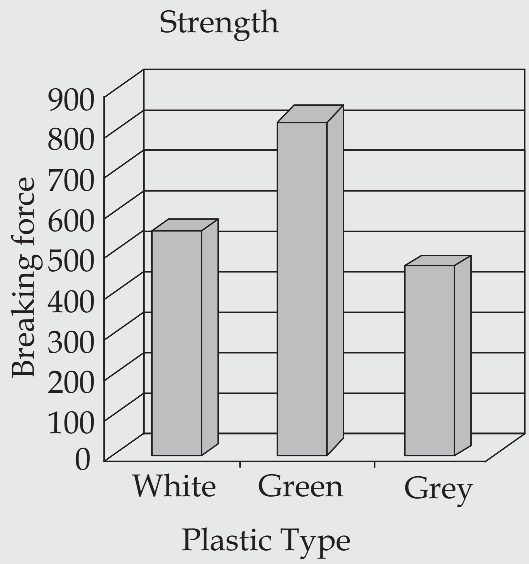
Method

1. Cut strips to be 30 cm long and 1 cm wide and measure the thickness to see if they are the same. We did this by putting 20 pieces on top of each other and measuring the thickness (then dividing by 20)
2. We did a preliminary experiment to find what size spring balance was needed. We found a 25 newton balance was good.
3. Pulled the balance and read the spring balance maximum value as the plastic just breaks.
4. We repeated each experiment 3 times with each plastic to get the averages.
5. We drew up a table of values
6. (Extra experiment) Each plastic sample was pulled again with the force gradually increasing and measured how the length changed for each one.
7. We plotted 2 graphs to show the data.

Results

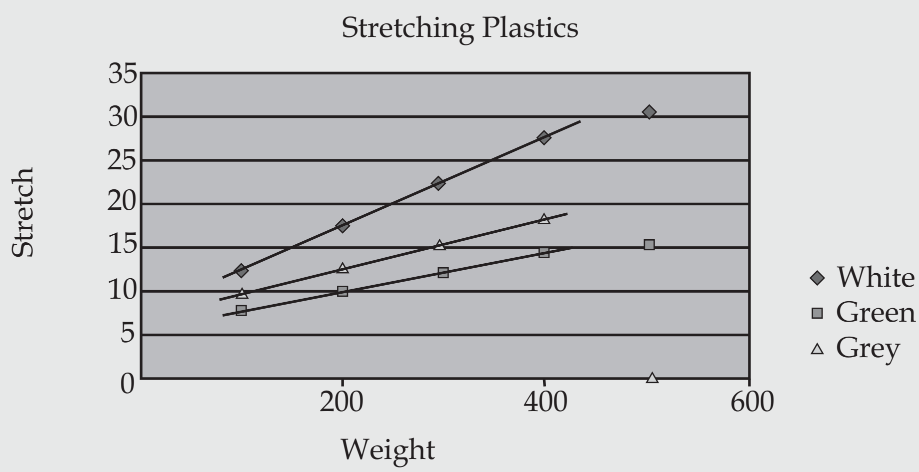
Force to break each plastic strip (grams)

	1	2	3	Average
White bag	550	500	525	525
Green bag	720	780	930	810
Grey bag	420	460	440	440



Extra experiment (Results of stretch)

Weight	**100**	**200**	**300**	**400**	**500**
White	12.5	17.2	22.2	28.1	31.0
Green	7.5	10.1	12.4	14.3	15.5
Grey	9.8	13	16	18.7	Broke



Conclusion

The green bag seems to be the strongest as it can hold about 780 g before breaking (we suspect the last reading of 930 g was an error) the grey bag was weakest.

From the extra experiment the white bag is the stretchiest as the slope of this graph is the steepest (see graph above).

Explanation

I think the molecules of the green plastic are longer and this causes the forces between them to be greater but I would have expected the green plastic to stretch less as it took more force to break it. There is not much difference between the green and grey plastic for stretch.

For wrapping food tightly (meat) the white plastic would be best as it would stretch tightly round the food without any slackness.

Give an evaluation of the two students experiments i.e. compare the good and bad points in the following areas:

a) Evaluate the two experimental designs

b) Evaluate the data presented by each student

c) Evaluate the data processing used by each student (averages, graphs, etc)

d) Evaluate the conclusions reached by each student

978-1-74098-173-6

Uncertainties Quiz

1. Add the following measurements. 15.3 ± 0.1 and 16.34 ± 0.05.

____

2. Subtract 15.3 ± 0.1 from 16.34 ± 0.05.

____

3. A wire has a diameter of (2.5 ± 0.1) mm. Calculate the cross-sectional area of the wire and the uncertainty in this value.

____

____

4. The formula for the density of a substance is given by D = m/V where m is the mass and V its volume.

   A rectangular block of granite has measurements of 7.80 cm × 10.60 cm × 0.30 cm (measured with a millimetre rule) and a mass of 62 g (measured on the kitchen scales to the nearest gram).

   a) Calculate the density of the granite

____

____

____

   b) Calculate the % uncertainty in this value of density

____

____

____

   c) Quote the density of granite and its absolute uncertainty to the correct number of s.f's

____

____

____

5. The resistivity of a piece of wire can be calculated from the formula: $p = \frac{RA}{l}$

   The resistance of the wire is measured at 235 Ω using a resistance meter that measures to the nearest 10 Ω, the diameter of the wire is measured at 0.60 mm, using a micrometer to the nearest 0.02 mm and the length of the wire is measured at 3.740 m with a tape-measure to the nearest 1 cm.

   a) Calculate a value for the resistivity ρ of the wire material

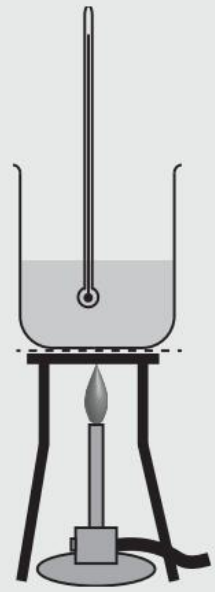
____

____

b) Estimate the % uncertainty in ρ.

c) Quote the density of granite and its absolute uncertainty to the correct number of s.f.s

6. The heating power of a Bunsen burner can be calculated by measuring the temperature rise of a known mass of water in a known time when heated by a Bunsen burner. The apparatus is shown opposite.



The mass of water was measured as 220 g, measured on scales reading to the nearest 5 g and the thermometers have graduations every 1 °C. The initial temperature of the water was 21 °C and after 60 seconds (measured at ± 1 second) it was 27 °C.

a) Use the data to calculate the power of the Bunsen burner from
m = mass of water
C = 4180 for water
t = time
ΔT = temperature rise (NB Difference in temperatures has twice the error as that in temperature!)

b) Estimate the % error in the answer

c) Quote the power of the Bunsen burner and its absolute uncertainty to the correct number of s.f.s

7. The time for a ball-bearing to fall from the bench top to the floor is given by the formula: $s = ut + \frac{1}{2} gt^2$ where s is the height of the bench (1.23 ± 0.01)m, t = time of fall, g is the acceleration due to gravity and, in this case, u = zero.

The time for the fall was measured with an electronic timer correct to ± 0.01 s with the following trial times: 0.55 s; 0.50 s; 0.45 s; 0.55 s; 0.60 s.

a) Calculate a value for 'g' from these data

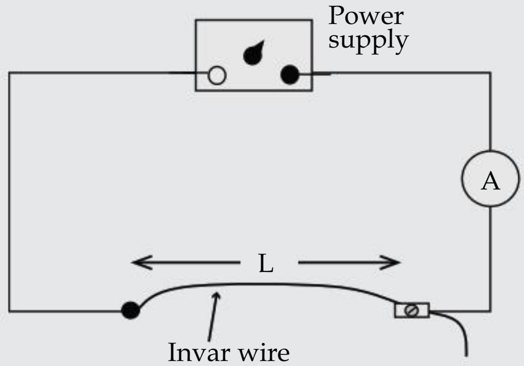
b) Estimate the % uncertainty in the answer.

c) Quote a final answer for 'g' and its absolute uncertainty to the correct number of s.f.s.

Drawing Conclusions Quiz

1. Resistance of a wire

Catherine was investigating a resistance wire called Invar that her teacher had told her did not change its resistance with temperature. For her investigation she attached the wire into the circuit shown where she could alter the length of the wire and measure the current in the circuit.



Catherine's teacher gave her the formula linking the current with the length of wire: $I = \frac{V}{\alpha L}$

I = current

V = voltage

α = resistance per metre of wire

L = length of wire

Catherine's results are show in the table below.

Length L (cm)	Current I (mA)	
6	5.45	
6.9	4.81	
7.5	4.39	
8.3	3.98	
8.7	3.78	
9.5	3.50	

a) From the formula given what variable should be plotted against I to obtain a straight line (assuming R is constant)?

____

b) Insert values into the end column above and plot the graph on Excel that should give a straight line (make sure I is on the y-axis).

c) Write a conclusion from these data about whether the resistance of the wire changes with temperature or not, giving evidence.

____

____

d) Check the probability that your graph is a straight line by plotting the data in excel and determining the R^2 value. Form a conclusion on the correlation between Current and Resistance.

____

____

e) If the voltage of the power supply was 2.0 volts calculate a value for α from the gradient of your graph.

Gradient = ______________________________

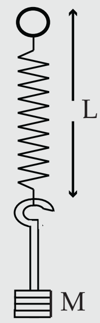
α = ______________________________

2. Stretching springs

Anna and Sarah were investigating how much springs stretch when weights are added to them. Anna placed an initial load of 50 g onto spring 1 and measured its length as the load was increased. Sarah did the same experiment with spring 2.

The girls' results are shown below.

	Spring 1	Spring 2
Mass M (g)	Length L (cm)	Length L (cm)
50	8.4	12.8
100	10.5	15.3
150	12.5	17.7
200	14.7	20.3
250	16.1	22.8
300	18.8	25.2



a) Use Excel to plot a line of best fit with mass as the independent variable (x-axis) and length of spring as dependent variable (y-axis). Plot the graphs for both springs on Excel and find the equation of both lines.

Spring 1 equation: ______________________________

Spring 2 equation: ______________________________

b) Write down the gradient for each graph:

Gradient 1 = ______________________________

Gradient 2 = ______________________________

c) One of the girls thinks she has an erroneous reading. Which reading do you think this could be?

____

d) Determine the R^2 value of each spring and determine the correlation.

Spring 1 = ______________________________

Spring 2 = ______________________________

e) Is there evidence that the two springs are not made of the same material? Explain.

____

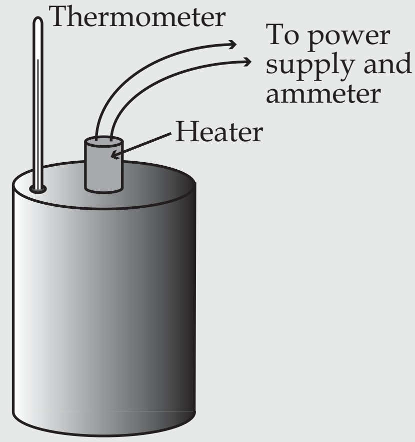
____

f) To be sure of your answer to part e), what other factors need to be controlled?

____

3. Electrical Heating

Peter and Tim are doing a project on electrical heating and want to investigate how the temperature rise of a block of copper depends on the current passing through an electrical heating element embedded in it. The apparatus is shown below.



Looking on the Internet, the boys find a formula linking temperature rise (**ΔT**) with the heater current (I): $\Delta T = \frac{I^2Rt}{mc}$

R = heater resistance

t = time of heating

m = mass of block

c = SHC of copper

The block of copper was first left to cool, its initial temperature taken and then a current was passed through the block for exactly 1 minute and the new temperature taken. This process was repeated for different sets of currents.

Peter and Tim's results are shown in the table below.

T_1	T_2	**ΔT** (°C)	I (amps)	
20	23		1.6	
22	32		2.8	
19	32		3.3	
21	38		3.7	
23	48		4.5	

a) From the formula given what variable should be plotted against ΔT to obtain a straight line (assuming values of R, t, m and c are constant)?

____

b) Insert values for temperature rise (ΔT) and a variable into the end column above that should make the equation linear (make sure ΔT is on the y-axis).

c) Write a conclusion from these data about how the temperature rise varies with current, giving evidence.

____

____

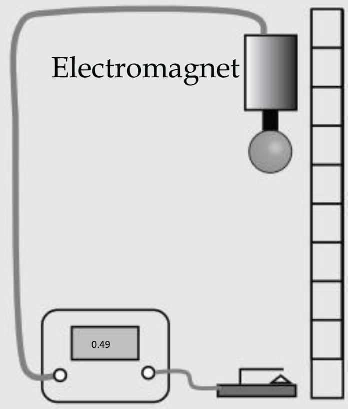
d) If the heating time was 1 minute, the heater resistance was equal to 5.0 Ω and the mass of the block was 500 g, use the gradient of the graph to find a value for c for copper.

____

____

4. Falling Balls

Nita and Ishani have set up an experiment to see how different sized balls fall under gravity by timing their fall over a known distance. For this, they had a special electromagnet that holds a steel ball and lets it fall at the same time as an electronic clock starts. When the ball hits a switch at the bottom the clock is stopped and the time of fall recorded on the timer. The apparatus is shown.



The two girls dropped ball 1 which was small and solid, then obtained results for t (time) for different heights (h) and repeated the experiment with ball 2 which was much larger and was hollow. The results are displayed below.

Height h (cm)	Time t (s)	
0	0	
20	0.20	
50	0.32	
80	0.40	
120	0.49	
170	0.59	

Ball 1

Height h (cm)	Time t (s)	
0	0	
20	0.20	
50	0.33	
80	0.42	
120	0.52	
170	0.64	

Ball 2

From the physics books the link between distance fallen and time is shown as:

$h = ½ gt^2$ (assuming no air resistance)

Fill in the right hand column in each of the tables with a variable that will allow a straight line to be drawn between the variables.

a) From the formula given what variable should be plotted against h to obtain a straight line (assuming g is a constant)?

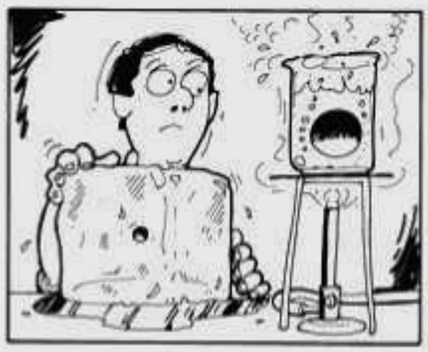
b) Plot separate scatter graphs for the motion of Ball 1 and Ball 2 and write your opinion on whether they are both linear or whether there is an apparent difference between the two.

c) From the graph of Ball 1, write the equation of the line and calculate a value for 'g', the acceleration of the ball.

d) Try to explain why the two graphs might be a different shape

5. Squash balls

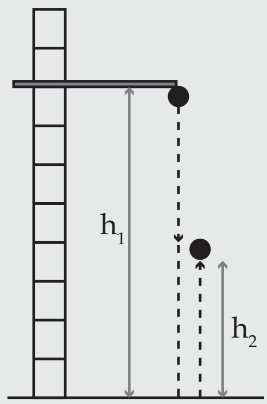
Arian plays squash a lot and knew that before a game it is customary to 'warm up' the ball by hitting it hard against the wall to make it bounce properly. He set up an investigation for his physics project where he places a squash ball into a bath of water of known temperature and measured the bounce height of the ball after it had been dropped from a height of 80 cm above the bench. Arian's results are shown below.



Arian's investigation

80 cm drop height (h_1) *Table 1*

Temp T (°C)	Bounce height (cm)			
	Trial 1	Trial 2	Trial 3	Average
20	21	27	25	
32	30	28	38	
44	40	47	36	
49	45	46	49	
58	54	58	59	
5	12	14	16	



Arian then repeated the whole experiment, dropping the ball from a different height, to investigate if the variable 'drop height' made any difference to the results.

50 cm drop height (h_1) *Table 2*

Temp T (°C)	Bounce height (cm)			
	Trial 1	Trial 2	Trial 3	Average
21	16	19	22	
33	26	26	32	
42	32	37	33	
50	43	44	41	
62	57	52	53	
3	5	12	10	

a) Fill in the end columns to find the average values of h_2 in each table.

b) Plot a graph from table 1 with temperature along the x-axis and bounce height on the y-axis.

c) Try different equation lines (linear, power, exponential, etc) to see for which equation the line fits best. Write the equation for the line of best fit:

d) Plot another graph from table 2 and find the equation for the line of best fit using a 50 cm drop height.

e) State how the 'drop height' affects the 'bounce height'.

Solutions

Chapter 1 – Heating & Cooling Solutions

Specific Heat Capacity Quiz

1. *16.0 kJ*
2. *38.1 ^oC*
3. *596 J kg^{-1} K^{-1}*
4. *195 J kg^{-1} K^{-1}*
5. *4.48 min*
6. *60.9^oC*
7. *43.0^oC*
8. *690 J kg^{-1} K^{-1}*
9. *4655 J kg^{-1} K^{-1}*
10. *639^oC*
11. *0.14^oC rise*
12. *2.39 x 10^6 J*
13. *1.29 x 10^4 J g^{-1}*
14. *140 J kg^{-1} K^{-1}*
15. *1.24^oC*
16. *19.7^oC*
17. *3.58 kW*
18. *31.8^oC*

19.

a) *Heat absorbed by water = 2 × 4180 × 1.6 = 13,380 J*

b) *Heat lost by copper = 1.78 × 390(T – 18) = 13440. So T = 37.36 ^oC*

c) *Heat absorbed by the sun = 1.78 × 390 × (37.36 – 18) = 13,440 J for a 20 x 20 cm square in 12 min, so for 1.0 m^2 in 1 second, heat absorbed = 13440/(0.2 × 0.2 × 12 × 60) = 467 W m^{-2}.*

20. *Heat produced in 2 min = 2200 × 2 × 60 = 264,000.*
Let temp rise = T. Heat absorbed by kettle and water is: 1.65 × 410 × T + 0.55 × 4100 × T = 2975.5T = 264,000; so T = 88.7^oC
Therefore final temp = 88.5 + 10 = 98.7 ^oC.

Heat Calculations Quiz

1.

a) *Heat given to water = mcΔT = 0.032 × 4180 × 14 = 1884 J*

b) *Loss of mass by nut oil = (2.98-2.33) = 0.56 g of oil; so heat per gram = 1884/0.56 = 3.37 x 10^3 J g^{-1}*

2. *Let the final temp = x*
Heat loss by boiling water = 0.06 × ~~4180~~ × (100 – x)
Heat gained by cold water = 0.15 × ~~4180~~ × (x – 15)
6 – 0.06x = 0.15x – 2.25
0.21x = 8.25; so x = 39.3^oC

3. *Let the final temp = X*
To melt ice: 0.03 × 3.36 × 10^5
To heat melted ice: 0.03 × 4180 × X
To cool hot water: 0.32 × 4180 × (70 – X)
Heat is exchanged: (0.03 × 3.36 × 10^5) + (0.03 × 4180 X) = 0.32 × 4180 × (70 – X)
10080 + 125X = 93,632 – 1337X
1462X = 83,552; so X = 57.1^oC

4. *Mass of steam = 0.025 × 5 × 60 m= 7.50 kg*
Heat given out by steam = 7.5 × 2.25 × 10^6 = m_I × 3.34 × 10^5
Mass of ice melted m_I = 50.5 kg.

5. *Heat lost by copper = 1.85 × 390 × (400 -100) = 216450 J*
Heat required to heat water to boiling = 0.62 × 4180 × (100 -29) = 184003.6 J
Heat remaining to boil water = 216450 -184003.6 = 32446 J
Mass of water boiled away = 32446/ 2.25 × 10^6 = 0.0144 kg

6. *Let final temp = T*
Heat ice to 0^{o}C → Melting ice → Heating water to T
Ice: (0.055 × 2100 × 5) + (0.055 × 3.34 × 10^5) + (0.055 × 4180 × T) = 0.16 × 4180(65-T)
577.5 + 18370 + 229.9T = 43472 – 668.8T
24524.5 = 898.7T
T = 27.3^oC

7. *PE gained = 70 × 9.8 × 500 = 3.43 × 10^5 J*
Let mass of sweat lost = m.
Heat needed to raise the temp and boil water = m × 4180 × (100 – 38.1) + m × 2.25 × 10^6 J
2.342 × 10^6 m = 3.43 × 10^5 J
m = 0.152 kg.

8. *Heat gained by cold water = 30 × 4180 × (60 – 40) = 2520000 J.*
Let mass of water added = m.
Heat lost by hot water = m × 4200 × (40 – 15) = 104500 m
m = 24 kg (24 litres).

9. *Heat extracted to cool 200 g of water and to freeze it is:*
(0.2 × 4180 × 20) + (0.2 × 3.34 × 10^5) J. = 835205 J.
Let t be the time the 'fridge is running.
Q = Pt = 250t = 83520; so t = 334 s.

10. *Heat needed to heat up and boil 1 kg of water = (1 × 4180 × 80) + (1 × 2.25 × 10^6) = J*
Let temp drop of plate be T: 10 × 440 × T = 2584400
So T = 587.4^oC so final temp = 600 = 587.4 = 12.6^oC

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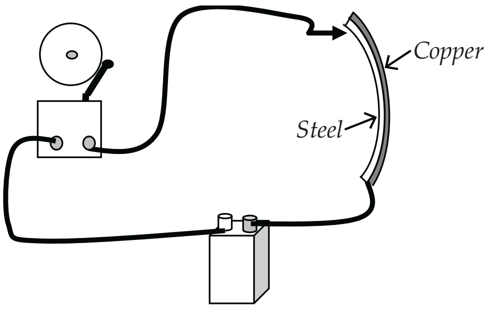
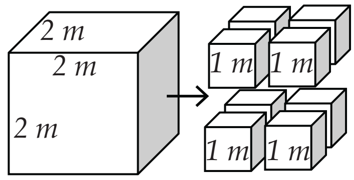
Heat Transfer Conceptual Quiz 1

1. *As the pipes heat up they will expand.*
   This expansion can cause forces in the pipe mountings that could make them break
   The bends allow expansion without force on the mountings.
2. *If long lengths of line are used there will be a large extension when they heat up in the sun. The gaps allow expansion without distortion of the line. The oval holes for the bolts allow the line to slide when it expands so no distortion forces can occur.*
3. *Copper expands more than steel so when the strip gets hot it curves to the left and joins the power to the electric bell circuit.*

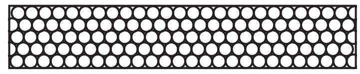


4. *All objects in the same environment eventually reach the same temperature*
   Brass is a better conductor than wood and so will take the heat away from the hand more efficiently. This causes the hand to cool down and feel colder.
5. *Air is a poor conductor. By wearing many layers of clothes or newspapers air becomes trapped between the layers hence not allowing much heat to transfer and so the tramps keep warmer.*
6. *Space blankets are silver coloured. Silver reflects radiant heat back to the body hence preventing the athlete from cooling down too fast (hyperthermia).*
7. *Black objects radiate heat fastest. Racing motorcycles engines get very hot and can seize if overheated. Hence by painting the engine black the engine radiates more heat and keeps cooler.*
8. *White clothing reflects the sun's infrared rays. In the tropics there is a lot of sunshine and people get very hot from the infrared absorbed.*
   By wearing white clothing they absorb less infrared and stay cooler.
9. *Vacuum flasks have the liquid contained in a double-walled glass bottle with a vacuum between the two walls The inside walls of the flask are silvered to reflect back the infrared radiation and the vacuum has a zero conductivity to retain the heat.*
10. *A cube measuring 2×2×2 has a volume of 8 m^3 and a surface area of 6×4 m^2 = 24 m^2*
    The same cube split into 8 smaller cubes
    Each cube has a surface area of 6×1 = 6 m^2, there are 8 cubes so the total area = 8 × 6 = 48 m^2 the volume is the same for each but the surface area is doubled so the heat loss (related to area) would be doubled.

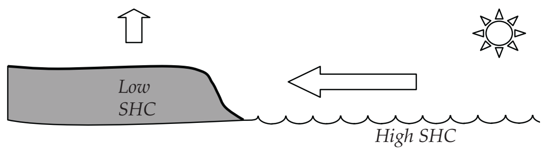


Heat Transfer Conceptual Quiz 2

1. *Metals are good conductors*
   Heat is conducted away from the hot hand
   Therefore it gets colder
2. *Wetsuits are cellular and trap the water close to the skin*



   Water is a bad conductor
   Therefore heat is prevented from being lost and the surfer stays warm
3. *Layers of clothes trap air in between them*
   Air is a bad conductor
   Therefore little heat is lost from the skin and the Eskimo stays warm
4. *Pink Batts are made from fibre glass wool which traps the air*
   Air is a bad conductor
   Therefore little heat is transferred in through the roof and the house stays cool
5. *Cold air is denser than warm air*
   Cold air from the freezer box will fall to the bottom of the fridge
   The warm air rises and forms convection currents, giving circulation and cooling all the air without a pump.
6.



   Land has a small SHP and water has a high SHC
   So land heats up quicker than the water
   Air will rise up above the land, leaving a low-pressure area
   Air flows in from the sea to fill the vacuum, giving a sea breeze.
7. *Water is a bad conductor*
   Water at the top is heated by the sun
   No convection or conduction takes place so the temperature difference stays the same.

8. *The hot air from the fire rises by convection*
This causes a low air pressure area in the fire
The air from the room will flow into the low pressure area, causing a draught.

9. *White paint reflects the sun's heat (infrared) rays. Therefore the house will stay cooler.*

10. *Tar is black and concrete is grey coloured*
Black absorbs infrared rays from the sun and grey will reflect more of them
The tar will get a lot warmer due to the absorbed heat rays

11. *Black surfaces absorb more heat radiation (IR)*
North-facing roofs absorb heat from the sun for a longer time during the day
Therefore black, North-facing panels will absorb more of the sun's radiation, on average during the day.

Heating and Cooling Test 1

1.
a) $H = 0.150 \times 390 \times (45\text{-}20) = 1.46$ kJ
b) $36 \times 10^6 = 280 \times 4180 \times \Delta T$
$\Delta T = 30.8^oC$ so final temp $= 52.8^oC$

2.
a) $225 \times 10^3 = 1.65 \times 880 \times \Delta T$;
so $\Delta T = 155^oC$
b) $225 \times 10^3 = 1.5 \times 880 \times \Delta T + 0.35 \times 4180 \times \Delta T$
$1452\ \Delta T + 1463\ \Delta T = 2915\ \Delta T$
so $\Delta T = 77.2^oC$

3.
a) $H = 0.33 \times 4180 \times (77\text{-}15) = 8.55 \times 10^4$ J
b) Power $= 8.55 \times 10^4/(2.5 \times 60) = 570$ W
c) Heat needed to reach $100^oC = 0.33 \times 4180 \times 23 = 3.173 \times 10^4$ J
$H = Pt = 570 \times 150$; so $t = (3.173 \times 10^4/ 8.55 \times 10^4) = 55.7$ seconds)

4.
a) $1.05 \times 10^6 = 72 \times 3470 \times \Delta T$; so $\Delta T = 4.20^oC$
b) $1.05 \times 10^6 = m \times 2.25 \times 10^6 + m \times 4180 \times (100 - 37.6)$
$4.67 \times 10^{-1} = 467$ g;
so $m = 4.18 \times 10^{-1}$ kg of sweat (418 g)

5. $\Delta H_{can} = 0.23 \times 390 \times 48 = 4305.6$ J
$\Delta H_{water} = 0.21 \times 4180 \times 48 = 42134.4$ J
$\Delta H_{ice} = m \times 2100 \times 7 + m \times 3.36 \times 10^5 + m \times 4180 \times 38 = 509540\ m$
$46440 = 509540\ m$; so $m = 91.1$ g

6.
a) *Heat extracted to freeze ice* $= 0.185 \times 3.36 \times 10^5$ J $= 62160$ J
At 285 joules per second the time for 62160 J to be extracted = 62160/285
$T = 218$ s $= 3.64$ min
b) *Let final temp = T*
mass of steam condensed = 600 g
Condensing steam +hot water temp falling = cold water temp rising
$(0.60 \times 2.25 \times 10^6) + (0.60 \times 4180[100 - T]) = 4.85 \times 4180(20 - T)$
$1350000 + 2508(100 - T) = 20273T - 405460$
$2006260 = 22781T$
$T = 88.1^oC$

Heating and Cooling Test 2

Section A – Multiple Choice

1. C 2. E 3. E 4. E 5. B 6. B 7. C 8. B
9. E 10. D 11. D 12. D 13. C 14. E 15. C

Section B

1. *Pressure increases by a factor of 3*
Molecules of gas get closer and make more collisions with the walls

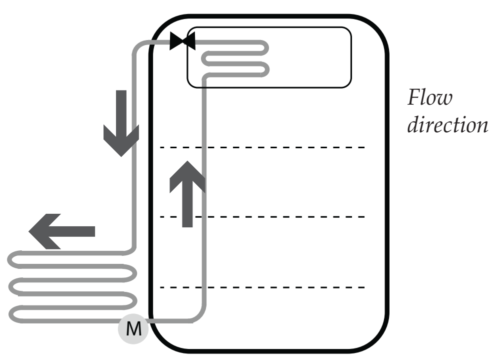
2.
a) *Pressure is directly proportional to absolute temperature*
b) *As temp increases so does the motion of the particles. This increases the rate of collisions and hence the pressure*

3.
a) *Element at the bottom produces hot air which rises and causes circulation and the food above gets heated by convection*
b) *Hot smoke will rise up to the ceiling due to convection. On the floor there will be cooler air free from smoke and you can breathe*

4.
a)
(i) *Calibrated means it has a scale on it*
(ii) *Thermometric liquid is a liquid used in a thermometer*
(iii) *Lower Fixed Point is taken as the melting point of pure ice* (0^0C)
b)
(i) $(9.65 - 3.8) = 5.85$
5.85/100 = 0.0585 cm, or about 0.59 mm between each division
(ii) *Expansion from zero = 6.68 – 3.8 = 2.88*
No. of degrees = 2.88/0.0585= 49.2^oC

5. *The fire heats the air making it expand and rise up the shaft. This causes low air pressure near the fire which causes air to flow in from the outside ventilating the mine.*

6.a)



b) *X is a radiator. It has a large area attached to black copper fins to allow heat to be lost easily by radiation and convection*
c) *Refrigerant liquid expands at the expansion valve, producing a vapour. Latent heat is*

absorbed from the surroundings, cooling the air inside the fridge
Warm gas moves down where it is compressed by the motor outside the fridge. When the gas condenses it gives out latent heat at the radiator and cools

7.
A *Fibreglass wool is a bad conductor due to the trapped air in its strands. This prevents conduction through the back of the panel*
B *Black copper plate absorbs sunlight efficiently because it is black. Being copper, it conducts heat to the water pipes very fast*
C *Black copper pipes absorbs sunlight efficiently because of their colour. Being copper, it will conduct heat from the back plate very quickly*
D *Glass covering produces a small greenhouse. The IR (heat rays) are trapped inside and create a greater heating effect*

Chapter 2 - Nuclear Physics Solutions

Atomic Structure Quiz

1. $^{162}_{66}Dy$
2.
a) *A,E and B, D are isotopes.*
b) $^{30}_{15}P$ and $^{35}_{17}C\ell$ $^{34}_{17}C\ell$
3. 2.72×10^{-2}
4. *(i) Carbon-14 (ii) Sodium-23 (iii) Zinc-66*
5. 35.45

Nuclear Decay Quiz

1. 28.6 μ Gy
2. 2.4×10^{-3} J
3. (i) 28.6 μSv (ii) 160 mSv
4. 11.4 years
5.
a) *(i) a (ii) proton (iii) neutron (iv) electron*
b) (i) $^{235}_{92}U$ (ii) $^{14}_{7}N$ (iii) $^{28}_{13}A\ell$ (iv) $^{214}_{83}Bi$
6. (i) $^{14}_{6}C$ (ii) $^{27}_{14}Si$ (iii) $^{76}_{32}Ge$ (iv) $^{14}_{7}N$
7. 30 Bq
8. 6 hours
9. 14.4 days
10. 1.08 mg
11. *Initial activity of 1.0 g of carbon = (2.72 – 0.42) = 2.30 Bq – allowing for background radiation from the lab i.e.* $A_o = 2.30$ Bq.
Activity of 0.35 g of scroll C14 = (1.10 – 0.42) = 0.68 Bq, $A_t = 0.68/0.35 = 1.94$ Bq *per gram.*
Using $A_t = A_o(0.5)^n$, $(1.94/2.30) = (0.5)^n$.
Solving: n = 0.246 half-lives = 1400 y old.

Nuclear Physics Quiz

Multiple Choice Questions

1. C 2. D 3. C 4. D 5. C 6. A 7. C 8. D 9. D 10. B 11. B 12. A 13. D 14. C 15. C 16. A 17. C 18. B 19. B 20. A

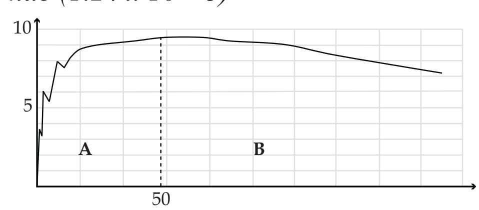
Nuclear Physics Test

1.
a)

a heavy,	*2 + charges,*	*highly ionising*
β light	*1- charge,*	*fairly ionising*
γ no mass	*no charge*	*not very ionising*

b) *(i) x = electron y = -1*
(ii) Pb y = 214
(iii) x = 12 (11) $y = \beta^+$ *(p)*
2.
a) 4.5×10^{12} years   b) 8 nuclei/second
3.
a) *Absorbed Dose = 30/60 = 0.5 Gy*
b) *DE = 0.5 × 20 = 10 Sv*
c) *Yes –death. 4.5 Sv is the* LD_{50} *dose.*
d) *DNA molecules become ionised which prevents functioning. Cancers can form*
4.
a) *x = 3*
b) *Mass defect = mass of reactants – mass of products*
c) *Mass defect is caused by some mass being converted into energy*
d) $236.04721 - (147.95736 + 84.93617 + 3 \times 1.00867) = 0.12767$
$\times 931 = 119$ MeV (1.90×10^{-11} J)
e) $118.86 \times 2.55 \times 10^{24} = 3.03 \times 10^{26}$ MeV
5.
a) $3.03 \times 10^{26} \times 1.6 \times 10^{-13} = 4.85 \times 10^{13}$ J

$$\text{Mass} = \frac{8.25 \times 10^{12}}{4.85 \times 10^{13} J} = 0.170 \text{ kg}$$

b)
(i) *Fuel rods contain U-235 which undergoes fission and releases energy*
(ii) *The moderator slows down neutrons so they can react more efficiently*
(iii) *Control rods absorb neutrons to increase/decrease the rate of reaction*
(iv) *Coolant flows into the heat exchanger from the core where heat is transferred to water. This water boils and drives the turbine to generate electricity.*
6.
a) *O-17 has 8ps and 9 ns* $\Sigma(n + p) = 17.13627$ u
$\delta = 17.13627 - 16.99474 = 0.14153$ U
BE per nuc $= 0.14153 \times 931/17 = 7.75$ *MeV/nuc* (1.24×10^{-12} J)
b)


c) *Two nuclei are formed with more BE per nucleon so mass has been converted into energy.*

d) $^{2}_{1}H + ^{2}_{1}H \rightarrow ^{3}_{2}He + ^{1}_{0}n$ + *Energy; so a neutron is emitted*

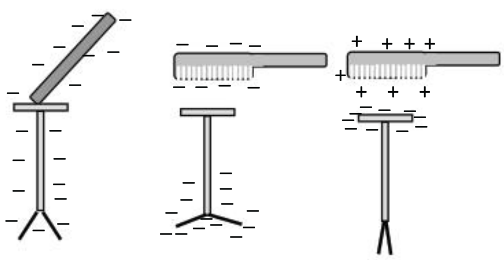
e) $\delta = 2 \times 2.01347 - (3.01456 + 1.00867)$
$= 0.00371\ u$
Energy released $= 0.00371 \times 931 = 3.45$ MeV

f) *Elapsed time = 31 hours; so No. of half-lives* $= 31/12.6 = 2.46$
$A = 1.2 \times 10^3 \times (½)^{2.46}$ $A = 218$ Bq

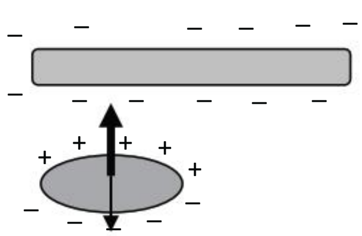
Chapter 3 – Electricity Solutions

Electrostatics Quiz

1. *Charge the electroscope negatively by touching it with negative rod A. Bring the charged comb towards the cap of the electroscope. If the leaves diverge more, then the charge on the comb must be negative. If the leaves go down then the charge must be positive*

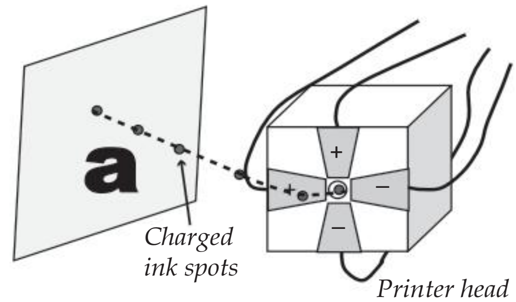


2. *If a –ve charged rod is placed near a neutral object the electrons become repelled to the underneath, leaving +ve on the top. The +ve charge produces attraction and the –ve charge causes repulsion but, because the +ve charge is nearer to the rod, the attractive force is greater and so the confetti moves towards the rod.*



3. *As bags of flour slide down tubes the metals of these tubes becomes charged. If there is no connection to earth then the metal will stay charged and can cause a spark if a person comes close whose feet are touching the ground. Flour dust has a very large surface area and will burn extremely quickly, causing an explosion. By earthing all metal objects no charge can build up, preventing explosions.*

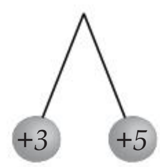
4. *Ink is atomised inside the print head to give tiny spots which are then charged. Conductors outside the head can also be charged by control from a computer program so the charged spot can be deflected in 2 dimensions to place it anywhere on the printing paper and thus form the letters or graphics.*



5. *The photocopier works using the principles of the photoelectric effect: when charged selenium has light shone onto it it loses its charge. Black plastic dust will be attracted to the charged areas that have not had light on them and this dust gets transferred to the paper, heated and retained as a black printed area.*

6. *Because trees are tall and pointed they are likely to be struck by lightning during a storm. If a golfer stands underneath the lightning, current could run through him and burn or kill him - so standing in the open is a better option!*

7. *Note: the angle of each ball to the vertical is the same as the force on each is the same (action = reaction)*



8. *1 electronic charge* $= 1.6 \times 10^{-19}$ C; *so No. of charges* $= (3.19 \times 10^{-13})/ 1.6 \times 10^{-19}$
$= 2 \times 10^{6}$ *charges.*

9. *The 2 forces are:*

$$F_A = 9 \times 10^9 \times \frac{1 \times 10^{-9} \times 6 \times 10^{-9}}{(9.6 \times 10^{-3})^2}$$

$$F_B = 9 \times 10^9 \times \frac{1 \times 10^{-9} \times 6 \times 10^{-9}}{(5.2 \times 10^{-3})^2}$$

$$F_{Total} = 5.86 \times 10^{-4}\ N + 9.99 \times 10^{-4} = 1.58 \times 10^{-3}\ N$$

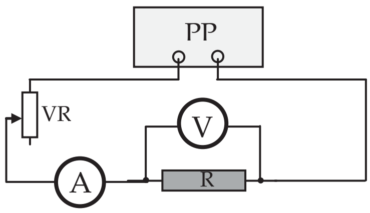
10. $E = V/d = 350/0.04 = 8.75 \times 10^3\ V\ m^{-1}$
$F = Eq = 8.75 \times 10^3 \times 1.6 \times 10^{-19}$
$= 1.40 \times 10^{-15}$ N

Charge and Energy Quiz

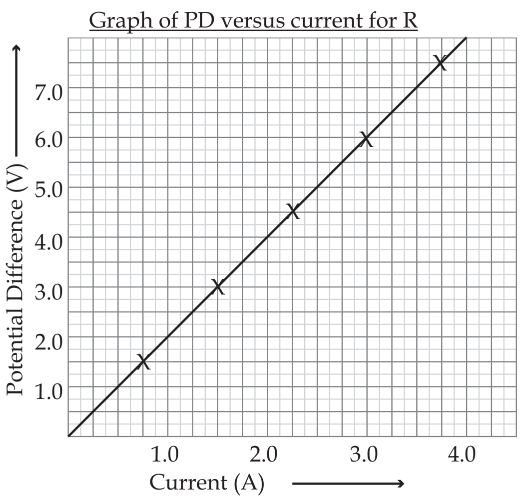
1. 12 A
2. 7.2 C
3. 50 µs
4. 9.38×10^{10} electrons
5. 6.4 A
6. 5.10 µA
7. 6 kJ
8. 200 V
9. 0.110 J
10. 7.26 MJ

Simple Ohm's Law Quiz

1 a) 75 Ω b) 0.1 A
2. 5 A
3. 312.5 V
4. a) 8 Ω b) 6 Ω
c) V_1 = 24 V, V_2 = 72 V
5.
a)



b)

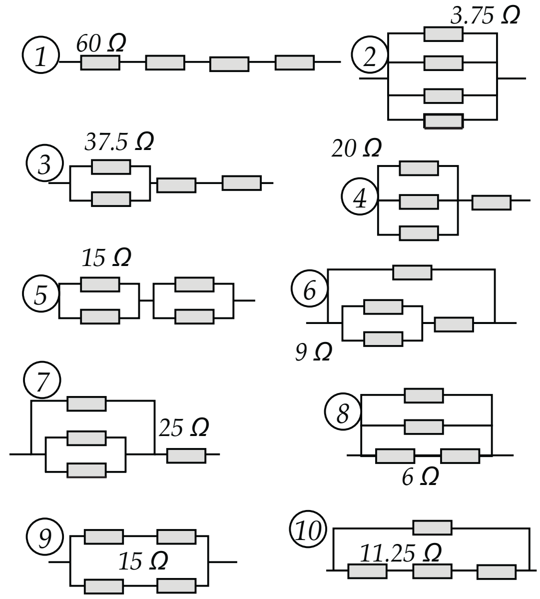


c) R = 2.0 Ω
6.
a) Not enough pd between the crow's feet to produce a fatal current in the body.
b) Resistance of wire between feet
$= 0.05 \times 1.5 \times 10^{-8} = 7.5 \times 10^{-10}\ \Omega$
$V = 6000 \times 7.5 \times 10^{-10} = 4.5 \times 10^{-6}$ V

Ohm's Law Calculation Quiz

1. B	2. C	3. A	4. C	5. C
6. A	7. A	8. B	9. A	10. C
11. B	12. D	13. D	14. D	15. D
16. A	17. C	18. D	19. C	20. A

21. There are 10 different ways



22.
a) $R_T = 6.55\ k\Omega$
b) Top: I = 12/8k = 1.5 mA; so
Potential A $= 1.5 \times 10^{-3} \times 2 \times 10^3 = +3.0$ V
Bottom: I = 12/36k $= 3.33 \times 10^{-4}$ A
Potential B $= 3.33 \times 10^{-4} \times 31.5 \times 10^3$
= +10.5 V
$PD_{AB} = 10.5 - 3 = 7.5$ V
23.
a) A lamps: Voltage of each = 240/20 = 12 V
R = V/I = 20 Ω each lamp
b) B lamps: Voltage of each = 240 (parallel)
R = V/I = 240/0.06 = 4000 Ω each lamp
c)
(i) I = 240/20 = 12 A through the added lamp which would blow the added lamp
(ii) Normal R_T = 20 × 20 = 400 Ω, but now R = 19 × 20 = 580 + 4000 Ω = 4580 Ω
so I = 240/580 = 41 mA (not 60 mA)
So the B lamps will be very dim.
24. $$R = \frac{2.8 \times 10^{8} \times 2.7}{\pi\left(0.14 \times 10^{3}\right)^2} = 1.23\Omega$$
So I = 6.1/2.087 = 2.98 A
$R_T = 0.82 + 1.23 = 2.087\ \Omega$
$V_R = 2.98 \times 1.23 = 3.66$ V
25.
a) Using $R_T = \dfrac{R_1 \times R_2}{R_1 + R_2}$ $\quad x = \dfrac{2(1 + x)}{3 + x}$
So $3x + x^2 = 2 + 2x$ or $x^2 - x - 2 = 0$
Solving: x = 1 Ω
b) 3 V

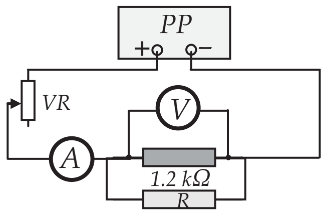
26.

a) $I = 12/3.6 = 3.33$ A; so $V_{2\Omega} = 2.33 \times 2 = 6.67$ V

b) 2 Ω and 5 Ω in parallel: 1.43 Ω $R_T = 3.03$ Ω
So $I_T = 12/3.03 = 3.96$ A. $V_{2\Omega} = 3.96 \times 2 = 7.92$ V

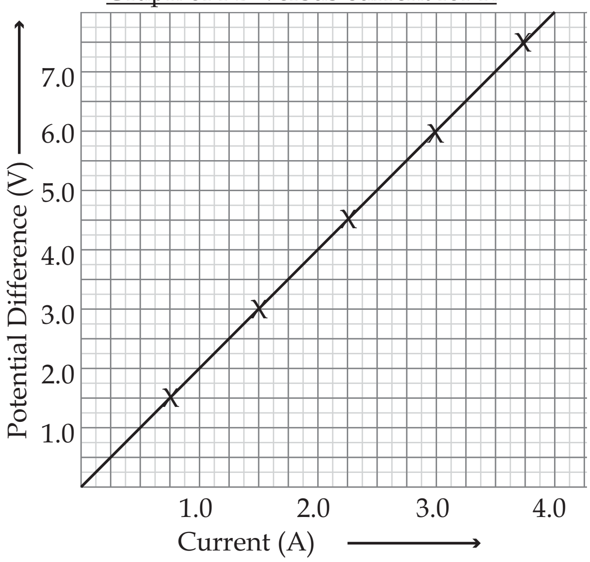
27.

a)



b) R_T = slope = 400 Ω

Graph of PD versus current for R



c) Using $R_T = \dfrac{R_1 \times R_2}{R_1 + R_2}$ $\quad 400 = \dfrac{1200 \times R}{1200 + R}$

$480{,}000 = 400R = 1200R$; so $R = 600\Omega$

28.

a) Max V across ammeter = 0.002 × 5 = 10 mV
At 1 A current 2 mA goes through the meter and (1000 – 2) mA goes through the shunt so resistance of the shunt = 0.01/0.998 = 0.01002 Ω

b) $\rho = \dfrac{RA}{l}$ $\quad l = 4.83$ cm

29.

a) $I = 12.2/(0.6 + 2.4) = 4.07$ A
$V_o = 4.07 \times 2.4 = 9.77$ V

b) I through internal r = (12.2 – 8.4)/0.6 = 6.33 A = total current through lamp/motor combination; so $R_T = 8.4/6.33 = 1.327$ Ω
So 3.1848 + 1.327R = 2.4 R
$R_{motor} = 2.97$ Ω

30.

a) $R_T = 80/12 = 6.67$ Ω

b) Current at bottom = 80/8 = 10 A
Therefore Top current = 2 A
Therefore R at top = 80/2 = 40 Ω so top right resistance = 37 Ω = $\dfrac{56 \times R}{56 + R}$ R = 109 Ω

c) V across top right combination = 2 × 37 = 74 V So $I_R = 74/109 = 0.679$ A

d) V drop across 3 Ω = 2 × 3 = 6 V;
V drop across 2 Ω = 10 × 2 = 20 V
Therefore pd = 20 - 6 = 14 V

31.

a) $R_A = V/I = 10/0.25 = 40$ Ω. R_B at 6 V = 6/0.194 = 30.9 Ω.

b) The current must be the same through both resistors and the sum of the voltages across each must equal 6.4 V. from the graph, this will occur for a series current of 0.11 A, then $V_{RB} = 2.0$ V and $V_{RA} = 4.4$ V (sum = 6.4 V).

c) When I = 0.11 A, $V_{RB} = 2.0$ V so $R_B = 2.0/0.11 = 18.2$ Ω.

Power and Safety Quiz

1.

a) $P = VI = 9 \times 1.5 = 13.5$ W

b) $P = I^2R = 2.2^2 \times 1.2 \times 10^3 = 5.80$ kW

c) $P = V^2/R = 9^2/12 = 6.75$ W

d) $P = V^2/R = 240^2/3.2 \times 10^3 = 18$ W

e) $P = VI = 240 \times 13 = 3.12$ kW

2.

a) $P = I^2R = 4.5^2 \times 60 = 1.22$ kW

b) $H = Pt = 1215 \times 15 \times 60 = 1.09$ MJ

3.

a) $H = Pt = 1.2 \times 10^3 \times 2 \times 3600 = 8.64$ MJ

b) $R = V^2/P = 240^2/1200 = 48$ Ω

c) I = V/R = 240/48 = 5 A so the 6 A fuse would be safe.

4.

a) Cost = 1.2 × 2 × 30 = 72¢.

b) Cost = 0.1 × 9 × 30 = 27¢

c) Cost = 2 × 4 × 30 = $2.40

d) Cost = (0.25 × 3 + 0.18 × 5 + 1 × 2.5 + 5 × 0.75) × 30 = $2.37

5. Lamp resistance = $V^2/P = 240^2/100 = 576$ Ω
so in series $R_T = 1152$ Ω
Old power = 200 W,
New power = $240^2/1152 = 50$ W
Change in power = 150 W decrease.

6. Heat absorbed
= $mc\Delta T = 1.5 \times 4180 \times 80 = 502$ kJ
Heat supplied
= $VIt = 2500 \times 3.5 \times 60 = 525$ kJ
so heat lost = 23 kJ
% loss = (21/525) × 100 = 4.4 %

7. Work done on car
= $mgh = 1000 \times 9.8 \times 0.3 = 2940$ J
Energy used in motor
= $VIt = 240 \times 2 \times 10 = 4800$ J
% efficiency = (2940/4800) × 100 = 61.3%

8.

a) Total power = (2x 42) + (2 x 21) + (2 x 36) = 198 W. I = P/V = 198/12 = 16.5 A

b) 20 A fuse

c) t = q/I = 20,000/16.5 = 1,212 s or 20.2 min

9.

a) Mass = volume × density = $\pi(0.15 \times 10^{-3})^2 \times 4 \times 10^{-2} \times 6500 = 1.84 \times 10^{-5}$ kg

b) $R = \dfrac{2 \times 10^{-8} \times 4 \times 10^{-2}}{\pi(0.15 \times 10^{-3})^2} = 0.0113\ \Omega$

c) $H = mc\Delta T = 1.84 \times 10^{-5} \times 490 \times (920 - 20) = 8.11$ J

d) $P = I^2R = 800^2 \times 0.0113 = 7232$ W

e) $t = H/P = 8.11/7232 = 1.12$ ms

Electricity Test 1

1.

a) $F = \dfrac{9 \times 10^9 \times 2.5 \times 10^{-6} \times 5 \times 10^{-6}}{(12.2 \times 10^{-2})^2} = 7.56$ N

b) $Q = (2.5 + 5)/2 = 3.75\ \mu C$

c) $F = \dfrac{9 \times 10^9 \times 3.75 \times 10^{-6} \times 3.75 \times 10^{-6}}{(9.55 \times 10^{-2})^2} = 13.9$ N

2.a) $I = Q/t = \dfrac{6 \times 10^{12} \times 1.6 \times 10^{-19}}{1.6 \times 10^{-3}} = 6.0 \times 10^{-4}$ A

b) A C E B

3.

a) C

b) Airship is charged by movement through the air. As it docks the charge leaks to earth through the mooring pole (spark)

4.

a) $R = 2000/ 5 \times 10^{-3} = 400\ k\Omega$

b) $I = V/R = 240/40 = 6$ A

c) $V = IR = 75 \times 10^{-6} \times 1.5 \times 10^6 = 112.5$ V

d) $V = IR = 0.150 \times 80 = 12$ V

5.

a) $R = \rho l/A = \dfrac{1.72 \times 10^{-8} \times 50}{2.5 \times 10^{-7}} = 3.44\ \Omega$

b) $l = RA/\rho = \dfrac{1 \times \pi(0.5 \times 10^{-3})^2}{1.1 \times 10^{-6}} = 0.714$ m

6.

a) C

$I = 3.7 + 1.5 + 2.5 = 7.7$ A

(use the fuse nearest to this above it)

b) $Q = It = 5.2 \times 6 \times 60 = 1872$ C

7.

a) (i)Ammeter (ii) Voltmeter

b) $R = 5/0.1 = 50\ \Omega$

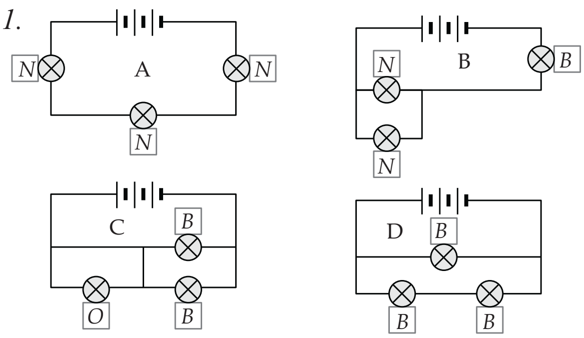
c) Slope = 1/R Slope decreases so R increases as it gets higher I (temp)

8.

Switch position	Switch position	Lamp L_1 on/off	Lamp L_2 on/off
$S_{1\ open}$	$S_{2\ open}$	OFF	OFF
$S_{1\ open}$	$S_{2\ closed}$	OFF	OFF
$S_{1\ closed}$	$S_{2\ open}$	ON	OFF
$S_{1\ closed}$	$S_{2\ closed}$	ON	ON

Electricity Test 2

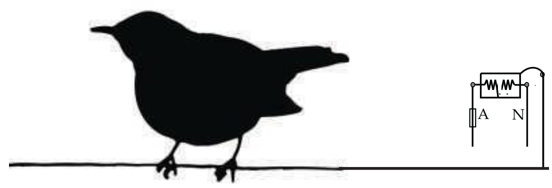
1.



2.

a) His hand is at a PD of 2000 V and feet at zero potential.
So PD across his body is 2000 V
Current has a path to Earth so a current flows through him (shock)

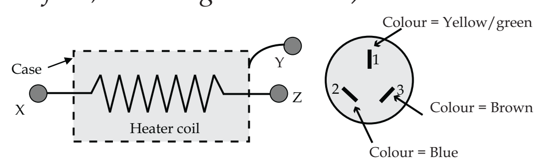
b) Both of the bird's feet are at the same potential (2000 V)
No PD across the bird, no circuit, so no current can flow.



3.

a) If wire breaks, case is now active and person touching it provides a circuit to Earth.
The Earth wire gives a low resistance path to Earth so a large current will flow and blow the fuse, disabling the device.)

b)



c) $P = VI$; so $180 = 240 I$; so $I = 180/240 = 0.75$ A

d) Resistance off each element = 240/0.75 = 320 Ω so $R_T = 640\ \Omega$
Total current = 240/640 = 0.375 A
So total power = 240 x 0.375 = 90 W

4.

a) B

b) No. of kW-h = (4.2 × 2.7) + (0.5 × 34) + (3.2 × 42) + (0.25 × 15.3) + (2.4 × 1.7) = 170.645
Cost per week = 170.645 × \$0.31 = \$52.9 × 52 = 2750 per year

c) $V = IR = 0.02 \times 15{,}000 = 300$ V

5.
a) $RT = 20/2 = 10\ \Omega$
b) $R^1 = 10 - 8 = 2\ \Omega$ $1/R + 1/6 = ½$
So $R = 3\ \Omega$
c) $R = \rho l/A$; so $A = (3.8 \times 10^{-6} \times 5)/3$
$= 6.33 \times 10^{-6}\ m^2$
$r^2 = 6.33 \times 10^{-6}/\pi = 2.02 \times 10^{-6}$
so $r = 1.42 \times 10^{-3}$ and $d = 2.84$ mm
d) $R^1 = 2\Omega$ $V = IR = 2 \times 2 = 4\ V$
e) $P = V^2/R = 4^2/3 = 5.33\ W$
$H = Pt = 5.33 \times 3600 = 19200\ J$

6.
a) D has an internal resistance.
When a current is drawn by the external resistor a voltage drop is produced in this resistor which subtracts from the e.m.f.
b) Battery L must have a lower internal resistance because there is less voltage drop when a current is drawn.
c) Current through the circuit = 8.5/0.85 = 10 A
r = ("lost volts")/current = (12 – 8.5)/10
= 0.35 Ω

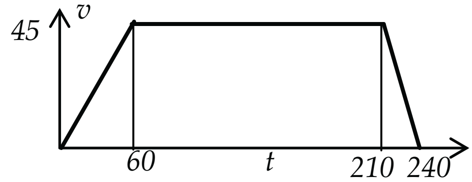
Chapter 4 – Linear motion and force.

Uniform Motion Quiz

1. 3 m s^{-1}.
2.
a) 144 km h^{-1}
b) 40 m s^{-1}
c) 25 s
3.
a) 0.16 s
b) 72.5 cm s^{-1}
4. 6.67 m s^{-1}.
5. 1.5 h
6.
a) 5 min
b) 2100 m.
7. A is stationary, B is constant velocity then stopping, C is constant backward speed followed by a slower forward speed, D is deceleration towards the zero point to a stop.
8.
a) t = 10.67 s.
b) v = 33.5 m s^{-1}.
9. $t_1 = 1.33$ s, t = 1.23 hours

Accelerated Motion Quiz

1. $a = 0.8/0.5 = 1.6$ m s^{-2}
2. $\Delta v = 30$ km h^{-1} = -8.33 m s^{-1} $a = -8.33/1.4$
= - 5.95 m s^{-1}
3. $a = \Delta v/\Delta t$ so $\Delta t = 15/9.8 = 1.53$ s
4. $\Delta v = 9$ so $t = 9/9.8 = 0.918$ s
5. $v = u + at$; so $30 = u + 9.8 \times 2$;
so $u = 30 - 19.6 = 10.4$ m s^{-1}
6. $v^2 = u^2 + 2as$; so $7^2 = 0^2 + 2 \times 0.767\ s$
$s = 31.9$ m
7. $v^2 = u^2 + 2as$; so $v^2 = 0^2 + 2 \times 0.11 \times 30$
$v = 2.57$ m s^{-1}
8. $s_1 = 16.5 \times 0.15 = 2.475$ m,
$v^2 = u^2 + 2as_2$; so $s_2 = 272.25/(2 \times 3.85)$
= 35.36 m
Total s = 37.83; so he misses the dog by 2.17 m
9.



a) $v = 0.75 \times 60 = 45$ m s^{-1},
b) $a = 45/30 = 1.5$ m s^{-2},
c) $s = (0.5 \times 60 \times 45) + (150 \times 45) +$
$(0.5 \times 30 \times 45) = 8775$ m
so $v_{av} = 8775/240 = 36.6$ m s^{-1},
10. $s = vt - ½at^2$; so $0.022 = 0 - 0.5 \times a \times 0.15^2$
a) So a = - 1.95 m s^{-2}
b) $v = u + at$ so $0 = u - 1.96 \times 0.15 = 0.294$ m s^{-1}
11.
a) $a = (v - u)/t = 9/1.8 = -5$ m s^{-2}
b) $v^2 = u^2 + 2as$ $0 = 9^2 - 2 \times 5 \times s$;
so s = 8.1 m
12. $s = ut + ½at^2 = 20 \times 6 - 0.5 \times 1.5 \times 6^2 = 93$ m
13. $s = ut + ½at^2$
$1000 = 0 + ½a \times 9.8^2$
$a = 20.8$ m s^{-2}, $v = 0 + 20.8 \times 9.8$
= 204 m s^{-1}
14. Reaction distance $s_1 = 16.66 \times 0.2 = 3.33$ m
then $v^2 = u^2 + 2as$: $0 = 16.67^2 - 2 \times 4.2s_2$
so $s_2 = 37.08$ m
Total s = 36.4 m – no, he stops in time.
15.
a) $s = ut + ½at^2$; $s = 8 \times 5 + ½ \times 1.6 \times 5^2$
= 60 m Yes he just makes it!
b) $v = u + at = 16$ m s^{-1}
16.
a) $s = ut + ½at^2$; $100 = 5t + 0.2t^2$
Solver: t = 13.1 s
b) $v^2 = u^2 + 2as$; $v^2 = 25 + 2 \times 0.4 \times 100$
= 10.2 m s^{-1}
17.
a) $s = ut + ½at^2$; u = 3.5; a = -9.8; s = -1200
so $v^2 = 3.5^2 + 2 \times -9.8 \times -1200$
so v = -153 m s^{-1}
b) $v = u + at$; $-153 = 3.5 + -9.8t$; t = 16.0 s
18.
a) $v^2 = u^2 + 2as$; u = 0; a = 9.8; s = (5.25 – 0.75)
So $v^2 = 0 + 2 \times 9.8 \times 4.5$; so v = 9.39 m s^{-1}
b) u = 9.39; v = 0; s = 0.75 – 0.05; $v^2 = u^2 + 2as$
So $0 = 9.39^2 + 2 \times a \times 0.7$; so a = -63.0 m s^{-2}

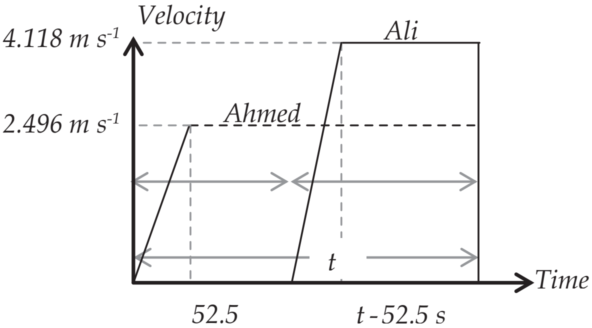
19.

a) $v^2 = u^2 + 2as$; so $0 = 55^2 - 2 \times 9.8 \times s$
so $s = 154$ m above the tower.

b) $s = ut + \frac{1}{2}at^2$; so $-35 = 55t - 4.9t^2$
Solver: $t = 11.8$ s

c) $v = u + at$; so $v = 55 - 9.8 \times 11.8 = -60.6$ m s^{-1}

20. Sketch the v/t graph:



Ahmed's constant velocity $v = at = 1.3 \times 1.92 = 2.496$ m s^{-1}

Ali's constant velocity $v = at = 1.45 \times 2.84 = 4.118$ m s^{-1}

Let the time for the Ahmed to finish = t seconds. Then the time for the Ali to finish = t – 52.5 seconds

Both camels will meet when they have travelled the same distance = area under each graph.

Ahmed area = △+□
$= \frac{1}{2}(1.92 \times 2.496) + 2.496(t - 1.92)$
$= 2.396 + 2.496t - 4.7928$
$= 2.496t - 2.3968$

Ali area = △+□
$= \frac{1}{2}(2.845 \times 4.118) + 4.118(t - 52.5 - 2.845)$
$= 5.858 + 4.118t - 227.91$
$= 4.118t - 222.05$

$2.496t - 2.3968 = 4.118t - 222.05$
$\rightarrow 219.68 = 1.622t$ so $t = 135.4$ s

So distance from the start where they meet
$= 2.496 \times 135.4 - 2.3968 = 335$ m

21.

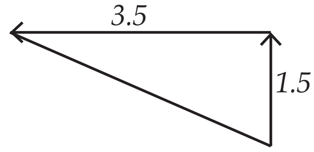
a) Let the time of flight = t seconds, at t displacement of lift floor = s_F, displacement of lipstick = s_L.
At time t, displacement of floor from zero position is: $s_f = 2.5t + \frac{1}{2} \times 1.25t^2$
At time t, displacement of lipstick from zero position is: $s_b = 1.2 + (2.5t + \frac{1}{2} \times -9.8t^2)$
When the bolt hits the floor the bolt and floor will both have the same displacement from the zero position, so: $2.5t + \frac{1}{2} \times 1.25t^2 = 1.2 + 2.5t + \frac{1}{2} \times -9.8t^2$
$0.625t^2 = 1.2 - 4.9t^2 \rightarrow 5.525t^2 = 1.2$
So $t = 0.4660$ s when the bolt meets the floor.

b) $v_L = u + at = 1.25 - 9.8 \times 0.466 = -3.32$ m s^{-1} (downwards)
$v_F = u + at = 2.5 + 1.25 \times 0.466 = 3.083$ m s^{-1} (upwards)
Relative velocity of lipstick to floor
$= 3.083 + 3.32 = 6.40$ m s^{-1}.

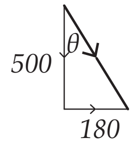
Vectors Quiz

1. $R^2 = 200^2 + 200^2$ So $R = 283$ N straight ahead

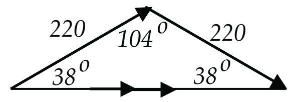
2. $R^2 = 3.5^2 + 1.5^2$
$R = 3.81$ m s^{-1}
Tan $\theta = 3.5/1.5$ θ
$= 66.8^o$ W of N



3. $R^2 = 500^2 + 180^2$
$R = 531$ ms^{-1}
Tan $\theta = 180/500$ $\theta = 19.8^o$
so bearing = 160.2^o



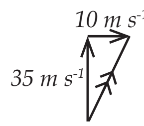
4. Sine rule: $220/\sin 38 = R/\sin 104^o$ $R = 347$ N at 38^0 to the string



5.

a) $R^2 = 35^2 + 10^2$ $R = 36.4$ m s^{-1}

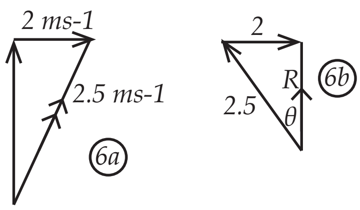
b) $s = vt = 36.4 \times 2.5 = 91$ m away



6.

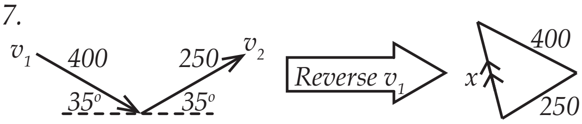
a) $R^2 = 2^2 + 2.5^2$ $R = 3.20$ m s^{-1} $\theta = 51.3^o$ to the bank

b) Time to cross = 40/2.5 = 16.0 s. Distance downstream = 2 × 16 = 32.0 m



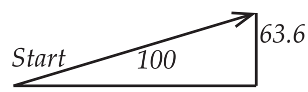
c) $\sin\theta = 2/2.5$ $\theta = 53.1^o$ So the canoe must head 36.9^0 to the bank.

7.



cos rule: $x^2 = 400^2 + 250^2 - 2.400.250\cos 70$
Change in velocity, $x = 392$ m s^{-1}.
Sine rule: $392/\sin 70 = 400/\sin\theta$ $\theta = 73.2^o$

8.

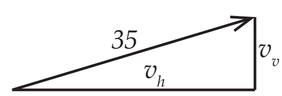


a) $\pi d = 100$
so diameter = 63.6 m $r^2 = 100^2 + 63.6^2$
so $r = 118.5$ m $\theta = 57.5^o$

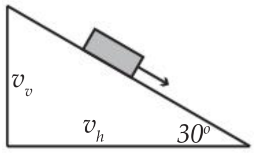
b) Speed = 200/(12.5 + 12.1) = 8.13 m s^{-1}

c) $v = s/t = 118.5/24.6 = 4.82$ m s^{-1} at $\theta = 32.5^o$

9.

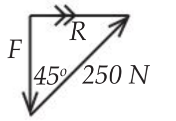


$\cos 20 = V_h/35$ so $V_h = 35\cos 20 = 32.9$ m s^{-1}

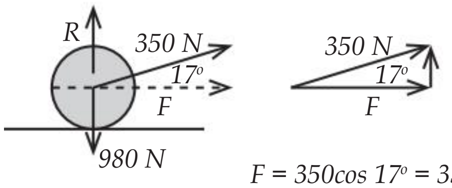
10. 

$36\ km\ h^{-1} = 10\ m\ s^{-1}$
$v_v = 10 \sin 30 = 5\ m\ s^{-1}$
Time = 12/5 = 2.4 s

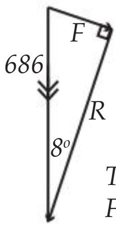
11. Resultant is forwards so F must be away from the boat
cos 45 = F/250
So F = 250cos45 = 177 N

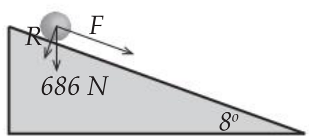


12.
a) Distance moved west at $15m\ s^{-1}$ = 40 m; so time taken = 40/15 = 2.67 s
b) Wind will have blown the ball a distance of 10 × 2.67 = 26.7 m

13.


F = 350cos 17° = 335 N

14.




Total weight = 70 × 9.8 = 686 N
F = 686sin8° = 95.5 N

15. Vertical velocity = 1600sin12 = 333 $km\ h^{-1}$ = 92.4 $m\ s^{-1}$
Time to reach the ground = 5300/92.4 = 57.4 s
v_h = 1600cos12 = 1565 $km\ h^{-1}$ = 435 $m\ s^{-1}$
Horizontal distance moved
= $v_h \times t$ = 435 × 57.4
= 2.50×10^4 m (25 km)

Newton's Laws Quiz

1. F = 1000 × 2.5 = 2.50 kN
2.
a) $a = 3/5 \times 10^{-3} = 600\ m\ s^{-2}$
b) $v = u + at = 0 + 600 \times 20 \times 10^{-3} = 12\ m\ s^{-1}$
3. The book has forward momentum because it is moving. When the car stops the book's momentum makes it continue moving, as there is almost no frictional force from the seat to stop it. Hence the book will hit the front seat where it experiences a backward force to stop it.
4. m = F/a = 60/500 = 0.120 kg
5.
a) $a = F/m = 120/0.12 = 1000\ m\ s^{-2}$
b) $v = u + at = 0 + 1000 \times 55 \times 10^{-3} = 55\ m\ s^{-1}$
6.
a) F = 1200 x –25 = 30 kN
b) $100\ kmh^{-1} = 27.7\ ms^{-1}$ $v^2 = u^2 + 2as$
So $0 = 27.7^2 - 2 \times 25s$ s = 15.4 m
7. The recoil force on the gun is the same as the forward force on the bullet.
If the gun has a small mass then its acceleration and final v will be high (a = F/m)
So a heavier gun will move backwards against the shoulder with less velocity
8.
a) Accelerating force F = 5200 × 150
= 7.80×10^5 N + 50960 = 8.31×10^5 N.
b) The acceleration will increase with time because the rocket loses mass (fuel).
If m decreases then a increases if F stays constant.
9. $v^2 = u^2 + 2as \Rightarrow 0 = 250^2 + 2\ a \times 0.3$
so $a = 1.04 \times 10^5\ m\ s^{-2}$
$F = 105 \times 1.04 \times 10^5$
$= 1.09 \times 10^7$ N
10. Weight = 75 × 9.8 = 735 N $\Rightarrow$ 680 + F = 735
so F = 55 N a = F/m = 55/75 = 0.733 $m\ s^{-2}$
11. $v^2 = u^2 + 2as$
$0 = 12^2 + 2\ x\ -9.8\ s \Rightarrow s = 7.35\ m$
12. A ball hitting his hand with high acceleration will exert a large force on him (hurts!)
Pulling the hands backwards to slow the ball allows the change in velocity to occur over a larger distance (and time) which reduces the acceleration and force on the hand.
13.
a) $\Sigma F = Ma = W + F_T$ 25(+2) = 25 × –9.8 + F_T
$F_T = 295$
b) At constant speed acceleration of case to floor = 9.8 so weight = 25 × 9.8 = 245 N
c) $\Sigma F = Ma = W + F_T$ 25(–3) = 25 × –9.8 + F_T
F_T = 170 N
14. Component of weight down slope = 60 × 9.8 × sin17° = 172 N which must equal the frictional force if the velocity is a constant.
15. v = 200/3.6 = 61.1 $m\ s^{-1}$
a = F/m = 15,000/900 = 16.7 $m\ s^{-2}$
$v^2 = u^2 + 2as$; so $61.1^2 = 0 + 2\ x\ 16.7 \times s$
so s = 112 m
16. Total acceleration = F/m
= 8000/4000 = 2 $m\ s^{-2}$
Tow-bar force = 1300 × 2 = 2600 N
17. Following through allows the force on the ball to occur over a longer time.
Acceleration also occurs for a longer time so v = u + at, therefore v will be larger
18. a = 150/0.05 = 3000 $m\ s^{-2}$.
F = ma = 0.01 × 3000 = 30 N
19.
a) Accelerating force = 3 × 9.8 = 29.4 N.
Total mass = 7 kg so a = 29.4/7 = 4.2 $m\ s^{-2}$
b) m = 5 so the net force acting = 5 × 4.2 = 21 N
Force down = 49 and net force = 21;
so tension (up) = 49 – 21 = 28 N
c) $s = ut + ½at^2$
so $0.5 = 0 + ½ \times 4.2t^2$ so t = 0.49 s
20.
a) Accelerating force = 4 x 9.8 = 39.2.
Total mass = 6 kg so a = 39.2/6 = 6.53 $m\ s^{-2}$ which is the same for the block.
b) $\Sigma F = Ma = T$ 2(6.53) = T T = 13.1N.

Momentum and Impulse Quiz

1. $\Delta p = (18 - 11) \times 1.2 = 0.15v$
   So $v_{ball} = 56.0$ m s^{-1}
2. Δp for dart and (board + dart)
   $= 0.025(45 - v) = (2.75 + 0.025)v$
   So $v_{board} = 0.405$ m s^{-1}
3. $I = F\Delta t = 63 \times 0.1 = 6.3$ Ns
4. Δp = Impulse So $195 = F \times 13$ so $F = 15$ N
5.

a) +ve $850 v_c - 1500 x 65 = 2350 \times -25$
   so $v_c = 45.6$ km h^{-1} = 12.7 m s^{-1}

b) KE before
   $= ½ \times 850 \times 12.7^2 + ½ \times 1500 \times 18.1^2$
   $= 3.14 \times 10^5$ J
   KE after
   $= ½ \times 2350 \times 6.94^2 = 5.67 \times 10^4$ J.
   Energy change = Heat gain = 2.58×10^5 J

6. p before: $20{,}000{,}000 \times 20$ = p after:
   $20{,}000{,}000\ v + 2 \times 550 \times 150$
   So $v = 19.99$ m s^{-1}
   So ship is slowed by 0.001 m s^{-1}.
7. Impulse must be the same:
   $48 \times 3 \times 10^{-3} = F \times 6 \times 10^{-2}$
   So $F = 2.4$ N
8. Δp for exhaust $= 600 \times 500 = \Delta p$ for rocket
   $= 900v$; so $v = 333$ m s^{-1}
9. By collapsing a rolling the time for the momentum change is prolonged
   As Ft = constant, if t rises then the force on the athlete decreases
10. $a = (v-u)/t = 2/8 = 0.25$ m s^{-2},
    $F = ma = 46 x 0.25 = 11.5$ N
    $I = F\Delta t = 11.5x 8 = 92$ N s
11. p Before $= 2200 \times 3.5$ = p after $= (2200 + 4200)v$; so $v = 1.20$ m s^{-1}
12. p Before $= (0.3 + 0.4) \times 15$ = p after $= 0.3 \times 450 - 0.4v$; so $v = 311$ m s^{-1} backwards
13. Changing their momentum in a short time will lead to a larger deceleration
    This leads to a larger force on the knee (F = ma) which can damage it
14. Crumple zones collapse quite slowly in the event of a crash. If the momentum change takes place over a larger time the decelerating force on the car and driver is less.
15. By striking the floor, a backwards reaction force is exerted on the judoka .This causes the body to lose velocity before it hits the ground and therefore it hits the ground with less velocity.
16. p Before $= 4800 x 12$ = p after $= (4800 + 15{,}200) x v_f$ So $v_f = 2.88$ m s^{-1}
    KE before $= 0.5 x 4800 x 12^2 = 3.46 x 10^5$ J
    KE after $= 0.5 \times 20{,}000 \times 2.88^2 = 8.29 \times 10^4$ which is less - an inelastic collision.
17. Let the mass of the trucks be m_1 and m_2. All impulses are equal
    so: $6m_1 = 8m_2 = (m_1 + m_2)v$
    Sub in $m_2 = {}^6/_8 m_1$ so $(m_1 + {}^6/_8 m_1)v = 6m_1$
    So $v = 3.43$ m s^{-1}
18. Estimate the area under the graph by assuming it is close to a triangle of height 77×10^3 and base 0.083

a) So the impulse $= 0.5 \times 77{,}000 \times 0.083$
   $= 3200$ N s.

b) Impulse = Δp so $3200 = 900$ v.
   $v = 3.55$ m s^{-1}

19.

a) $\Delta p = 0.4 \times 8 - (-0.4 \times 8.5) = 6.6$ kg m s^{-1}

b) $F = \Delta p/\Delta t = 6.6/0.25 = 26.4$ N

c) The change in momentum of the ball must equal the change in momentum of the object it collides with This means that the Earth must recoil with the same momentum change, but as the Earth is so large its recoil speed will be negligible.

20.

a) Velocity change of water = 24 – (-25) = 49 so momentum change per second (force)
   $= 49 x 41 = 2.00 \times 10^3$ N

b) Total mass of blades $= 55 \times 0.25 = 13.75$ kg.
   $a = F/m = 2000/13.75 = 145$ m s^{-2}

21.

a) The total momentum of the man + boat must remain at zero to conserve momentum. Hence
   $M_{man} x V_{man} - M_{boat} x V_{boat} = 0$
   $90 x 3 - 180 x V_{boat} = 0$ so $V_{boat} = -1.50$ m s^{-1} (backwards)

b) If the boat maintains this velocity backwards for a time of 0.30 s the man's velocity relative to the jetty will be 3.0 – 1.5 = 1.50 m s^{-1} forwards. So in a time of 0.30 s he will have moved forwards a distance of $1.50 \times 0.30 = 0.45$ m and he will miss the jetty by 0.50 – 0.45 m = 0.05 m.

Work, Energy & Power Quiz

1.

a) The ball will rise to point C

b) The ball must rise to the same vertical height to conserve the original PE.

2. $E_{TOT} = KE + PE = ½mv^2 + mgh$
   $= ½ \times 65 \times 20^2 + 65 \times 9.8 \times 3 = 14.9$ kJ (constant)
3. (ii) and (iv) D Total momentum is conserved
4.

a) KE of trucks = WD in friction
   So $½ \times 15{,}000 \times 2^2 = 500$ d; so d = 60 m

b) Heat = WD against friction = F × d
   $= 500 \times 60 = 30$ kJ

5. KE = heat generated:
   $½mv^2 = ½ \times 27{,}000 \times 44.4^2 = 26.7$ MJ

6. Vertical height fallen = 150sin30 = 75 m
PE lost = KE gained
So $mg \times 75 = ½mv^2$ $v^2 = 2 \times 9.8 \times 75$;
so $v = 38.3$ m s^{-1}

7. $a = F/m = 100{,}000/5500 = 18.18$ m s^{-2}
$u = 38.3$, $v = 0$, $a = 18.18$
KE lost = WD: $½ \times 5500 \times 38.3^2 =$
100000 s   s= 40.3 m

8. D

9. WD = 65 x 9.8 x 52 x 0.22 = 7287 J.
Power = WD/t = 7287/9.2 = 792 W

10.
a) $\Delta KE = ½ \times 0.22 \times 15^2 - ½ \times 0.22 \times 2^2$
= 24.3 J
b) $24.3 = 0.03 \times 440 \times \Delta T = 1.84\ ^oC$

11. $s = ut + ½at^2$
So $s = 0 + 3.4 \times 7.2^2 = 176.3$ m
Force $F = ma = 1500 \times 6.8 = 10{,}200$ N
$P = WD/t = (10{,}200 \times 176.3)/7.2 = 250$ kW

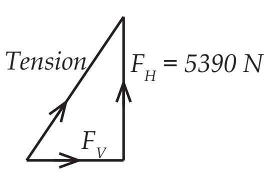
12.
a) $PE_{top} = KE_{bottom}$
So $mgh = ½mv^2$ or $v^2 = 2gh = 2 \times 9.8 \times 6$
So $v = 10.8$ m s^{-1}
b) At X (vertically) $u = 0$, $a = -9.8$, $s = -2$
Using $s = ut + ½at^2$ $2 = 0 + 4.9t^2$
So $t = 0.639$ s
$S_H = ut = 10.8 \times 0.639 = 6.90$ m
Total dist from bank = 6.0 + 6.90 = 12.9 m

13.
a) $PE_{top} = KE_{bottom}$ or $v^2 = 2gh = 2 \times 9.8 \times 2$
So $v = 6.26$ m s^{-1} before collision
Momentum conservation: 700×6.26
$= (1200 + 700)v$ $v = 2.31$ m s^{-1}
b) $a = F/m = 30{,}000/1900 = -15.79$ m s^{-2}
$v^2 = u^2 + 2as$; so $0 = 2.31^2 - 2 \times 15.79s$
s = 0.168 m into the ground
c) $WD = Fs = 30{,}000 \times 0.168 = 5.07$ kJ

14.
a) Vertical height = 180sin40 = 120.4
$WD = mgh = 950 \times 9.8 \times 120.4 = 1.12$ MJ
b) At B total energy = 90% of 1.12 MJ = 1.00 MJ = PE + KE at A
$1 \times 10^6 = (950 \times 9.8 \times 80) + ½ \times 950 \times v^2$
So $v = 23.2$ m s^{-1}

15. Energy from fuel = $0.4 \times 400 = 160$ J which is converted to PE + KE
So $160 = (0.3 \times 9.8 \times 35) + ½ \times 0.3 \times v^2$
So $v = 19.5$ m s^{-1}

16.
a) Weight of engine
$= 550 \times 9.8 = 5390$ N
$F_H = 5390\tan 15$
= 1444 N
$WD = 1444 \times 0.45 = 650$ J



b) P = 650/15 = 43.3 W

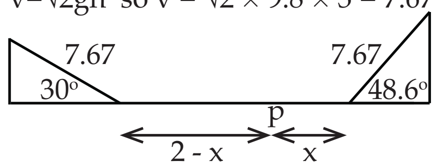
17. PE at end = PE + KE at start:
$(m \times 9.8 \times 0.025) + ½mv^2$
$= (m \times 9.8 \times 0.037)$ [m cancels]
$½v^2 = 0.3626 - 0.245$ $v = 0.485$ m s^{-1}

18. Estimate the area as a triangle plus a trapezium.
$A_1 = (½ \times 280 \times 0.9 \times 10^{-2})$
$A_2 = ½(280 + 330) \times 2.1 \times 10^{-2}$
= 1.26 + 6.405 = 7.67 J

19. Motor energy in = $Pt = 23{,}000 \times 120$
= 2.76 MJ
Lift energy out = $mgh = 800 \times 9.8 \times 255$
= 2.00 MJ % = 2.00/2.76 = 72.5%

20. Length above zero = $3.5\cos 27^o = 3.118$ m.
So height raised = 3.5 - 3.118 = 0.3815 m
$PE = mgh = 500 \times 9.8 \times 0.3815 = 1869$ J

21. PE Lost = KE gained so ½ ~~m~~v^2 = ~~m~~gh
$v = \sqrt{2gh}$ so $v = \sqrt{2 \times 9.8 \times 3} = 7.67$ m s^{-1}



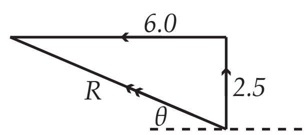
PE Lost = KE gained.
$Mgh = ½ mv^2$ $v = \sqrt{2gh} = \sqrt{2(9.80)(3)}$
= 7.67
Time to travel s1 = 2s1/v+u = 1.56 s
Time to travel s2 = 2s2/v+u = 1.04 s
Extra time for m1 to travel along 6.0 m
= 0.52 m.
Extra distance for m1 to travel along 6.0 m
= 4.00 m.
Balls are travelling at same speed in opposite directions and will meet mid-way of the remaining 2 m hence, 1 m from the start of slope 2.

Motion Test 1

Section A Multiple Choice
1. C 2. B 3. C 4. B 5. C 6. C 7. A 8. C 9. B 10. C

Section B Longer Questions
1.
a) Constant velocity
b) $8 \times 0.02 = 0.16$ s
c) $v = d/t = 0.14/0.16 = 0.875$ m s^{-1}
d) $V_A = 2.9/0.02 = 1.45$ m s^{-1}
$V_B = 4.2/0.02 = 2.10$ m s^{-1}
Acceleration = (2.10 - 1.45)/0.02
= 32.5 m s^{-2}

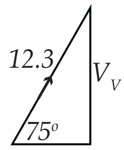
2.
a) $v^2 = 36 + 6.25$
$v = 6.5$ km h^{-1}
(1.81 m s^{-1})
$\tan\theta = 2.5/6$
so $\theta = 22.6^o$ to the bank



b) v across = 2.5/3.6 = 0.694 m s^{-1} t = d/v
= 30/0.694 = 43.2 s
c) Similar triangles: sin22.6 = 30/s so s = 78.1 m at 67.4° W of N

3.

a) $s = 9.2 – 1.5 = 7.7$ m
$v^2 = u^2 + 2as$
So $0^2 = u^2 – 19.6 \times 7.7$
so $u = 12.3$ m s^{-1}



b) $v_v = 5\sin75 = 4.83$ m s^{-1}

4.a)
(i) A: constant acceleration
(ii) B: constant velocity
(iii) D: stationary (rest)
(iv) D: acceleration backwards

b) $a = 6/7 = 0.875$ m s^{-2}
c) d = area of B = 6 × 8 = 48 m
d) Area ABC = ½(18 + 8) × 6 – ½(8 + 6) × 8
= 78 – 56 = 22 m

5.
a) $v^2 = 5^2 + 19.6 \times 25$ $v = 22.7$ m s^{-1}
b) $v = u + at$; so $22.7 = 5 + 9.8t$ So $t = 1.81$ s
c) $22.5^2 = u^2 + 2 \times 9.8 \times 25$
$506.25 – 490 = u^2$
So $u = 4.03$ m s^{-1}

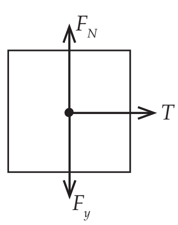
Motion Test 2

1.
a) C
b) The ball has to regain its original PE
So it must go to the same vertical height
(PE = mgh)

2.
a) Striking the ground gives a resisting force that allows deceleration
So the body strikes at a lower velocity and less injury
b) When the strings stretch this gives a longer time over which the force acts
So impulse ($F\Delta t$) is bigger, giving a larger momentum change and so larger v

3.
a) Elastic – no loss of KE in collision
Inelastic – loss of KE in collision
b) Before collision: 2m – 3m = -0.25m + mv
-~~m~~ = 0.75 ~~m~~ v
So $v = -0.75$ m s^{-1}
c) KE before = ½m x 4 + ½m x 9 = 2m + 4.5m
= 6.5 m joules
KE after = ½m x 0.25^2 + ½m x 0.75^2
= 0.03125 m + 0.28125 m = 0.3125 m joules
KE lost = 6.1875 m joules so it an inelastic collision

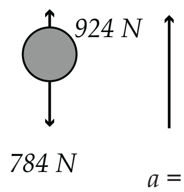
4.
a)



b) Accelerating force = 0.15 × 9.8 = 1.47 N
$a = F/m = 1.47/1 = 1.47$ m s^{-2}

c) Tension = ma = 0.85 × 1.47 = 1.25 N

5.
a) F = 80 x 9.8 = 784 N
b) PE = mgh = 784 x 1.46 = 1140 J
c) P = E/t = 1140/1.58 = 724 W
d)

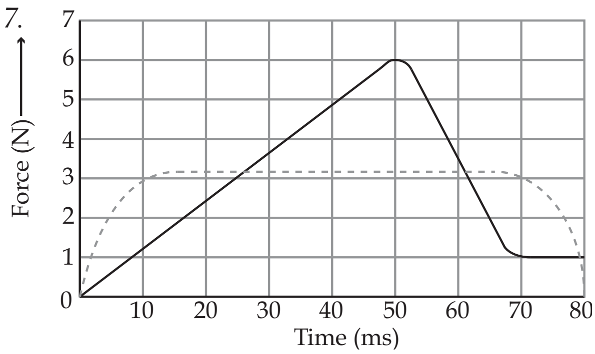


Net force up = 140 N

$a = F/m = 140/80 = 1.75$ m s^{-2}

6.
a) h = 180 sin42 = 120.4 m
W = mgh = 950 × 9.8 × 120.4
= 1.12×10^6 J
b) $PE_A = PE_B + KE_B$
$1.12 \times 10^6 = 950 \times 9.8 \times 30 + ½ \times 950 \times v^2$
$v^2 = 1772.7$
So $v = 42.1$ m s^{-1}
c) $KE_B = ½ \times 950 \times 42.1^2 = 842{,}029$
= F x d = F x 35
So $F = 2.41 \times 10^4$ N
d) E = Pt = 30,000 × 44.7
= 1.34×10^6 J

7.



a) Impulse = area under graph
= (½ x 60 x 0.05) + (½ x 60 x 0.02)
= 2.1 N s
b) Impulse = change in momentum
So 2.1 = m x 0.25
m = 8.4 m s^{-1}
c) Larger area under graph

Chapter 5 – Waves Solutions

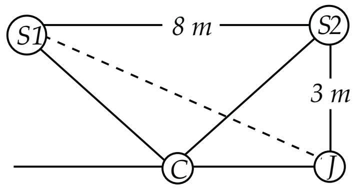
Sound Waves Quiz

1. Av time to travel 240 m = 0.6957
So v = 240/0.6957 = 345 m s^{-1}.
2. E-W average time = 0.6877 s
So E-W velocity = 240/0.6877 = 349 m s^{-1}
W-E average time = 0.7037 s so W-E velocity = 240/0.7037 = 341 m s^{-1}
Wind must be blowing from the east at 349-345 = 4.0 m s^{-1}.
3. a,b and c,e and b,d.
4.
a) v = d/t = 10/5 = 2.0 m s^{-1}
b) f = 25/5 = 5.0 Hz
c) λ = 10/25 = 0.40 m

5. $v = 405 + 0.085 \times 25 = 407$ m s^{-1}
6. $v = 405 + 0.085 \times 51 = 409.34$ m s^{-1}
   $d = 300$ m so $t = 300/409.34 = 0.733$ s.
7. Time between pulses $= 4 \times 20$ ms $= 80 \times 10^{-3}$ s
   $2d = 1520 \times 80 \times 10^{-3} = 121.6$ m
   So $d = 60.8$ m
8. Rotation rate = 1500/60 = 25 Hz
   No. of holes passing per second = 25 × 200 = 5000 Hz which is the generated frequency.
9. f is constant so
   $$\frac{v_1}{\lambda_1} = \frac{v_2}{\lambda_2} \text{ so } \frac{310}{0.6} = \frac{360}{\lambda_2} \quad \lambda_2 = 69.7 \text{ cm}$$
10. i) false, ii) false, iii) true, vi) true, v) true
11. Correct diagrams are: ii) and iv)
12. Correct diagrams are: ii) and iv)
13. B (sound slows down going from water to air)
14.
a) $P = I \times A = 3.4 \times 10^{-4} \times 4\pi \times (55.5)^2$
   $= 13.2$ W.
b) $$l_2 = \frac{l_1 r_1^2}{r_2^2} = \frac{3.4 \times 10^{-4}\,(55.5^2)}{10^2}$$
   $= 1.03 \times 10^{-4}$ Wm^{-2}
15. Mass/metre $= 2.08 \times 10^{-4}/0.625$
   $= 3.312 \times 10^{-4}$
   $v^2 = T/m = 226/\,3.312 \times 10^{-4}$
   so v 826 m s^{-1}
16. The sound travels 192 cm in a time of 6 ms
   so $v = 1.92/6 \times 10^{-3} = 320$ m s^{-1}
   Period of wave = 3 ms so frequency
   $= 333.3$ Hz $\lambda = v/f = 320/333.3 = 0.96$ m.
17.
   $$4.9993 \times 10^6 = 5.0000 \times \left\{10^6 \; \frac{1}{1 + \frac{V_b}{1480}}\right\}$$
   $$0.99986 \left\{1 + \frac{V}{1480}\right\} = 1$$
   $v = 0.200$ m s^{-1}
18. Total fraction absorbed by combination tile
   $= 0.55 \times 0.2 + 0.08 \times 0.2 = 0.126$
   Fraction transmitted $= 1 - 0.126 = 0.874$
   So intensity at $X = 2.0 \times 10^{-4} \times 0.874$
   $= 1.75 \times 10^{-4}$ W m^{-2}
19. $i = 50^o$ and $r = 40^o$
   $n = \sin 50^o/\sin 40^o = 1.19$
   (note: must be the angles to the normal).
20. Correct answer is B

Interference Quiz

1. $\lambda = 340/680 = 0.50$ m
   Length $(S_2X)^2 = 6.0^2 + 2.5^2$
   so $S_2X = 6.5$ m
   Path difference $S_2X - S_1X = 0.5$ m
   = 1 whole wavelength
   Therefore constructive interference D.
2. $\lambda = 346/162 = 2.136$ m



   At C there is no path difference but distance
   $S_1J^2 = 32 + 82S1J = 8.54$m
   8.54 - 3 = 5.54 m pathdiff. = 2.54 λ.
   So there are 2 loud points between C and J.
3. B
4. Pattern: as people get older their perception of high frequency sounds becomes less.
   Also there is a large deterioration after age 55.
5. Volume $= 8 \times 4 \times 2.5 = 80$ m^3
   Area of walls $= (2 \times 8 \times 2.5) + (2 \times 4 \times 2.5)$
   $= 60$ m^2
   $K = 0.55 \times 60 = 33$
   So $T = 80/(6.25 \times 33) = 0.388$ s
6. $n = v_1/v_2 = 344/266 = 1.293$
   $n = \sin i/\sin r$
   So $1.293 = \sin 40^o/\sin r$
   $r = 29.8^o$
7. Answer: C
8. The truck engine transmits waves through the ground and air which force the 'planes to move.
   The frequency of the truck matches the natural frequency of only one of the 'planes, depending on the length of string. This causes resonance which makes the 'plane swing wildly.
9. Assuming the wavelength of the ultrasonic waves is 1 mm
   $$f = \frac{v}{\lambda} = \frac{1.52 \times 10^3}{0.001} = 1.52 \times 10^6 \text{ Hz}$$
10. To cancel out a note of constant frequency (engine, drill, etc) a wave needs to be generated that is the same frequency but out of phase with it. The earphones sense this constant note and generate inside the earmuffs the same note but with a 180^0 phase difference, producing destructive interference.

Standing Waves Quiz

1. Standing waves will be produced if two waves of the same frequency are travelling in opposite directions e.g. from 2 separate sources or one source being reflected.
2. $\lambda_1 = v/f = 346/2200 = 0.1573$ m.
   $L = \lambda/4$ so $L = 3.93$ cm
3. 17 nodes means 16 half wavelengths or 8 whole waves in 8.5 m
   So $\lambda = 1.06$ m
4. $\lambda = 4 \times 2.5 = 10$ cm. $f = v/\lambda$
   $= 346/0.1 = 3460$ Hz.

5. 1st harmonic:

$$f_1 = \frac{v}{4(L+e)} = \frac{360}{4(0.9+0.02)} = 97.8 \text{ Hz}$$

3rd harmonic:

$$f_3 = \frac{3v}{4(L+e)} = \frac{3 \times 360}{4(0.9+0.02)} = 293 \text{ Hz}$$

5th harmonic: $f_5 = 5 \times 97.8 = 489$ Hz

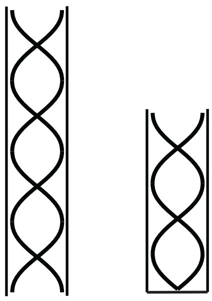
6. $\lambda/2 = 0.75$ so $\lambda = 1.50$ m
$f_1 = 850/1.50 = 566.7$ Hz
So $f_3 = 3 \times 566.7 = 1700$ Hz

7. Distance between antinodes = 13 cm
so $\lambda = 26$ cm
$v = f\lambda = 1300 \times 0.26 = 338$ m s^{-1}

8. $33.4 \times 4 = \lambda = 1.34$ m
$v = 256 \times 1.34 = 342$ m s^{-1}

9. 3rd overtone of an open pipe = 4th harmonic
2nd overtone of a closed pipe = 5th harmonic

Open: 4th harmonic



Closed: 5th harmonic

Open pipe frequency
F = 4 x fundamental = $4f_o$
Closed pipe frequency
F = 5 x fundamental = $5f_o$
F = $4f_o = 5f_o$/ so ratio f_o/f_o = 5/4 or 1.25:1

10. Answer is B
1750 Hz = 2 x 875 so it must be the 2nd harmonic. 2nd harmonic can only be produced with an open pipe. For the fundamental λ = 346/875 = 0.395 m. pipe length L = $\lambda/2$ = 19.8 cm.

Chapter 6 – Investigations

Aims Quiz

1.
(i) To see which paint is most weather-proof.
(ii) To see which paint keeps the house warmest.

2.
(i) To see which coloured logos are the most visible
(ii) To compare people's eyesight in different lighting conditions.

3.
(i) To see which parts of the pylons are warmest.
(ii) To see if any insulators are breaking down and starting to conduct.

4.
(i) To see which type of weatherboard is the best insulator.
(ii) To compare the reflective abilities of different weatherboards.

5.
(i) To see which type of shampoo produces tangle-free hair.
(ii) To see if a shampoo can strengthen hair, as claimed.

Hypothesis Quiz

1. The new weatherboard will be a better insulator because it is coated with a known bad conductor.
2. The Remington will dry hair quicker because it is the most expensive and should be better.
3. The thicker the metal the better absorber it is because there will be a greater mass of metal with more atoms to "capture" the rays.
4. Paper A will be the most absorbent because it has a more open weave of fibres to absorb the water molecules by surface tension.
5. Material 3 will keep Suzie warmer because it is thicker and white so it is a worse conductor and a better reflector.

Preliminary Testing Quiz

1. Cornflour would be the best to use in the main experiment as it gives a greater variation of colour at different temperatures. The top shelf seems to be the hottest position.

2.
a) 300 grams seems to be the best as it gives the greatest variation of frictional force between each oil.
b) Oil 1 seems to be the best lubricant as it gives the least resistance to motion.

3.
a) 20 minutes is best as it shows the greatest variation and allows a better comparison.
b) Soil 3 retains water better than soil 1 and the least retentive is Soil 2.

4.
a) 20 days (the nails have lost their maximum mass by then).
b) Comparisons can be made if the % loss in mass of each nail is calculated.
c) % losses are: Nail 1 = 0.85/6.71 (12.7%); Nail 2 = 0.18/9 (2.0%).13; Nail 3 = 0.3/3.95 (7.6%); Nail 4 = 2.65/5.50 (48.2%). Least corrosion is with Nail 2.

5.
a) Josh's experiment is best as his method of attachment ensures an even distribution of force on the paper. The hole used in John's experiment provides a weak point for breaking and would give large variability.
b) The variance in Josh's results (spread of values in the same conditions) is much larger and indicates a lack of variable control and more randomness.

c) 2 cm width seems the best as it shows clearer differences between the types of paper.
d) Paper C seems stronger but is very close to Paper B.

Variable Control Quiz

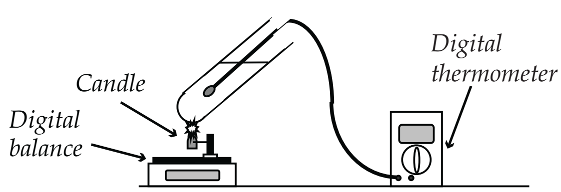
1.
a) Independent variable = Type of sock. Dependent variable = Temperature difference of bottles.
b) Controls: Same sized bottles, Same volume of water, Same starting temperature, Same environment (position, room temp, etc).
c) Comparisons made on "Temperature drop of the water".

2.
a) Dependent Var. is "Amount of rust formed" which could be estimated from the area of brown produced by rusting on each surface.
b) Variables: Same area of steel painted; Same painting method (spray, brush, etc); Same environment (position in the sun, moisture, temp etc).

3.
a) Dependent Var. is "Strength of concrete" which could be investigated by making blocks of a standard size, placing a set of scales under each end and pushing down on the middle with a car jack until the block breaks. The scale readings operationally define the "Strength" variable.
b) Independent Vars: Same size of blocks – cast in same sized mould; Same quantity of cement dust – by weighing; Same mixing method – vibrating air bubbles out; Same test rig and scales spacing; Same position of applied force – mark the centre point.

4.
a) Indep.Var. is "Tissue type" and Dep.Var. is "Mass of water absorbed".
b)
(i) Weigh tissue,
(ii) Immerse in water and allow to drain,
(iii) Reweigh tissue,
(iv) Find the gain in mass of tissue (= water absorbed),
(v) Divide the % gain in mass by the area of tissue.

5.
a) Diagram below.



b) Controls: Same tube and mass of water, Same starting temp of water, Same distance to the flame, Same time of heating.
c) Indep. Var. is "Type of fuel". Dep. Var is "Heat per gram of fuel", measured by $H = mc\Delta\theta$.

Rule of Many Quiz

1. Weigh 100 balls and divide by 100
2.
a) Collect 1000 drops of water, measure the volume and divide by 1000.
b) No. of drips per year = 365 x 24 x 60 = 525600 x 22 = 1.156×10^7 drips
Volume lost = $1.156 \times 10^7 \times 0.62 \times 10^{-3}$ = 7.17×10^3 litres.
3. Measure the time for 100 flashes and divide by 100.
4. Example: No. of pages in 1 cm thickness = 166, so 1 page = 1/166 cm = 0.6 mm.
5. Measure the length of ink in the refill (suppose 120 mm). Draw 1000 lines each 30 cm long on paper (= 300 m). Measure by how much the ink length has fallen (suppose 1 mm). Find how many 300 m lengths can be drawn from the whole ink (= 120/1). Example calculation: Total length of line = 120 x 300 = 36 km.

Analysing Data Quiz

1. Temperature of the fire is around 1100°C (between copper and steel) as copper has started to melt and steel has not melted.
2. Shape C loses heat fastest. The colour black loses heat fastest.
3.
a) Comparing results 1 and 4, doubling the length will give half the current (inverse relationship).
b) Comparing results 1 and 2, doubling the diameter will increase the current by a factor of 4.
c) Area = πr^2. If I = kA then k should be the same if length is the same.
Result 1: k = 64.9 and Result 2 k = 63.3 (v. close). Result 3 k = 131.4,
Result 4 k = 138.8.
4.

Image size (mm)	Lens width (mm)
10	7.5
14.5	11
5.8	4.5
19	14

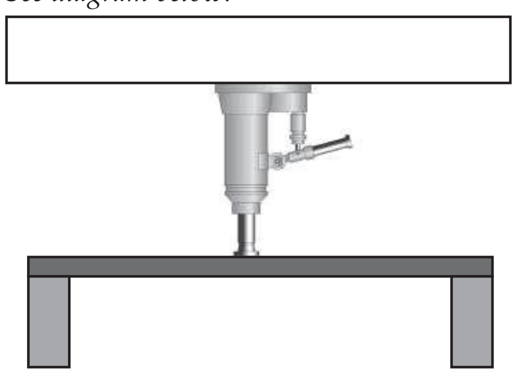
a) Size of the image is directly proportional to the lens width.
b) Size of image = 1.35 × lens width, approx.

5.
a) *Sag is directly proportional to load (straight line graph)*
b) *Graph is a curve upwards left to right.*
c) *It is not a linear graph – maybe a quadratic or cubic. A plot of d^3 versus Sag (s) is linear.*
d) $d^3 = ks$
e) *Other variables: Bridge material; Width; Thickness; Anchoring method for ends; position of weights.*

Evaluating Investigations Quiz

1. *The variables not controlled are: Amount of dirt present; Mass of soap used; Volume of water used; Width of vessel; shaking and rest time.*
Improvements: Use the same amount of dirt in the same shaped vessel, containing the same volume of water and using the same amount of soap. Water is shaken for the same time and the lather height measured after 1 minute.

2.
a) *The variables not controlled are: Size of concrete block; width and spacing of supports. Hitting with a hammer is not controllable as invisible cracks can have formed – not a continuous variable.*
b) *Important variables: Size and shape of concrete, Spacing of supports, Hammer force.*
c) *See diagram below.*



The car jack pushes upwards on a rigid beam and can exert a variable force downwards which could be measured from scales placed under the 2 supports.
d) *Perform each test 5 times with the same variables controlled and average out the results.*

3.
a) *The size of the bricks was not controlled but this could be overcome by finding the % absorption by mass for each brick type. The drum is too large for accuracy.*
b) *With a narrower tank the drop in water level would be greater and more accurately measured.*
c) *Comparing the water absorbed per kg of mass would be a Fair Test.*

4.
a) *Tanya's data does not really compare like with like. Her variables are not controlled.*
b) *Variables needed to control: How old the car is and the condition of the tyres. What safety features the car has (airbags, etc), Average distance each car has covered, What type of person drives the car (age, sex, personality, etc)*
c) *Use a very large sample and calculate the No. of deaths per kilometre travelled.*
d) *Find the No. of deaths per kilometre travelled over the last 5 years only.*
e) *Compare only women drivers of a certain age living in the same area for instance.*

5.
a) *In both cases it is difficult to judge "Broken" as the bags will all stretch a lot first. Karen has controlled the width of the strips and the force is continuously variable and so will give more accurate results.*
b) *Karen has repeated readings and averaged them but Jeffrey's results have a large average uncertainty of ± "1 pipe-weight". Karen's results also have a much lower variance.*
c) *Bar graphs are OK to use with Independent Vars. Like "Colour" but Karen's 2nd graph shows more detail on how the bag stretches.*
d) *Karen's hypothesis on the strength due to molecular forces is more scientific than Jeffrey's one merely due to colour. Karen has also suggested a reasonable use for the weakest plastic with a large stretch. Overall, Karen's investigation is of a much higher quality.*

Uncertainties Quiz

1. $(15.3 + 16.34) \pm (0.1 + 0.05) = 31.64 \pm 0.15 = 31.6 \pm 0.2$
2. $(15.3 - 16.34) \pm (0.1 + 0.05) = 1.04 \pm 0.15 = 1.0 \pm 0.2$
3. $A = \frac{\pi d^2}{4} = \frac{\pi(2.5 \times 10^{-3})^2}{4} = 4.9 \times 10^{-6} m^2$
(2 sig fig) $unc = 2 \times (0.1/2.5) \times 2\ 100 = 8\%$
$A = (4.91 \pm 4.9 \times 8/100) \times 10^{-6}$
$= (4.9 \pm 0.4) \times 10^{-6}\ m^2$

4.
a) *Volume = 7.8 × 2 10.6 × 0.3 = 25* cm^3
(2 sig fig)
$D = m/V = 62/24.8 = 2.50\ gcm^{-3}$ *(2 sig fig)*
b) *% errors are: 1.3%, 1%, 3.3% in lengths and 1.6% in mass. Total = 7.2%*
c) $D = 2.5 \pm 0.2\ g\ cm^{-3}$

5.

a) *Area* = $\pi\ (0.30\times 10^{-3})^2 = 2.8 \times 10^{-7}\ m^2$

$$\square = \frac{235 \times 2.82 \times 10^{-7}}{3.74}$$

$$\square = 1.80 \times 10^{-5}\ \Omega\ m$$

b) *% R = 4.3, %A = 3.33 × 2 = 6.7, % l = 0.1 Total = 11.3%.*

c) $(1.8 \pm 0.2) \times 10^{-5}\ \Omega\ m$.

6.

a) $p = \dfrac{0.22 \times 4180 \times 6}{60} = 90\ W$ *(1s·f)*

b) *% m = 2.3, ΔT = 2 x 1/6 = 33, %t = 1.7. Total = 37% (temperature error is large!)*

c) $(9 \pm 3) \times 10^1\ W$.

7.

a) *Average t = 0.53 s.* $g = 2h/t^2 = 8.2$ *sig* $m\ s^{-2}$

b) *% h = 0.8%.* $\%t = \dfrac{0.01}{0.53} \times 100 = 0.5$ *= 0.014.*

c) $(9 \pm 5)\ m\ s^{-2}$

Drawing Conclusions Quiz

1. Resistance of a wire.

a) *A graph of* ***I versus 1/L*** *should be plotted*

b) *Values of 1/L are*

$0.838 = \dfrac{R\,t}{m\,c} = \dfrac{5 \times 60}{0.50 \times c}$ $\qquad c = 716\ J\ kg^{-1}\ K^{-1}$

0.167; 0.145; 0.133; 0.120; 0.115; 0.105.

c) *I versus 1/L graph is a straight line but R is proportional to 1/I so R is directly proportional to L. Since the slope of the line does not change (not a curve) R must stay at a fixed value for larger I values (higher temperatures)*

d) *Spring 1:* $R^2 = 0.996$*: a very strong positive linear relationship exists*
Spring 2: $R^2 = 0.999$*: a very strong positive linear relationship exists*

e) *Gradient = 32.2 so a = 62* $\Omega\ m^{-1}$

2. Stretching springs

a) *Spring 1 equation: L = 0.041 m + 6.4.*
Spring 2 equation: L = 0.050 m + 10.3

b) *Gradient 1 = 0.041* $g\ cm^{-1}$*. Gradient 2 = 0.050*$g\ cm^{-1}$.

c) *The 5th reading on spring 1 seems wrong.*

d) *Spring 1:* $R^2 = 0.996$*: a very strong positive linear relationship exists.*
Spring 2: $R^2 = 0.999$*: a very strong positive linear relationship exists.*

e) *The gradients are different. Spring 2 stretches more then spring 1 for a given load.*

f) *Spring length and diameter must be controlled.*

3. Electrical heating

a) I^2 *needs to be plotted*

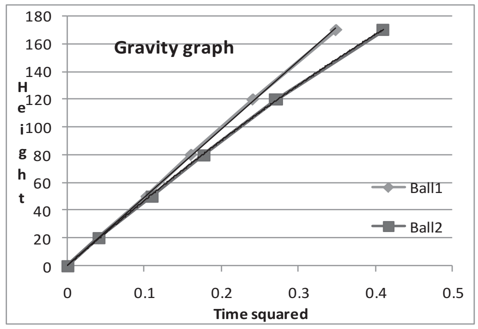
b) *A good straight line fit graph is obtained*

c) *Temp rise (ΔT) is directly proportional to* I^2 *because the points are very close to being on the line. A T-test shows p<0.13% confidence level (1 in 1000 probability of obtaining by chance)*

d) *Gradient = 0.838*

4. Falling Balls

a) *h should be plotted against* t^2 *for a straight line relationship (see graph)*



b) *The graph of h versus* t^2 *for ball 1 is a good straight line but for ball 2 the graph is a slight curve.*

c) *Equation is:* $h = 491t^2$ *so g/2 = 491 and g equals 982* cms^{-2}

d) *Ball 2 being bigger and light (hollow) will be more affected by air resistance so it loses speed quicker, reducing the slope of the graph and the apparent value of g.*

5. Squash balls

a) *Average* h_2 *values in table 1: 24.3; 32; 41; 46.7; 57; 14.*
Average h_2 *values in table 2: 19; 28; 34; 42.7; 54; 9.*

b) *The graph seems to show a slight curve (quadratic?)*

c) *Equation from table 1 is* $h_2 = 0.005T^2 + 0.433T + 12.24$

d) *Equation from table 2 is* $h_2 = 0.005T^2 + 0.428T + 7.735$

e) *The larger the drop height the higher the bounce height, but the variables do not seem to be directly proportional. Comparing the bounce heights at the same temperatures for a 50 cm and 80 cm drop height we find that the ratio* $h_2/h_1 = 0.84$ *for 50 cm but* $h_2/h_1 = 0.58$ *for 80 cm.*

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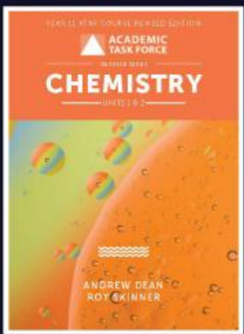

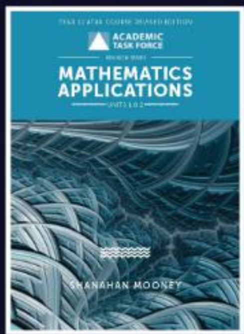

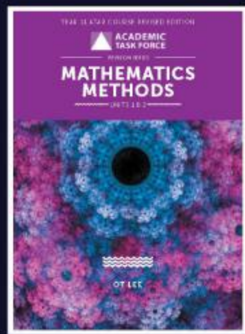

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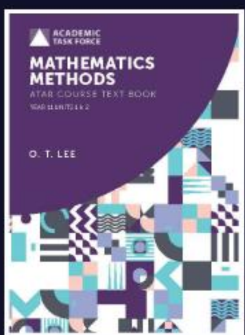

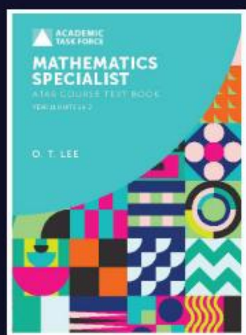

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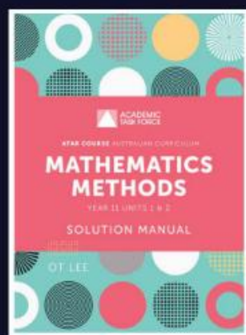

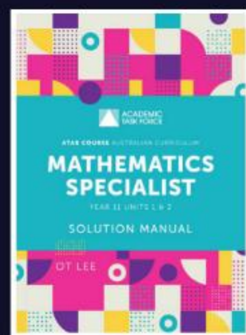

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