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Topical REVISION NOTES

PHYSICS

Tan Kim Seng
PhD, FCollT, MSc, PGDE, BSc (Hons)

O LEVEL

Includes

- ✓ Detailed Worked Examples
- ✓ Comprehensive Revision Notes
- ✓ Effective Study Guide

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PREFACE

O Level Physics Topical Revision Notes has been written in accordance with the latest syllabus issued by the Ministry of Education (Singapore).

This book is divided into 22 topics, each covering a topic as laid out in the syllabus. Important concepts and formulae are highlighted in each unit, with relevant worked examples to help students learn how to apply theoretical knowledge to examination questions.

We believe this book will be of great help to teachers teaching the subject and students preparing for their O Level Physics examination.

CONTENTS

TOPIC 1 Physical Quantities, Units and Measurement

Objectives

Candidates should be able to:

(a) show understanding that all physical quantities consist of a numerical magnitude and a unit
(b) recall the following base quantities and their units: mass (kg), length (m), time (s), current (A), temperature (K), amount of substance (mol)
(c) use the following prefixes and their symbols to indicate decimal sub-multiples and multiples of the SI units: nano (n), micro (μ), milli (m), centi (c), deci (d), kilo (k), mega (M), giga (G)
(d) show an understanding of the orders of magnitude of the sizes of common objects ranging from a typical atom to the Earth
(e) state what is meant by scalar and vector quantities and give common examples of each
(f) add two vectors to determine a resultant by a graphical method
(g) describe how to measure a variety of lengths with appropriate accuracy by means of tapes, rules, micrometers and calipers, using a vernier scale as necessary
(h) describe how to measure a short interval of time including the period of a simple pendulum with appropriate accuracy using stopwatches or appropriate instruments

NOTES...

1.1 Physical Quantities and SI Units

1. Physical quantities consist of:
   (a) Numerical magnitude – denotes the size of the physical quantity.
   (b) Unit – denotes the physical quantity it is expressing.

2. Physical quantities can be classified into:
   (a) Basic quantities

Basic Quantity	Name of SI Unit	SI Unit
length	metre	m
mass	kilogram	kg
time	second	s
thermodynamic temperature	kelvin	K
amount of substance	mole	mol

   (b) Derived quantities – defined in terms of the basic quantities through equations. SI units for these quantities are obtained from the basic SI units through the equations.

Example 1.1

Density = $\frac{\text{Mass}}{\text{Volume}}$ (Unit for mass: kg, Unit for volume: m^3)

Therefore unit for density = $\frac{kg}{m^3}$ = kg/m^3

3. (a) Units of measurements: SI units are used as standardised units in all measurements in the world. SI is the short form for "International System of Units".
   (b) Other Units:

Length	**Mass**	**Time**
1 km = 1000 m	1 kg = 1000 g	1 h = 60 min
1 m = 100 cm	1 g = 1000 mg	1 min = 60 s
1 cm = 10 mm		

4. Examples of some derived quantities and their units:

Derived Quantity	**SI Unit**
area	m^2
volume	m^3
density	kg/m^3
speed	m/s

A complete list of key quantities, symbols and units used for the O Level examination can be found in the syllabus.

1.2 Prefixes, Symbols and Orders of Magnitude

1. Physical quantities can be very large, like 23 150 000 000 m, or very small, like 0.000 000 756 m. Writing down such numbers can be time consuming and error-prone. We use prefixes to indicate decimal sub-multiples and multiples of the SI units to make writing such numbers easier.

2. Some prefixes of the SI units are as follows:

Prefix	Multiple	Symbol	Factor	Order of Magnitude
Tera	1 000 000 000 000	T	10^{12}	12
Giga	1 000 000 000	G	10^{9}	9
Mega	1 000 000	M	10^{6}	6
Kilo	1000	k	10^{3}	3
Deci	0.1	d	10^{-1}	–1
Centi	0.01	c	10^{-2}	–2
Milli	0.001	m	10^{-3}	–3
Micro	0.000 001	μ	10^{-6}	–6
Nano	0.000 000 001	n	10^{-9}	–9
Pico	0.000 000 000 001	p	10^{-12}	–12

The ones in bold are specifically required in the syllabus.

Example 1.2

(a) 0.000 0031 m = 3.1 μm = 3.1×10^{-6} m

(b) 0.000 000 0012 s = 1.2 ns = 1.2×10^{-9} s

3. When measurements are too large or too small, it is convenient to express them in standard form as follows:
   $M \times 10^{N}$
   M lies in the range of: $1 \leqslant M < 10$
   N denotes the order of magnitude and is an integer.

4. Orders of magnitude are often being used to estimate numbers which are extremely large to the nearest power of ten.
   E.g.
   (a) Estimate the number of strands of hair on a person's head.
   (b) Estimate the number of breaths of an average person in his lifetime.

5. The following tables show how the orders of magnitude are used to compare some masses and lengths.

Mass/kg	Factor
Electron	10^{-30}
Proton	10^{-27}
Ant	10^{-3}
Human	10^{1}
Earth	10^{24}
Sun	10^{30}

Length/m	Factor
Radius of a proton	10^{-15}
Radius of an atom	10^{-10}
Height of an ant	10^{-3}
Height of a human	10^{0} ($10^{0} = 1$)
Radius of the Earth	10^{7}
Radius of the Sun	10^{9}

Example 1.3

Find the ratio of the height of a human to that of an ant.

Ratio of height of human to that of an ant = $\frac{10^{0}}{10^{-3}} = 10^{3} = 1000$.

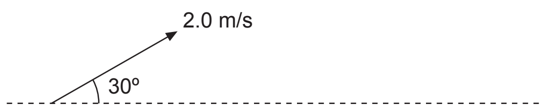
1.3 Scalars and Vectors

1. A scalar quantity – has only magnitude but does not have direction.
   E.g. mass, distance, time, speed, work, power.

2. A vector quantity – has both magnitude and direction.
   E.g. weight, displacement, velocity, acceleration, force.

Example 1.4

The velocity of a particle can be stated as: "speed of particle = 2.0 m/s and it is moving at an angle of 30° above the horizontal".

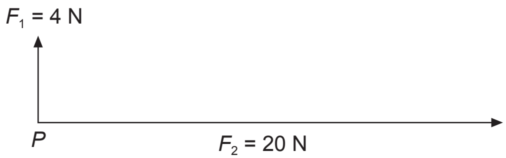


1.4 Addition of Vectors

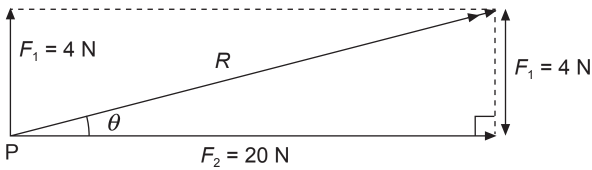
1. Involves magnitude and direction.

Example 1.5

Find the resultant force R at point P due to F_1 and F_2.



Method 1: Trigonometric Method



Using Pythagoras' Theorem:

$$R = \sqrt{(F_1)^2 + (F_2)^2}$$

$$R = \sqrt{4^2 + 20^2} = \sqrt{416}$$

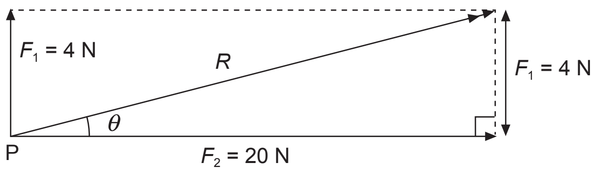
R = 20.4 N

R is at an angle θ above the horizontal

$$\tan\theta = \frac{F_1}{F_2} = \frac{4}{20} = \frac{1}{5}$$

$\theta = 11.3°$

Method 2: Graphical Method



(Not drawn to scale)

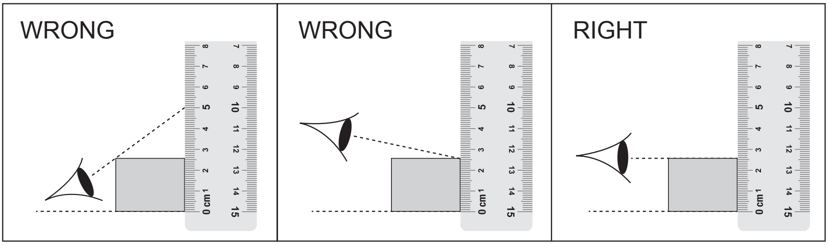
Step 1: Select an appropriate scale
E.g. 1 cm to 2 N.
Step 2: Draw a parallelogram of vectors to scale.
Step 3: Measure the diagonal to find R.
Step 4: Use the protractor to measure angle θ.

1.5 Measurement of Length

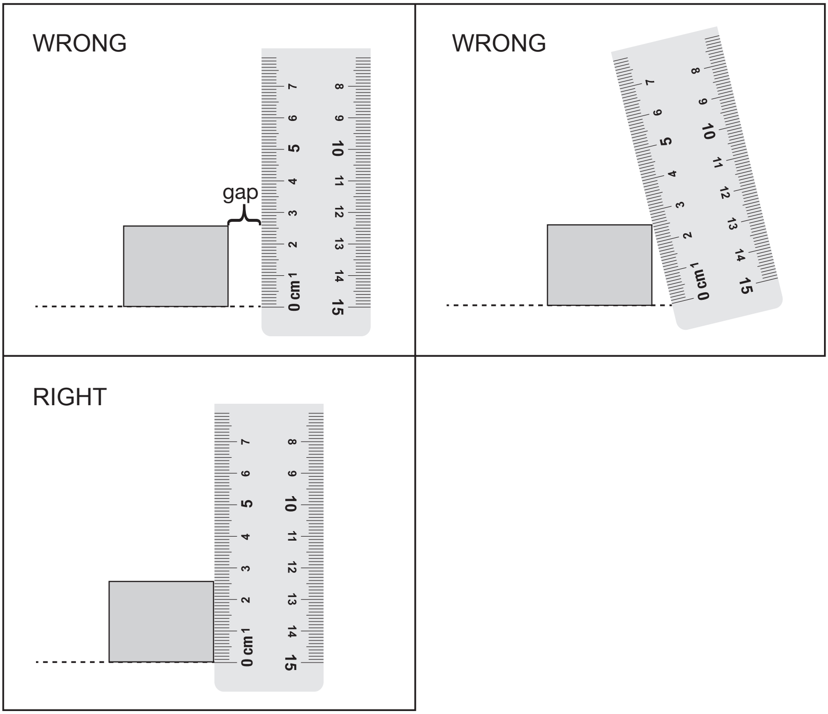
1. Choice of instrument depends on the degree of accuracy required.

Range of length, *l*	Instrument	Accuracy	Example
l > 100 cm	Measuring tape	± 0.1 cm	waistline of a person
5 cm < *l* < 100 cm	Metre rule	± 0.1 cm	height of an object
1 cm < *l* < 10 cm	Vernier calipers	± 0.01 cm	diameter of a beaker
l < 2 cm	Micrometer screw gauge	± 0.001 cm	thickness of a length of wire

2. How parallax errors can occur during measurement:
   (a) incorrect positioning of the eye



   (b) the object is not touching the marking of the scale
   (for measuring tape and metre rule, ensure that the object is **in contact** with the scale)



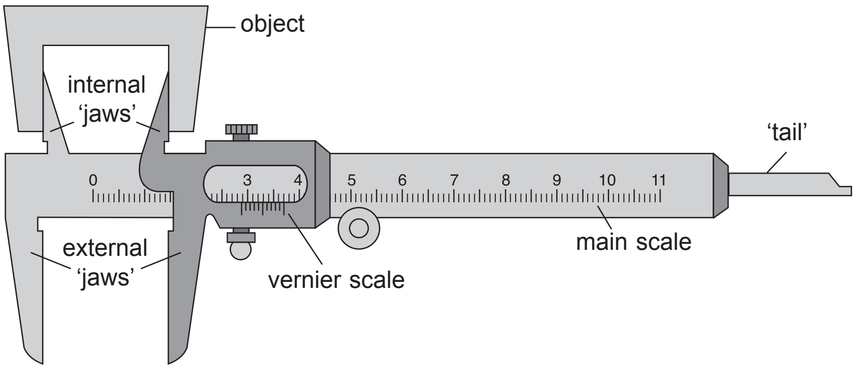
3. A measuring instrument can give precise but not accurate measurements, accurate but not precise measurements or neither precise nor accurate measurements.

   (a) Precision is how close the measured values are to each other but they may not necessarily cluster about the true value. Zero errors and parallax errors affect the precision of an instrument.

   (b) Accuracy is how close a reading is to the true value of the measurement. The accuracy of a reading can be improved by repeating the measurements.

4. **Vernier calipers**

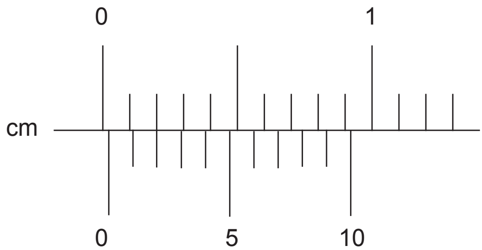
A pair of vernier calipers can be used to measure the thickness of solids and the external diameter of an object by using the external jaws. The internal jaws of the caliper are used to measure the internal diameter of an object. The tail of the caliper is used to measure the depth of an object or a hole. Vernier calipers can measure up to a precision of ±0.01 cm.



Precautions: Check for zero error and make the necessary correction.

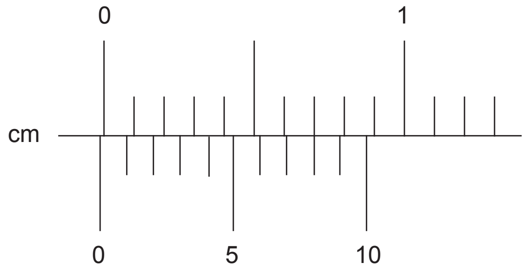
Example 1.6

(a) Positive zero error:



Zero error = +0.02 cm

(b) Negative zero error:

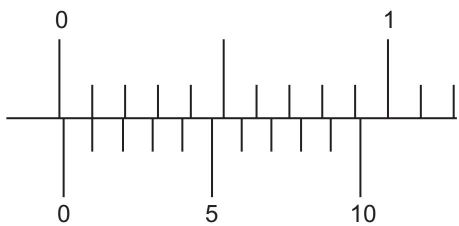


Zero error = –0.02 cm

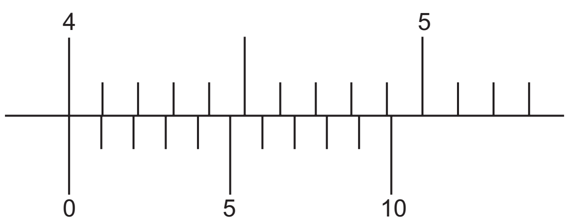
Note: In (b), the pair of vernier calipers is built with an existing zero error. There is a negative reading without any object between its jaws. The vernier scale is pushed 0.02 cm to the left.

Example 1.7

When the jaws of a pair of vernier calipers are closed, the vernier caliper reading is as shown.



When the same pair of vernier calipers is used to measure the diameter of a beaker, the vernier caliper reading is as shown.

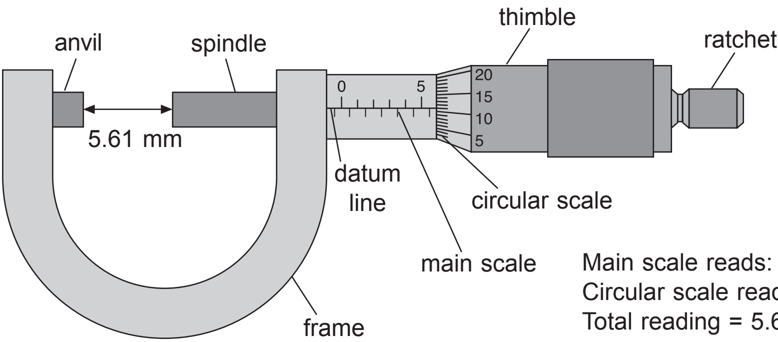


What is the diameter of the beaker?

Solution

Zero Error = +0.01 cm
Reading = 4.00 + 0.01 = 4.01 cm
Actual reading = 4.01 − 0.01 = 4.00 cm

5. Micrometer screw gauge

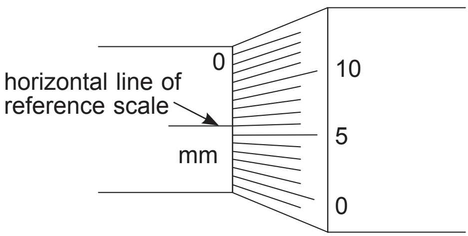


Main scale reads: 5.50 mm
Circular scale reads: 0.11 mm
Total reading = 5.61 mm

Precautions:
(a) Ensure that the jaws of the micrometer screw gauge are completely closed by turning the ratchet until you hear a 'click' sound.
(b) Check that the '0' mark of the thimble scale is completely in line with the horizontal line of the reference scale. If not, there is zero error.

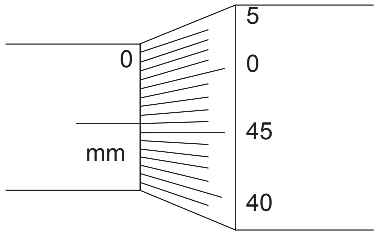
Example 1.8

(a) Positive zero error: '0' mark is below the horizontal line



Zero error = +0.06 mm

(b) Negative zero error: '0' mark is above the horizontal line



Zero error = –0.04 mm

Example 1.9

A micrometer screw gauge is used to measure the thickness of a plastic board. When the jaws are closed without the plastic board in between, the micrometer reading is shown in Fig. (a).

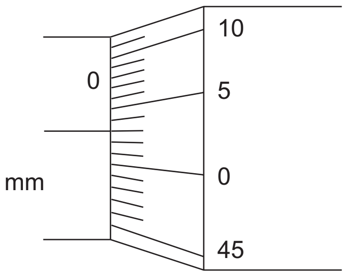


Fig. (a)

With the jaws closed around the plastic board, the micrometer reading is shown in Fig. (b).

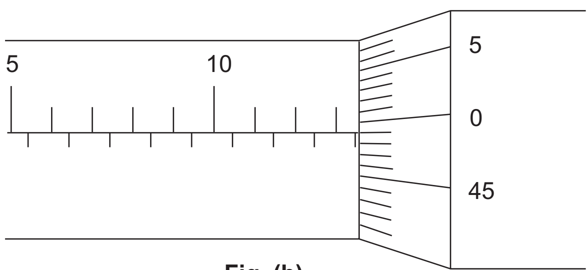


Fig. (b)

What is the thickness of the plastic board?

Solution

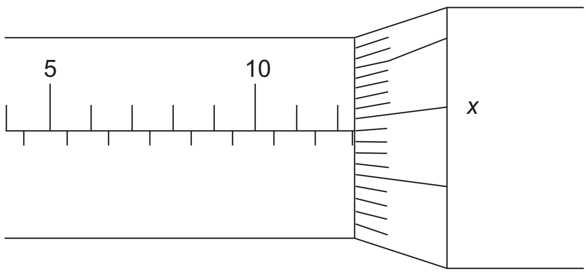
Zero error = +0.03 mm

Reading = 13.5 + 0.49 = 13.99 mm

Actual thickness of plastic board = 13.99 – (+0.03) = 13.96 mm

Example 1.10

The micrometer reading as shown in the figure is 12.84 mm.



What is the value of x on the circular scale?

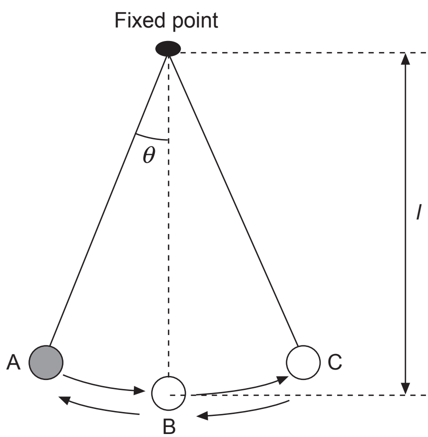
Solution

Reading = 12.5 + reading on the circular scale = 12.84 mm

Reading on the circular scale = 12.84 – 12.5 = 0.34 mm

Since the marking x is 1 mark above 0.34 mm, the value of x is 35.

6. Period of oscillation of a simple pendulum.



(a) (i) One oscillation – One complete to-and-fro movement of the bob from point A to B to C and back to A.

(ii) Period, T – Time taken for one complete oscillation.

(iii) Amplitude – The distance between the rest position of the bob (point B) to the extreme end of the oscillation (either point A or point C).

(b) Steps to find the period of oscillation:

Step 1: Take the total time for 20 oscillations.

Step 2: Repeat **Step 1**.

Step 3: Take the average of the two timings.

Step 4: Divide the average in **Step 3** by 20 to obtain the period.

(c) The period of the pendulum, T, is affected only by its length, l, and the acceleration due to gravity, g.

$$T = 2\pi \sqrt{\frac{T}{g}}$$

T is not affected by the mass of the pendulum bob.

Example 1.11

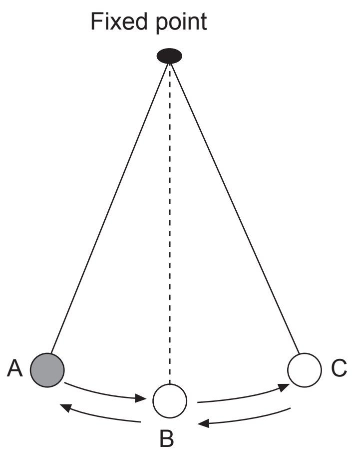
A pendulum swings backwards from B to A and forwards to C passing through B, he middle point of the oscillation. The first time the pendulum passes through B, a stopwatch is started. The thirtieth-time the pendulum passes through B, the stopwatch is stopped and the reading taken is 25.4 seconds. What is the period of the pendulum?

Solution

$$\text{Period} = \frac{\text{Total time taken}}{\text{Number of oscillations}}$$

$$= \frac{25.4}{15}$$

$$= 1.69 \text{ s}$$



TOPIC 2 Kinematics

Objectives

Candidates should be able to:

(a) state what is meant by speed and velocity
(b) calculate average speed using *distance travelled / time taken*
(c) state what is meant by uniform acceleration and calculate the value of an acceleration using *change in velocity / time taken*
(d) interpret given examples of non-uniform acceleration
(e) plot and interpret a displacement-time graph and a velocity-time graph
(f) deduce from the shape of a displacement-time graph when a body is:
   (i) at rest
   (ii) moving with uniform velocity
   (iii) moving with non-uniform velocity
(g) deduce from the shape of a velocity-time graph when a body is:
   (i) at rest
   (ii) moving with uniform velocity
   (iii) moving with uniform acceleration
   (iv) moving with non-uniform acceleration
(h) calculate the area under a velocity-time graph to determine the displacement travelled for motion with uniform velocity or uniform acceleration
(i) state that the acceleration of free fall for a body near to the Earth is constant and is approximately 10 m/s^2
(j) describe the motion of bodies with constant weight falling with or without air resistance, including reference to terminal velocity

NOTES

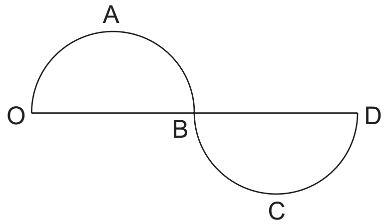
2.1 Distance vs Displacement and Speed vs Velocity

1.

Scalar	Vector
Distance	Displacement
Speed	Velocity

Example 2.1

A car travelled from point O to D along the curved path OABCD.



The distance travelled by the car is OABCD.

The displacement of the car from point O is OD (to the right of O).

2. When measuring/ calculating the displacement of an object, one has to include its starting point.

Example 2.2

Wrong: "The displacement of the bus is 500 m." (*500 m from where?*)

Right: "The displacement of the bus from point A is 500 m in the backward direction." or "The displacement of the bus from point A is –500 m (taking the forward direction as positive)."

3. (a) The formula for calculating speed is

$$\text{Speed} = \frac{\text{Distance travelled}}{\text{Time taken}}$$

(b) $\text{Average speed} = \dfrac{\text{Total distance travelled}}{\text{Total time taken}}$

(c) Velocity is the rate of change of displacement of an object from a fixed point (displacement per unit time).

(d) $\text{Average velocity} = \dfrac{\text{Resultant displacement from a fixed point}}{\text{Total time taken}}$

The average velocity v_{avg} of an object moving through a displacement (Δx) along a straight line in a given time (Δt) is:

$$v_{avg} = \frac{\Delta x}{\Delta t}$$

where $\Delta x = x_{final} - x_{initial}$

$x_{initial}$: Initial displacement from starting point

x_{final} : Final displacement from starting point

2.2 Acceleration

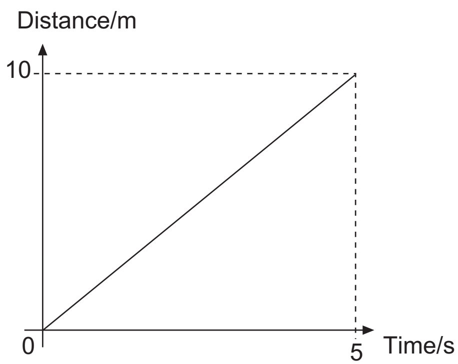
1. Acceleration is the rate of change of velocity.
2. $a = \frac{\Delta x}{\Delta t} = \frac{v - u}{\Delta t} =$ where v is the final velocity, u is the initial velocity and Δt is the time taken.
3. Acceleration is a vector quantity. (You need to give both the magnitude and direction when writing down the answer.)

2.3 Graph of Distance vs Time

1. The distance-time graph of a moving object along a straight road is used to find its speed.
2. The gradient of the graph gives the speed of the object.

Example 2.3

Object moving at uniform speed



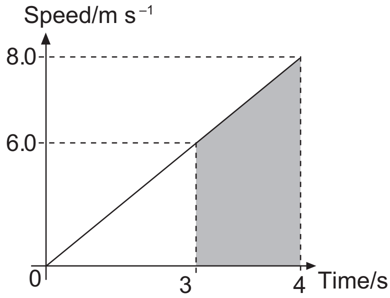
$$\text{Speed} = \frac{10 - 0}{5 - 0} = \frac{10}{5} = 2 \text{ m/s or } 2 \text{ m s}^{-1}$$

2.4 Graph of Speed vs Time

1. The speed-time graph of a moving object along a straight road is used to find:
   (a) Acceleration (Using the gradient of graph)
   (b) Distance travelled (Using the area under the graph)

Example 2.4

Object moving with uniform acceleration:



Acceleration = $\dfrac{8.0 - 0.0}{4 - 0}$ = 2 m/s^2 or 2 m s^{-2}

Distance travelled from t = 0 to t = 4 s

$= \dfrac{1}{2}(4 - 0)(8.0 - 0.0) = 16$ m

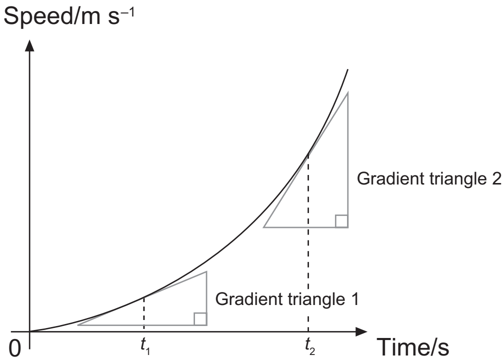
Distance travelled from t = 3 to t = 4 s

$= \dfrac{1}{2}(4 - 3)(8.0 + 6.0) = 7$ m

2. For an object moving with constant acceleration, the speed-time graph is a sloping straight line. A constant acceleration means that speed is increasing at a constant rate.

2.5 Interpret Other Speed-Time Graphs (Non-Uniform Acceleration)

1. Increasing acceleration:



Notice that the gradient of the graph becomes steeper.

The gradient of triangle 2 is larger than the gradient of triangle 1.

(Gradient gets more and more positive).

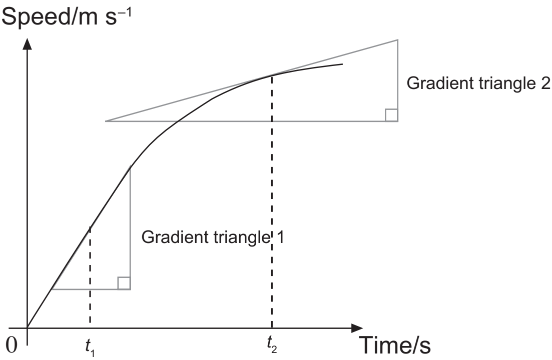
The **speed is increasing** with **increasing acceleration** (increasing rate).

At time = t_1, acceleration = a_1.

At time = t_2, acceleration = a_2.

$a_2 > a_1$

2. Decreasing acceleration:



Notice that the gradient of the graph becomes less steep.
The gradient of triangle 2 is smaller than the gradient of triangle 1.
(Gradient gets less and less positive).
The **speed is increasing** with **decreasing acceleration** (decreasing rate).
At time = t_1, acceleration = a_1.
At time = t_2, acceleration = a_2.
$a_2 < a_1$

2.6 Acceleration Due to Free-Fall

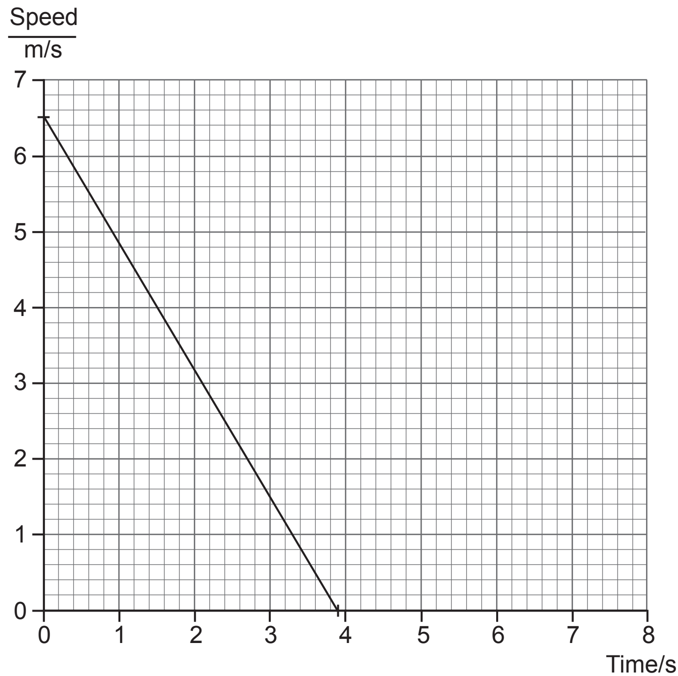
Near the surface of the earth, the acceleration of free fall for an object is constant and is approximately 10 m/s^2. When an object drops from the top of a building, its speed will increase from 0 m/s uniformly at a rate of 10 m/s per second.

2.7 Effect of Air Resistance

1. In real life, a falling object will encounter air resistance on Earth, unless it is moving in a vacuum.
2. Air resistance acts against the motion of the object increasingly to reduce its downward acceleration (NOT SPEED) to zero.
3. When the air resistance increases till it is equal to the weight of a falling object, the acceleration of the object is zero.
4. With zero acceleration, the object will continue falling downward at a constant velocity.
5. The constant velocity of the object is known as “terminal velocity”.

Example 2.5

An astronaut standing on the Moon's surface throws a rock vertically upwards. The figure shows the speed-time graph of the rock where at t = 0 s, the rock just leaves the astronaut's hand. Air resistance on the Moon can be neglected.



(a) (i) What is the time taken for the rock to reach its maximum height?

(ii) What is the total distance travelled by the rock when it returns to its initial position?

(iii) Find the acceleration of the rock.

(b) The rock is then brought back to the Earth's surface and the astronaut repeats the same action as on the Moon. Determine whether the speed-time graph of the rock, when it is thrown on Earth, will be different. Explain your answer.

Solution

(a) (i) From the graph, the time taken for the rock to reach its maximum height is 3.90 seconds.

(ii) Total distance travelled = 2 × area under the graph

$$= \left(\frac{1}{2} \times (6.50 - 0.00) \times (3.90 - 0.00)\right) \times 2$$

$$= 25.4 \text{ m (to 3 s.f.)}$$

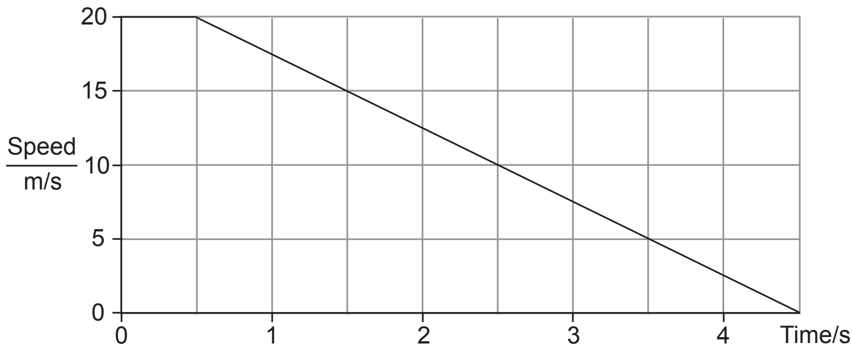
(iii) Acceleration of rock = $\dfrac{6.50 - 0.00}{0.00 - 3.90}$

$$= -1.67 \text{ m s}^2 \text{ or } -1.67 \text{ m s}^{-2} \text{ (to 3 s.f.)}$$

(b) The speed-time graph of the rock on Earth is different because the speed of the rock decreases as it falls from a height. This is due to air resistance. The speed of the rock is decreasing at an increasing rate. The deceleration of the rock increases as the speed decreases. Hence, the gradient of the speed-time graph is steeper initially and becomes gentler after some time. The sketch of the speed-time graph is a curve and not a straight line.

Example 2.6

The graph shows the speed of a car from the time the driver saw an obstacle on the road and applied the brakes till the car came to a stop.



(a) How long did it take the driver to begin applying the brakes after seeing the obstacle?

(b) Calculate the distance travelled

(i) before the brakes were applied,

(ii) while the brakes were being applied.

(c) Calculate the average speed of the car.

Solution

(a) The speed remains at 20 m/s for the first 0.5 seconds, so the driver took 0.5 seconds to begin applying the brakes after seeing the obstacle.

(b) (i) Distance travelled before braking

$= 20 \times 0.5$

$= 10$ m

(ii) Distance travelled while the brakes were being applied

$= \frac{1}{2} \times 20 \times (4.5 - 0.5)$

$= 40$ m

(c) Average speed of car $= \frac{\text{Total distance travelled}}{\text{Total time taken}}$

$= \frac{10 + 40}{4.5}$

$= \frac{50}{4.5}$

$= 11.1$ m/s or 11.1 m s^{-1} (to 3 s.f.)

TOPIC 3 Dynamics

Objectives

Candidates should be able to:

(a) apply Newton's Laws to:

(i) describe the effect of balanced and unbalanced forces on a body

(ii) describe the ways in which a force may change the motion of a body

(iii) identify action-reaction pairs acting on two interacting bodies (stating of Newton's Laws is not required)

(b) identify forces acting on an object and draw free body diagram(s) representing the forces acting on the object (for cases involving forces acting in at most 2 dimensions)

(c) solve problems for a static point mass under the action of 3 forces for 2-dimensional cases (a graphical method would suffice)

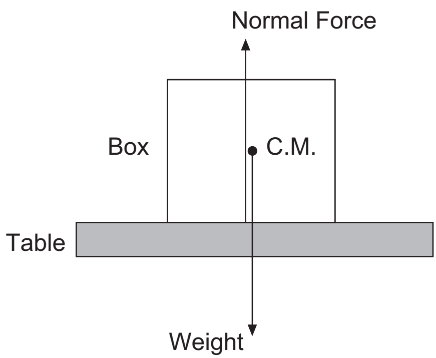
(d) recall and apply the relationship *resultant force* = *mass* × *acceleration* to new situations or to solve related problems

(e) explain the effects of friction on the motion of a body

NOTES..

3.1 Forces

1. A force (SI unit: Newton, symbol: N) is a push or a pull exerted on a body by another body, i.e. an object resting on a table will have a contact force (normal force) acting on it upwards. This force is equal to its weight.



Note:

1. The Normal Force and Weight arrows are of the same length but in opposite directions.
2. Normal Force arrow starts from the base of box (contact between the box and the table top).
3. Weight starts from the centre of mass of the box, C.M. (indicated by the black dot).

2. Effects of a force on a body:
   (a) Increase/ decrease speed of a body (accelerate/ decelerate)
   (b) Change direction of a moving body

3. Newton's First Law:
   A body will remain stationary or in continuous linear motion unless acted upon by a resultant force.

4. Newton's Second Law:
   Resultant vector sum of forces on body is given by:

$$F = ma$$

   where m is the mass of the body and a is the acceleration of the body in the direction of F.

5. Newton's Third Law:
   For every action, there is an equal and opposite reaction.

3.2 Balanced and Unbalanced Forces

1. Balanced forces: If resultant $F = 0$ N, the body is either stationary or moving with constant velocity.

   Example 3.1
   A parachutist falls to the ground at terminal velocity when his weight is equal to the upward force acting on him due to air resistance. Hence, the resultant force acting on him is zero, i.e. his acceleration is zero.

2. Unbalanced forces: If resultant $F \neq 0$ N,
   (a) a stationary body will start moving,
   (b) a moving body will change its velocity.

3.3 Friction

1. Friction is the force which opposes motion when objects slide over each other. For a moving object, the friction on the object acts in the direction opposite to its motion.

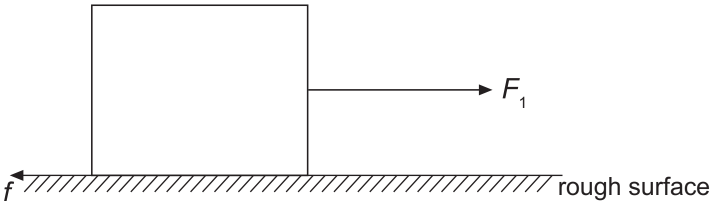
2. Advantages of friction:
   (a) Walking on roads.
   (b) Friction in brake pads and wheels of cars and bicycles.

3. Disadvantages of friction:
   (a) Wears down moving parts of machines.
   (b) For an object moving on a rough surface, more energy is needed to move the object as compared to moving on a smooth surface.
   (c) For an object moving on a rough surface, energy is required for the object to maintain a constant speed. Otherwise, it will slow down and come to a stop.

4. Ways to overcome friction:
   (a) Use lubricant (i.e. graphite or oil) for moving parts of machines.
   (b) Use ball-bearings between moving surfaces.
   (c) Make sure moving parts of machines have very smooth surfaces.

Example 3.2

An object weighing 50 N lies on a rough surface. A constant F_1 force of 12 N acts on the object. The frictional force f acting on the object is 2 N. Find the acceleration of the object. (Take acceleration due to gravity to be 10 m/s^2.)



Solution

Vertically, resultant force = normal force – weight = 0 N

Horizontally, resultant force $R = F_1 - f = 12 - 2 = 10$ N

(Object will only accelerate on horizontal plane)

Mass of object $= \frac{50}{10}$ kg

$= 5$ kg

Using formula:

$F = ma$

$10 = 5a$

$a = 2$ m/s^2

(Object is accelerating at 2 m/s^2 to the right, i.e. in the direction of F.)

Example 3.3

An object moves in a circular path at a constant speed. Is the object accelerating?

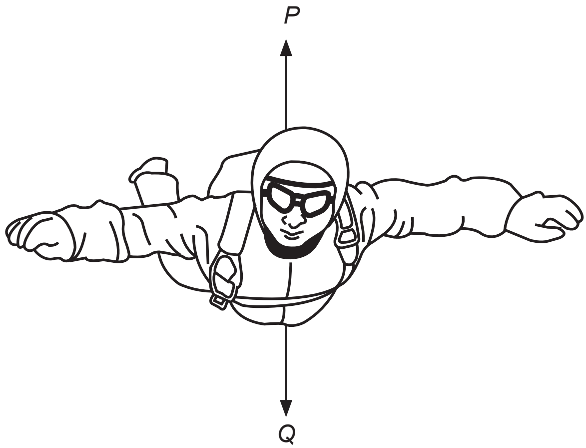
Solution

Yes. Its velocity keeps changing (because direction keeps changing), hence there is a resultant force causing the change. Resultant force acts towards the centre of the circle.

Example 3.4

A skydiver of mass 60 kg falls from rest vertically downwards at a constant velocity.

The figure shows the forces, P and Q, acting on him.



(a) Identify the forces P and Q acting on the skydiver.

(b) Explain why P is acting upwards.

(c) When the skydiver starts to fall from rest, the forces P and Q are unbalanced.

  (i) Find P and Q at $t = 0$ s.

  (ii) Find P and Q when the velocity of the skydiver is uniform.

  (iii) Describe, in terms of the forces acting on the sky diver, why the velocity of the skydiver increases before reaching terminal velocity.

Solution

(a) P is the air resistance on the skydiver and Q is the weight of the skydiver.

(b) Air resistance opposes the motion of the skydiver. Since the skydiver is falling vertically downwards, the air resistance acting on him is in the upward direction to oppose his motion.

(c) Take all forces acting downwards as positive.

(i) $P = 0$ N

$Q = mg = 60 \times 10 = 600$ N

(ii) When the velocity of the skydiver is uniform, he has reached terminal velocity. The resultant force acting on him is 0 N.

$Q - P = 0$

$P = Q = 600$ N

(iii) As a result of unbalanced forces, there will be a non-zero resultant force acting on the skydiver, and it is acting vertically downwards. By Newton's 2nd Law, the skydiver is accelerating downwards. Hence, the velocity of the skydiver increases before it reaches terminal velocity.

TOPIC 4 Mass, Weight and Density

Objectives

Candidates should be able to:

(a) state that mass is a measure of the amount of substance in a body
(b) state that mass of a body resists a change in the state of rest or motion of the body (inertia)
(c) state that a gravitational field is a region in which a mass experiences a force due to gravitational attraction
(d) define gravitational field strength, g, as gravitational force per unit mass
(e) recall and apply the relationship *weight = mass × gravitational field strength* to new situations or to solve related problems
(f) distinguish between mass and weight
(g) recall and apply the relationship *density = mass / volume* to new situations or to solve related problems

NOTES

4.1 Mass

1. Defined as a measure of the amount of substance in a body. (SI unit: kilogram, symbol: kg)
2. The magnitude of mass depends on the size of the body and the number of atoms in the body.
3. Mass is a scalar quantity.

4.2 Inertia

1. Defined as the resistance of the body to change in its state of rest or motion due to its mass.
2. To overcome inertia of a body, a force has to be applied.
   This force is dependent on the body's mass.

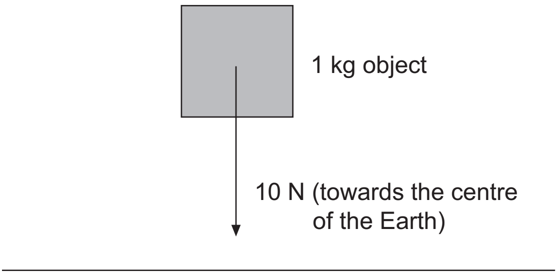
4.3 Gravitational Field Strength

Defined as the gravitational force acting on a body per unit mass.

	Gravitational Field Strength
Earth	$10\ N\ kg^{-1}$
Moon	$1.6\ N\ kg^{-1}$

Note:
These are approximate values for points close to and on the planets' surface.

i.e. on Earth, a force of 10 N is pulling on a 1 kg falling object.



Note:
Since the resultant force on object is 10 N (weight), the acceleration of the object is (by Newton's 2nd Law) $10\ m\ s^{-2}$.

4.4 Weight

1. Defined as the gravitational force *W* acting on an object of mass *m*.
2. When a body falls, its gravitational force (weight) can produce an acceleration, *g* (the acceleration due to gravity).
3. Using Newton's 2nd Law of $F = ma$, we have $W = mg$.
4. Comparison of weight and mass:

		Mass	**Weight**
1.	definition	the amount of substance in a body	the gravitational pull acting on a body
2.	depends on location	no	yes
3.	measured by using	beam balance	spring balance
4.	unit	kilogram	Newton

4.5 Density

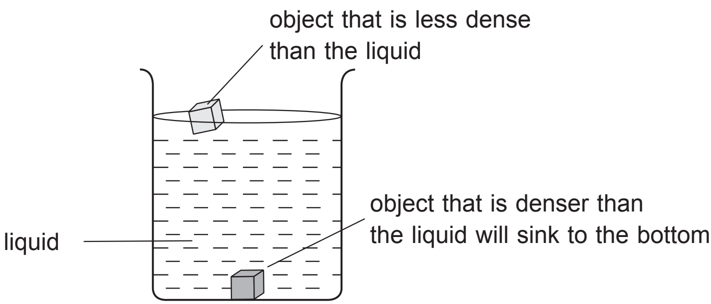
1. The density of a body, ρ, is defined as its mass, m, per unit volume, V.

$$\text{Density} = \frac{\text{Mass}}{\text{Volume}}$$

$$\rho = \frac{m}{V}$$

2. SI Unit: kg m^{-3}

3. For an object to float in a liquid, the object has to be less dense than the liquid. As such, if an object is denser than the liquid, the object will sink in the liquid.



TOPIC 5 Turning Effect of Forces

Objectives

Candidates should be able to:

(a) describe the moment of a force in terms of its turning effect and relate this to everyday examples
(b) recall and apply the relationship *moment of a force (or torque) = force × perpendicular distance from the pivot* to new situations or to solve related problems
(c) state the principle of moments for a body in equilibrium
(d) apply the principle of moments to new situations or to solve related problems
(e) show understanding that the weight of a body may be taken as acting at a single point known as its centre of gravity
(f) describe qualitatively the effect of the position of the centre of gravity on the stability of objects

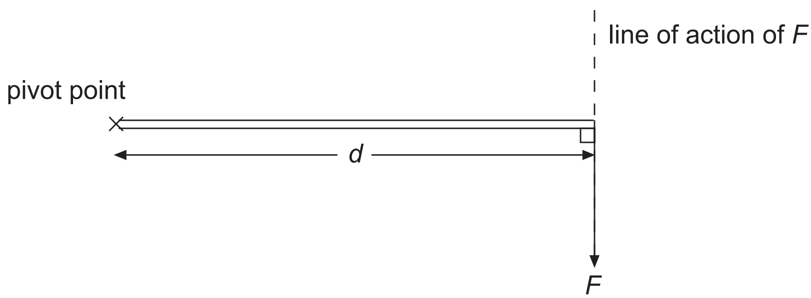
NOTES...

5.1 Moment of a Force

1. Moment – the turning effect of a force about a pivoting point
2. Moment of force = $F \times d$

   F: Force

   d: perpendicular distance of line of action of F from pivot



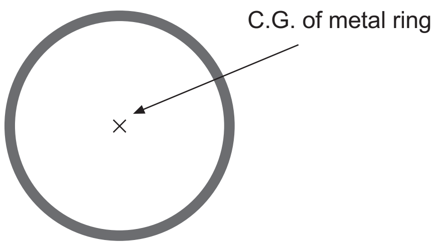
3. SI unit of moment: N m

4. Conditions for object to be in equilibrium:
   (1) The sum of moments about any point is zero. (Principle of Moments)
   (2) The vector sum of forces on object is zero.

5. Principle of Moments:
   For an object in equilibrium, the sum of clockwise moments about any point is equal to the sum of anticlockwise moments about the same point.
   (Resultant moment = 0 N m)

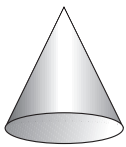
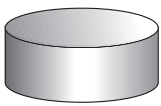
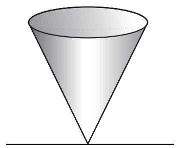
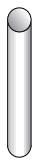
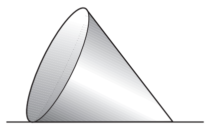
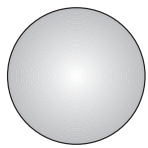
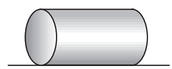
5.2 Centre of Gravity (C.G.)

1. The C.G. of an object is the point where the whole weight appears to act on.
2. The C.G. will not change regardless of how the object is orientated.
3. The C.G. can lie outside an object.
   E.g. C.G. of a metal ring is in the middle of the circle.



5.3 Stability

1. Stability – the ability of an object to retain its original position after being displaced slightly.

	Stable	**Unstable**	**Neutral**
Base Area	Large	Small	1 line of contact or point(s) of contact with surface
Height of C.G.	Low	High	–
Slight displacement from equilibrium position	Return to original position	Topple over	Stay in new position
Example	 Cone resting on its base  Cylindrical shape, resting on its base (large base)	 Cone at its vertex  Cylindrical shape, resting on its base (small base)	 Cone resting on its side  Sphere  Cylinder resting on its side

2. The stability of an object can be improved by:
   (a) Lowering its C.G. (Add weights to the object's lower part).
   (b) Increasing the base area of the object.

TOPIC 6 Pressure

Objectives

Candidates should be able to:
(a) define the term pressure in terms of force and area
(b) recall and apply the relationship *pressure* = *force* / *area* to new situations or to solve related problems
(c) describe and explain the transmission of pressure in hydraulic systems with particular reference to the hydraulic press
(d) recall and apply the relationship pressure due to a *liquid column* = *height of column* × *density of the liquid* × *gravitational field strength* to new situations or to solve related problems
(e) describe how the height of a liquid column may be used to measure the atmospheric pressure
(f) describe the use of a manometer in the measurement of pressure difference

NOTES...

6.1 Pressure

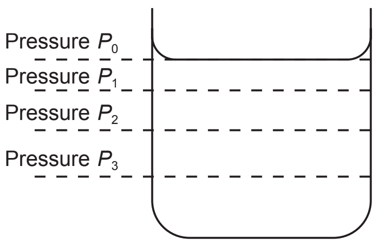
1. Pressure is the force acting per unit area.

$$\text{Pressure} = \frac{\text{Force}}{\text{Area}}$$

2. SI unit: Pascal (Pa) or N m^{-2}

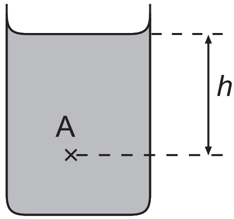
6.2 Liquid Pressure

1. An object immersed in a uniform liquid will experience a pressure which depends only on the height of the liquid above the object.

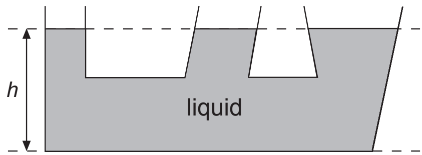


P_0: Atmospheric pressure
Pressure increases with depth: $P_0 < P_1 < P_2 < P_3$

2. Pressure at point A due to the liquid, $P = \rho gh$



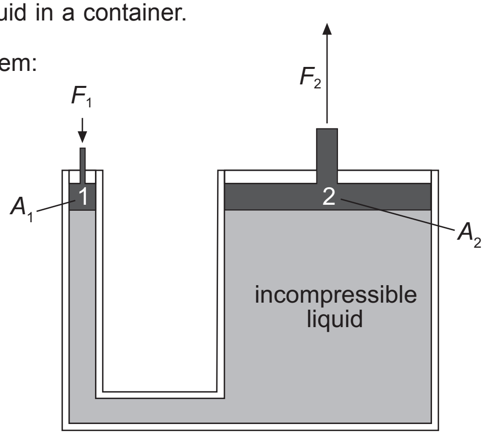
3. When a liquid is at equilibrium, the pressure is the same at any point along the same horizontal surface. Thus the liquid in the container settles at a common height, *h*.



6.3 Transmission of Pressure in Hydraulic System

1. Pressure can be transmitted in all directions if it is exerted on an incompressible fluid in a container.

2. Components of a hydraulic system:
   - Container with two openings
   - A press
   - A piston
   - Incompressible fluid



Hydraulic System

3. In the above figure, if the two pistons at '1' and '2' have the same area, then the force F_1 exerted on one piston will have the same magnitude as F_2 at the other piston.

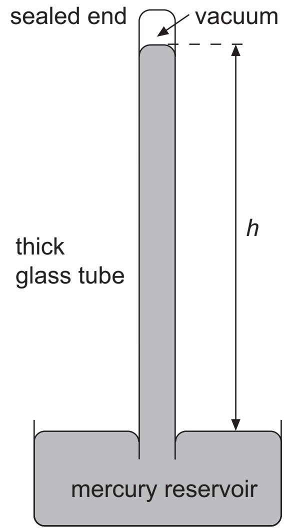
4. If the area A_1 is smaller than area A_2, then the force exerted at '1' will produce a larger force at '2'.

$$\text{Pressure} = P = \frac{F_1}{A_1} = \frac{F_2}{A_2}$$

5. Thus we can use a hydraulic system to lift heavy objects.

6.4 Atmospheric Pressure

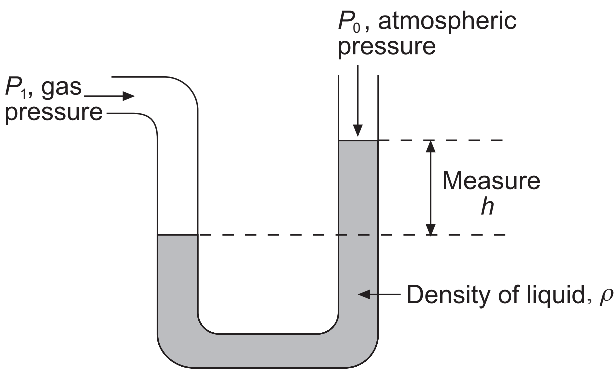
1. Defined as the force per unit area exerted against a surface by the weight of air above that surface.
2. Instrument to measure atmospheric pressure: mercury barometer
3. At sea-level, h = 760 mm.
   Atmospheric pressure recorded as 760 mm Hg.
4. Even if the tube is tilted, h will still remain the same unless it is brought to a different level where the atmospheric pressure is different.



Mercury Barometer

6.5 Manometer

1. The manometer is an instrument that is used to measure gas pressure.
2. Gas pressure, $P_1 = P_0 + \rho gh$ where h – difference in height.



Manometer

TOPIC 7 Energy, Work and Power

Objectives

Candidates should be able to:

(a) show understanding that kinetic energy, potential energy (chemical, gravitational, elastic), light energy, thermal energy, electrical energy and nuclear energy are examples of different forms of energy
(b) state the principle of conservation of energy and apply the principle to new situations or to solve related problems
(c) calculate the efficiency of an energy conversion using the formula efficiency = energy converted to useful output / total energy input
(d) state that kinetic energy $E_k = \frac{1}{2}mv^2$ and gravitational potential energy $E_p = mgh$ (for potential energy changes near the Earth's surface)
(e) apply the relationships for kinetic energy and potential energy to new situations or to solve related problems
(f) recall and apply the relationship *work done = force × distance moved in the direction of the force* to new situations or to solve related problems
(g) recall and apply the relationship *power = work done / time taken* to new situations or to solve related problems

NOTES..

7.1 Energy

1. Different forms: kinetic energy (*KE*), elastic potential energy, gravitational potential energy (*GPE*), chemical potential energy, thermal energy.
2. SI unit: Joule (J)
3. Principle of Conservation of Energy: The total energy in a system remains constant and cannot be created or destroyed. It can only be converted from one form to another without any loss in the total energy.

7.2 Gravitational Potential Energy (*GPE*) and Kinetic Energy (*KE*)

1. Take the surface of the Earth to be the reference level ($GPE = 0$).
   GPE of an object of mass m at height h above surface:

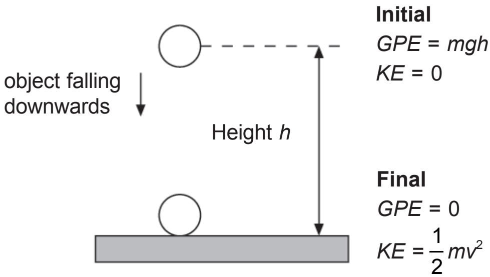
$$GPE = mgh$$

2. *KE* of a moving object of mass m, with a velocity v is

$$KE = \frac{1}{2}mv^2$$

Example 7.1

For a free-falling object of mass m, its gravitational potential energy is converted into kinetic energy. Take ground level as reference level ($GPE = 0$).



Apply the Principle of Conservation of Energy and assuming there is no air resistance:

Total energy at height h = Total energy at ground level

$$mgh = \frac{1}{2}mv^2$$

Velocity of object, $v = \sqrt{2gh}$

Note: The total energy of the object is constant throughout its fall, not just at the two positions used in the above calculation.
($GPE + KE$ = Total energy = Constant)

7.3 Work

1. Energy is required for an object to do work.
2. Defined as the product of applied force (F) and the distance moved (s) in the direction of the force.

$$W = Fs$$ Unit: J

3. No work is done if the applied force F does not displace the object along the direction of the force.

7.4 Power

1. Defined as the rate of work done.

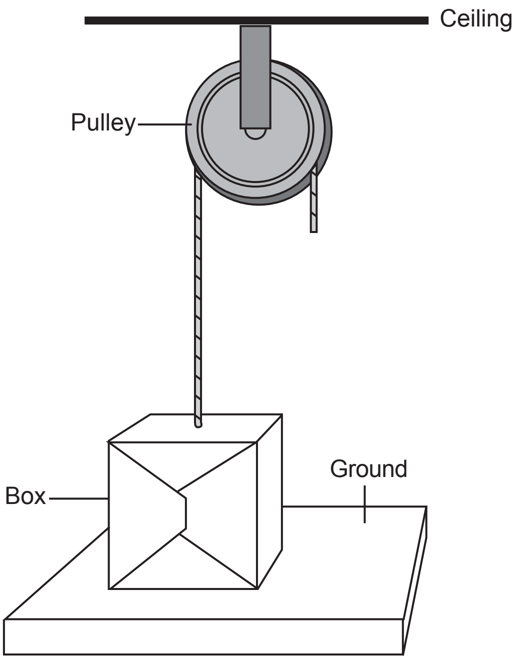
$$\text{Power} = \frac{\text{Work done}}{\text{Time taken}}$$

2. SI unit: Watt (W) or J s^{-1}
3. Efficiency of an energy/ power conversion:

$$\text{Energy} = \frac{\text{Energy converted into useful output}}{\text{Total energy output}} \times 100\%$$
$$= \frac{\text{Useful power output}}{\text{Total power output}} \times 100\%$$

Example 7.2

A box with a mass of 30 kg can be lifted by a light rope threaded through a smooth pulley.



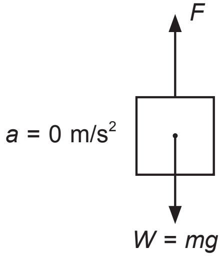
(a) If the box is lifted at a constant speed from the ground to a height of 2.0 m in 4.0 s, what is the power required?

(b) If the box is lifted with a constant acceleration of 1.5 m/s^2 from rest to a height of 3.0 m above the floor, what is the power required?

Take g, the gravitational field strength as 10 N/kg.

Solution

(a) Draw a free body diagram of the box and identify all the forces acting on it.



F – Applied force
W – Weight of the box
R – Resultant force on the box
s – Displacement of the box from the ground

Take forces acting upwards to be positive.

Using Newton's 2nd Law,

$F - mg = 0$

$\therefore F = mg$

$= (30)(10)$

$= 300$ N

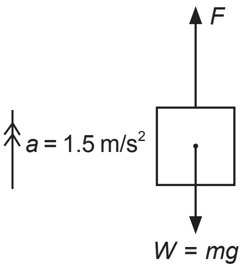
Power required = rate of work done

$$= \frac{Fs}{t}$$

$$= \frac{300 \times 2.0}{4.0}$$

$= 150$ W

(b)



F – Applied force

W – Weight of the box

R – Resultant force on the box

Take forces acting upwards to be positive.
Using Newton's 2nd Law,

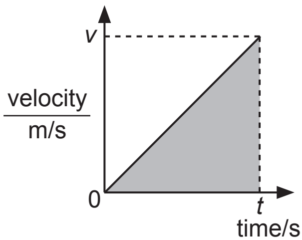
$F - mg = ma$

$F - 300 = 30 \times 1.5$

$F = 45 + 300$

$F = 345$ N

Sketch the speed-time graph of the box to obtain the time taken for the box to move to a height of 3.0 m above the ground.



t – time required for the box to reach a height of 3.0 m.

v – final velocity of the box

From the graph, we can obtain the velocity (gradient of graph) and the total displacement of the box.

Gradient of velocity-time graph,

$$a = \frac{v - u}{t} = \frac{v - 0}{t}$$

$$1.5 = \frac{v}{t}$$

$$v = 1.5t \text{ ------ } (1)$$

Area under the graph (shaded) = Displacement s of box from the ground

$$s = \frac{1}{2} \times \text{Base} \times \text{Height} = \frac{1}{2} \times t \times v$$

$$s = \frac{1}{2} vt$$

$$\frac{1}{2} vt = 3.0 \text{ ------ } (2)$$

Substitute (1) into (2):

$$\frac{1}{2}(1.5t)t = 3.0$$

$$\frac{3}{4} t^2 = 3.0$$

$$t^2 = 4.0$$

$$(t - 2.0)(t + 2.0) = 0$$

$$t = 2.0 \text{ s (since } t > 0)$$

$$\text{Power required} = \frac{345 \times 3.0}{2.0}$$

$$= 518 \text{ W (to 3 s.f.)}$$

TOPIC 8 Kinetic Model of Matter

Objectives

Candidates should be able to:

(a) compare the properties of solids, liquids and gases
(b) describe qualitatively the molecular structure of solids, liquids and gases, relating their properties to the forces and distances between molecules and to the motion of the molecules
(c) infer from Brownian motion experiment the evidence for the movement of molecules
(d) describe the relationship between the motion of molecules and temperature
(e) explain the pressure of a gas in terms of the motion of its molecules
(f) recall and explain the following relationships using the kinetic model (stating of the corresponding gas laws is not required):
  (i) a change in pressure of a fixed mass of gas at constant volume is caused by a change in temperature of the gas
  (ii) a change in volume occupied by a fixed mass of gas at constant pressure is caused by a change in temperature of the gas
  (iii) a change in pressure of a fixed mass of gas at constant temperature is caused by a change in volume of the gas
(g) use the relationships in (f) in related situations and to solve problems (a qualitative treatment would suffice)

NOTES...

8.1 States of Matter

The 3 States of Matter

	Solid	**Liquid**	**Gas**
Volume	Definite	Definite	Indefinite (Takes the shape and size of container)
Shape	Definite	Indefinite (Takes the shape of container)	Indefinite (Takes the shape of container)
Compressibility	Not compressible	Not compressible	Compressible

	Solid	Liquid	Gas
Arrangement of atoms/molecules	1. Closely packed together 2. Orderly arrangement 3. Held together by large forces	1. Closely packed in clusters of atoms or molecules 2. Atoms/ molecules slightly further apart compared to particles 3. Held together by large forces	1. Atoms or molecules are very far apart and occupy any given space 2. Negligible forces of attraction between atoms/ molecules.
Density	High (Usually)	High	Low
Forces between atoms/ molecules	Very strong	Strong	Very Weak
Movement of atoms/ molecules	Can only vibrate about fixed positions	Able to move pass each other and not confined to fixed positions	Move in random manner independent of each other and at high speed.

Common mistakes:

1. Some substances, such as carbon dioxide, are commonly known to be in gaseous state at room temperature. However, this does not mean that the carbon dioxide molecules move in random motion.

   (Check its state (temperature): solid or gas, etc.)

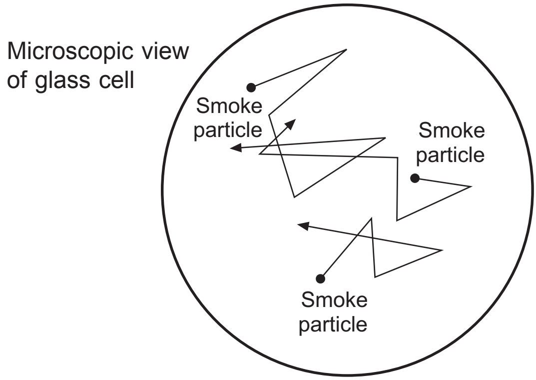
   E.g. Dry ice is a solid which consists of carbon dioxide molecules in an orderly arrangement.

2. ***Not all*** solids have high density, i.e. “ice” is a solid consisting of water molecules arranged orderly in an open hollow structure. Hence, its density is lower than water (liquid) and it can float in water.

8.2 Brownian Motion

The random and irregular motion of gas and liquid molecules.

Experimental observation (using microscope): Smoke particles in a sealed glass cell move about randomly and irregularly, because of bombardment by air molecules in the cell.



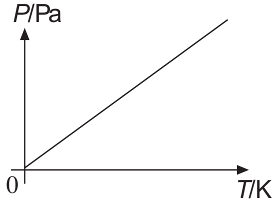
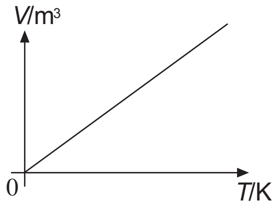
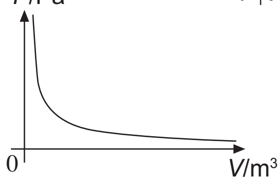
Smoke particles moving randomly

8.3 Pressure of Gas

1. In a sealed container, gas can exert pressure on the walls of the container.
2. The large number of molecules move at high speed, colliding against the container's walls and exerting a force against the wall when they bounce off the walls.
3. The force per unit area exerted by the molecules on the wall is the pressure of the gas on the wall.
4. Gas pressure increases when the
   (a) number of molecules in the container increases,
   (b) speed of molecules increases,
   (c) molecules have larger mass.

8.4 Relationship between Pressure (P), Volume (V) and Temperature (T)

1. For a constant mass of gas:

	P	***V***	***T***	***Relationship***
1.	Increase	Constant	Increase	P is directly proportional to T.  $\frac{P_1}{T_1} = \frac{P_2}{T_2}$
2.	Constant	Increase	Increase	V is directly proportional to T.  $\frac{V_1}{T_1} = \frac{V_2}{T_2}$
3.	Increase	Decrease	Constant	P *is* inversely proportional to V. $P_1V_1 = P_2V_2$ 

Example 8.1

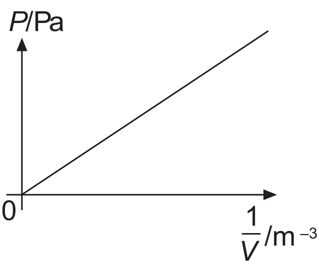
To get a linear graph that shows P is inversely proportional to V, rearrange the equation:

$P_1V_1 = P_2V_2$ = constant, k

$$P_1 = \frac{k}{V_1}$$

Sketch the graph of P against $\frac{1}{V}$:

y-axis (P), x-axis $\left(\frac{1}{V}\right)$, gradient = k



TOPIC 9 Transfer of Thermal Energy

Objectives

Candidates should be able to:

(a) show understanding that thermal energy is transferred from a region of higher temperature to a region of lower temperature
(b) describe, in molecular terms, how energy transfer occurs in solids
(c) describe, in terms of density changes, convection in fluids
(d) explain that energy transfer of a body by radiation does not require a material medium and the rate of energy transfer is affected by:
  (i) colour and texture of the surface
  (ii) surface temperature
  (iii) surface area
(e) apply the concept of thermal energy transfer to everyday applications

NOTES

9.1 Types of Heat Transfer

1. 3 types of heat transfer: Conduction, Convection, Radiation
2. Transfer of thermal energy is ***always*** from a high temperature region to a low temperature region (Temperature gradient).

	Conduction	Convection	Radiation
Medium	Solids Liquids Gases	Liquids (fluid) Gases (fluid)	Vacuum*
Process	1. Vibration of atoms/ molecules 2. Movement of free electrons (if any, i.e. metals) For solids, their atoms/molecules are in fixed positions	Movement of atoms/ molecules in the form of convection by currents set up by density change in parts of the fluid being heated.	Infrared waves (no medium required)

* Radiation does not require matter to transfer heat, but radiation can travel through matter (through several thousands of metres in air or a few metres in common solids).

9.2 Conduction

1. A direct contact between media is necessary.
2. Metals are the best solid conductors because of their free electrons.
3. Liquids and gases are poor conductors because their molecules are not closely packed together in fixed positions like solids.
4. Application: Use metals to make cooking utensils.

9.3 Convection

1. Molecules/ atoms must be free to move.
2. Set-up of a convection current: The fluid closer to the heat source expands, and its density decreases and the surrounding denser fluid displaces it.
3. Application: Air conditioners are placed near the ceiling because cold air, being denser, will sink to displace the warm air in the room.

9.4 Radiation

1. Factors affecting radiation:
   (a) Colour
   (b) Roughness
   (c) Area exposed to radiation
2. Good radiator/ good absorber of radiation: black, dull surface, with a huge amount of surface area exposed.
3. Poor radiator/ poor absorber of radiation: bright, shiny and polished surface.
4. Application: Greenhouses for growing plants.

9.5 Vacuum Flask

1. Reduces heat transfer in or out through conduction, convection and radiation.
2. Can store and maintain temperature (either hot or cold) of the contents in the flask.

Type of heat transfer	How heat transfer is reduced
Convection	Vacuum between the double glass walls.
Conduction	Vacuum between the double glass walls. Insulated cover and stopper.
Radiation	Shiny silvered inner surface of the glass walls.

TOPIC 10 Temperature

Objectives

Candidates should be able to:

(a) explain how a physical property which varies with temperature, such as volume of liquid column, resistance of metal wire and electromotive force (e.m.f.) produced by junctions formed with wires of two different metals, may be used to define temperature scales

(b) describe the process of calibration of a liquid-in-glass thermometer, including the need for fixed points such as the ice point and steam point

NOTES...

10.1 Temperature

1. A measure of the degree of 'hotness' or 'coldness' of a body.
2. SI Unit: Kelvin (K)
3. Commonly-used unit is degree Celsius (°C): θ (K) = θ (°C) + 273.15

10.2 Measurement of Temperature

1. Material for temperature measurement: Substance/ material which possesses temperature-dependent property and thus can change continuously with temperature variations.

2. Temperature-dependent (Thermometric) Properties:

Thermometric Property	Thermometer	Range
Volume of a fixed mass of liquid (**e.g.** mercury or alcohol)	Mercury Alcohol Clinical thermometer	–10 ºC to 110 ºC –60 ºC to 60 ºC 35 ºC to 42 ºC
Electromotive force (e.m.f.) (between hot and cold junctions of two different metals joined together)	Thermocouple	–200 ºC to 60 ºC Common ones
Resistance of metal **e.g.** Platinum	Resistance thermometer	–200 ºC to 1200 º C
Pressure of a fixed mass of gas at constant volume	Constant-volume gas thermometer	Estimated –258 ºC to 1027 ºC

10.3 Temperature Scale

1. Temperature is measured with reference to 2 fixed points:
   (a) Lower Fixed Point or Ice point (0 °C):
   Temperature of pure melting ice at standard atmospheric pressure.
   (b) Upper Fixed Point or Steam point (100 °C):
   Temperature of pure boiling water at standard atmospheric pressure.

2. The length between the 2 fixed points is divided into 100 equal intervals of 1 °C.

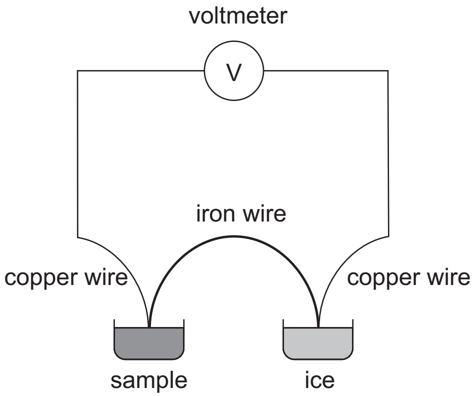
3. Apply the following general formula to calculate temperature of a material:

$$\theta °C = \frac{X_\theta - X_0}{X_{100} - X_0} \times 100 °C$$

where:
θ is temperature of material
X_θ is thermometric property at θ
X_{100} is thermometric property at steam point
X_0 is thermometric property at ice point
i.e. for clinical thermometer, X is the length of the mercury thread at temperature θ; for thermocouples, it is the voltmeter reading at temperature θ.

10.4 The Thermocouple

1. To measure the temperature of an unknown substance:
   (a) One junction is kept at a constant temperature (i.e. ice point).
   (b) The other junction is kept at the point where the temperature is to be measured.



2. Advantages:
   (a) Can withstand high temperature with suitable metals.
   (b) Large temperature range. Can measure very low or very high temperatures.
   (c) Junctions used are sharp and pointed and therefore can be used to measure temperature accurately at a point.
   (d) Rapid response to temperature change.

TOPIC 11 Thermal Properties of Matter

Objectives

Candidates should be able to:

(a) describe a rise in temperature of a body in terms of an increase in its internal energy (random thermal energy)
(b) define the terms heat capacity and specific heat capacity
(c) recall and apply the relationship *thermal energy* = *mass* × *specific heat capacity* × *change in temperature* to new situations or to solve related problems
(d) describe melting/ solidification and boiling/ condensation as processes of energy transfer without a change in temperature
(e) explain the difference between boiling and evaporation
(f) define the terms latent heat and specific latent heat
(g) recall and apply the relationship *thermal energy* = *mass* × *specific latent heat* to new situations or to solve related problems
(h) explain latent heat in terms of molecular behaviour
(i) sketch and interpret a cooling curve

NOTES..

11.1 Introduction

1. Temperature – a measure of the internal energy of the substance's atoms/ molecules.
2. Increase in temperature – caused by the supply of heat which increases internal energy.
3. Internal energy – sum of kinetic energy and potential energy of the atoms/ molecules.

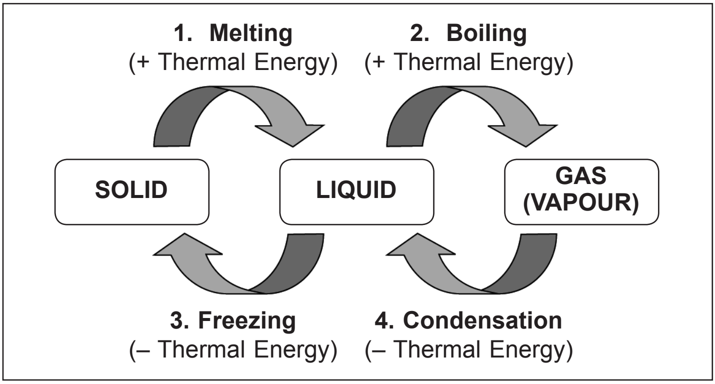
4. Types of internal energy:

State of substance	Type of internal energy
Solid	vibrational kinetic energy + potential energy
Liquid	translational kinetic energy + potential energy
Gas	mainly translational kinetic energy

11.2 Change of States

1. Two main changes occur when heat is supplied to a substance
   (a) Increase in temperature
   (b) Change of state (i.e. solid to liquid)

2. The following chart shows the changes of state (without temperature change) and their corresponding processes involved:



+ Thermal Energy: Heat is absorbed by substance
– Thermal Energy: Heat is removed from substance (Released to surroundings)

1. Melting	(i) Definition: a change of state from solid to liquid without a change in temperature. (ii) Melting point: constant temperature at which a solid melts into a liquid. (iii) Process: Heat absorbed is used to do work to break intermolecular bonds between the atoms/ molecules of the solid. (iv) The reverse process is freezing.
2. Boiling	(i) Definition: a change of state from liquid to gas without a change in temperature. (ii) Boiling point: constant temperature at which a liquid boils. (iii) Process: Heat supplied to the liquid is used to do work in separating the atoms or molecules as well as in pushing back the surrounding atmosphere. (iv) The reverse process is condensation.
3. Freezing	(i) Reverse process of melting. (ii) Definition: a change of state from liquid to solid without a change in temperature. (iii) Freezing point: constant temperature at which a liquid changes to a solid. (iv) Process: Heat is released as the intermolecular bonds are formed when the liquid atoms or molecules come together to form a solid. (v) For a pure substance, the melting point is the same as the freezing point.
4. Condensation	(i) Reverse process of boiling/ evaporation. (ii) Definition: a change of state from gas to liquid without a change in temperature. (iii) Condensation point: constant temperature at which a gas changes to a liquid. (iv) Process: Heat is released as the intermolecular bonds are formed when the gaseous atoms or molecules come together to form a liquid. (v) For a pure substance, the boiling point is the same as the condensation point.

3. Other processes:
   (a) Evaporation (liquid to gas)
   (b) Sublimation (solid to gas)

4. Differences between boiling and evaporation:

Boiling	Evaporation
occurs at a fixed temperature	occurs at any temperature
occurs throughout the liquid	occurs on the surface of substance
bubbles are visible	bubbles are not visible
fast process	slow process
heat is supplied to substance by an energy source	heat is absorbed by substance from the surroundings

5. Factors affecting melting and boiling points of water:

Factor	Melting Point	Boiling Point
Increase Pressure	Lower	Higher
Add Impurities	Lower	Higher

11.3 Heat Capacities and Latent Heat

1. The following terms are used in calculations in this chapter:

Term	SI Units	Definition	Formula
Heat capacity, C	J $^{o}C^{-1}$ or J K^{-1}	Thermal energy needed to increase temperature of substance by 1 ºC or 1 K.	$Q = C\Delta\theta$
Specific heat capacity, c	J $kg^{-1}\,^{o}C^{-1}$ or J $kg^{-1}\,K^{-1}$	Thermal energy needed to increase temperature of 1 kg of substance by 1 ^{o}C or 1 K.	$Q = mc\Delta\theta$

Term	SI Units	Definition	Formula
Specific latent heat of fusion, l_f	J kg^{-1}	Thermal energy needed to change 1 kg of substance from solid to liquid without temperature change.	$Q = ml_f$
Specific latent heat of vaporisation, l_v	J kg^{-1}	Thermal energy needed to change 1 kg of substance from liquid to gas without temperature change.	$Q = ml_v$

Q – Amount of thermal energy needed (J), $\Delta\theta$ – Change in temperature

2. Comparison between substances of high and low heat capacities

Heat Capacity	Time to cool down/ heat up	Reason
High	Longer	Need to lose more energy (cooling) or absorb more energy (heating).
Low	Shorter	Need to lose less energy (cooling) or absorb less energy (heating).

TOPIC 12 General Wave Properties

Objectives

Candidates should be able to:

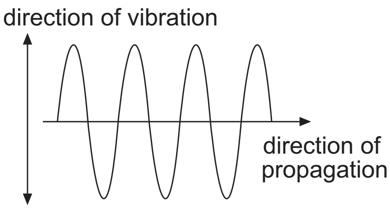
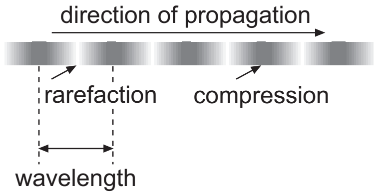
(a) describe what is meant by wave motion as illustrated by vibrations in ropes and springs and by waves in a ripple tank
(b) show understanding that waves transfer energy without transferring matter
(c) define speed, frequency, wavelength, period and amplitude
(d) state what is meant by the term wavefront
(e) recall and apply the relationship *velocity* = *frequency* × *wavelength* to new situations or to solve related problems
(f) compare transverse and longitudinal waves and give suitable examples of each

NOTES

12.1 Introduction

1. Wave motion is the propagation of oscillatory movement or disturbance from one region to another.
2. A wave transfers energy from one place to another without transferring matter.
3. All waves follow the laws of reflection and refraction.
4. Mechanical waves require a medium (i.e. water or air molecules) for propagation.
5. Electromagnetic waves (See Topic 14) are propagations of oscillations in electromagnetic fields. The propagation does not require a medium, thus electromagnetic waves can travel in vacuum.

6. We classify waves in this topic into two types based on their propagation method:
   (a) Transverse
   (b) Longitudinal

Transverse waves	Longitudinal waves
	
Movement of particles in the medium: Perpendicular to the direction of propagation (movement) of wave	**Movement of particles in the medium:** Parallel to the direction of propagation (movement) of wave
Examples Water waves, electromagnetic waves **Characteristics** 1. The particles oscillate perpendicularly (up and down) to the direction of travel. 2. Peak: Highest point reached by the particle from its neutral position 3. Trough: Lowest point reached by the particle from its neutral position 4. The distance between adjacent particles remains constant, in the direction of the propagation of the wave.	**Examples** Sound wave **Characteristics** 1. The particles oscillate along (to-and-fro) the direction of travel. 2. Compression: Section in which the particles are closest together 3. Rarefaction: Section in which the particles are furthest apart. 4. The distance between adjacent particles varies from a maximum value (furthest apart) to a minimum value (closest together), in the direction of the propagation of the wave.

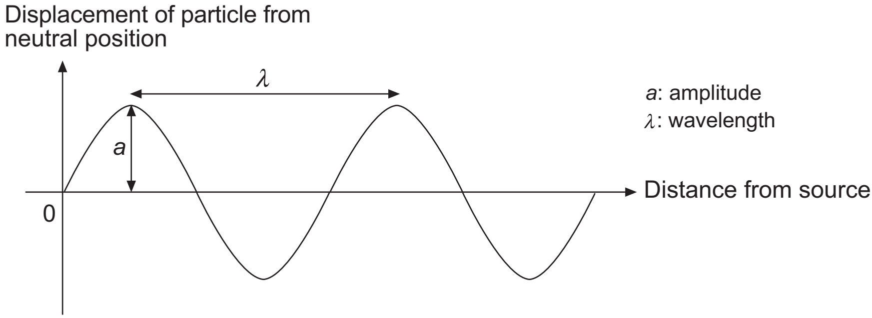
12.2 Terms used to describe a wave

1. For both transverse and longitudinal waves, the particles oscillate about their undisturbed positions (neutral positions). The neutral positions lie along an axis in the direction of wave propagation.

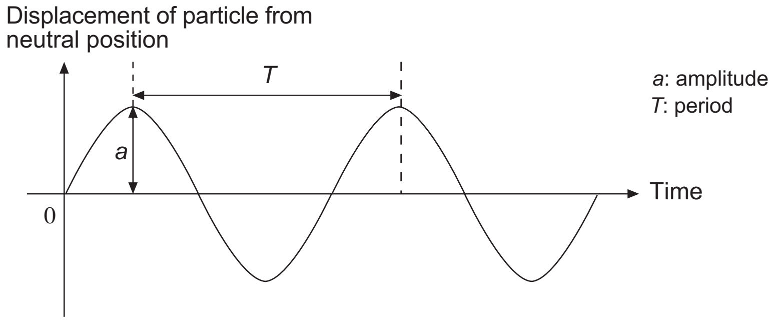
2. The following graphs show sine-curves used to describe the wave terms used for both types of waves.

Note: These are graphs and not transverse waves!

Displacement-distance Graph



Displacement-time Graph



3. Common wave terms:

Term	Transverse waves	Longitudinal waves
Amplitude, *a* (m)	The maximum displacement of the particle from its neutral position **perpendicular** to the direction of propagation. (i.e. height of crest from neutral position.)	The maximum displacement of the particle from its neutral position **along** the direction of propagation.
Wavelength, λ (m)	The distance between two successive crests or two successive troughs.	The distance between two successive compressions or two successive rarefractions.
Frequency, *f* (Hz)	The number of complete waves produced in one second.	
Period, *T* (s)	The time taken to produce one complete wave. **Formula:** $T = \frac{1}{f}$	
Speed, *v* (m)	The distance moved by any part of the wave in one second. **Formula:** $v = f\lambda$	

12.3 Wavefront

1. A wavefront is a line or surface, in the path of a wave motion, on which all particles are oscillating in phase.
2. There are two types of wavefronts:
   (a) Circular wavefront (close to point source of disturbance)
   (b) Plane wavefront (straight wavefronts far from point source of disturbance)
3. The amplitude of particles along the same wavefront is the same.

TOPIC 13 Light

Objectives

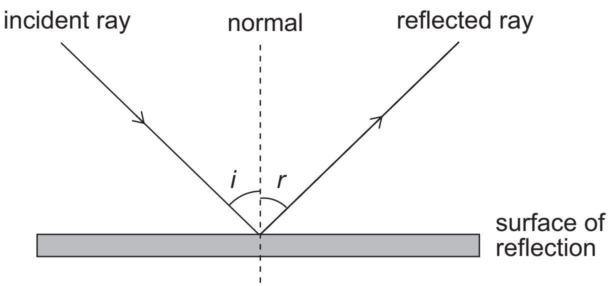
Candidates should be able to:

(a) recall and use the terms for reflection, including *normal*, *angle of incidence* and *angle of reflection*
(b) state that, for reflection, the angle of incidence is equal to the angle of reflection and use this principle in constructions, measurements and calculations
(c) recall and use the terms for refraction, including *normal*, *angle of incidence* and *angle of refraction*
(d) recall and apply the relationship $\frac{\sin i}{\sin r} = constant$ to new situations or to solve related problems
(e) define *refractive index* of a medium in terms of the ratio of speed of light in vacuum and in the medium
(f) explain the terms *critical angle* and *total internal reflection*
(g) identify the main ideas in total internal reflection and apply them to the use of optical fibres in telecommunication and state the advantages of their use
(h) describe the action of a thin lens (both converging and diverging) on a beam of light
(i) define the term *focal length* for a converging lens
(j) draw ray diagrams to illustrate the formation of real and virtual images of an object by a thin converging lens

NOTES

13.1 Reflection

1. The diagram below shows a ray of light being reflected from a plane surface.



2. The following terms are commonly used in the reflection of light:

Term	Definition
Normal	Imaginary line perpendicular to the surface of reflection
Angle of incidence, *i*	Angle between the incident ray and the normal
Angle of reflection, *r*	Angle between the reflected ray and the normal

3. Laws of reflection:
   (a) Angle *i* = Angle *r*
   (b) The incident ray, reflected ray and the normal at the point of incidence all lie on the same plane.

4. Characteristics of an image formed in a plane mirror:
   (a) Upright
   (b) Virtual (Cannot be captured on a screen)
   (c) Laterally inverted
   (d) Same size as the object
   (e) Image distance from the other side of the surface of reflection is the same as the object's distance from the surface of reflection.

13.2 Refraction

1. The diagrams below show a ray of light refracted as it passes from air into glass and from glass into air. Note how the light ray bends in each case.

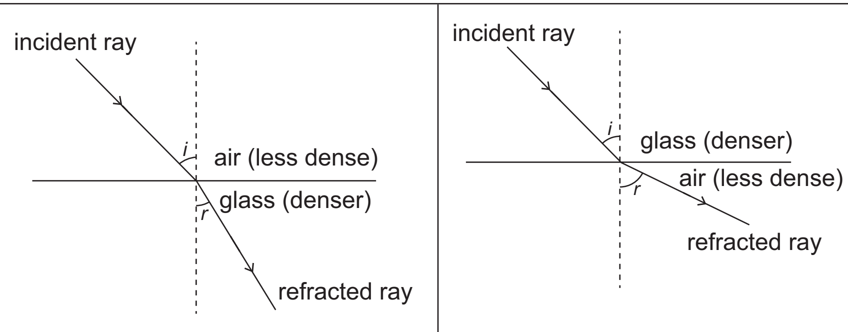


Fig. (a) Fig. (b)

2. The following terms are commonly used in refraction:

Term	Definition
Normal	Imaginary line perpendicular to the surface of reflection
Angle of incidence, *i*	Angle between incident ray & normal
Angle of refraction, *r*	Angle between refracted ray & normal
Refractive index of a medium, *n*	Ratio of the speed of light in vacuum to the speed of light in medium
Critical angle	Angle of incidence in a denser medium for which the angle of refraction in the less dense medium is 90^{o}
Total internal reflection	Complete reflection of an incident ray of light within a denser medium surrounded by a less dense medium when the incident angle is greater than the critical angle

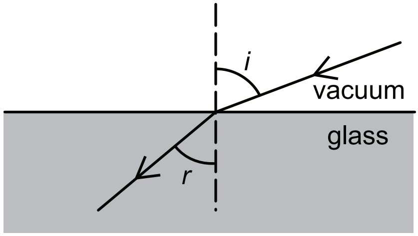
3. Refractive index of vacuum is taken as 1.
   Air has a refractive index of 1.0003 which is very close to 1, but is not equal to 1.

4. Laws of refraction:

(a) The incident ray, refracted ray and the normal at the point of incidence all lie on the same plane.

(b) Snell's Law: $\dfrac{\sin i}{\sin r}$ = constant, for two given media.

***E.g.* 1**: For the light ray passing from a **less dense** medium to a **denser** medium (such as vacuum to glass),

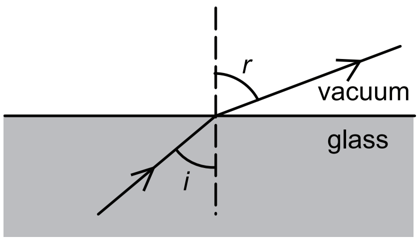


$$\frac{\sin i}{\sin r} = \frac{n_{\text{denser medium}}}{n_{\text{vacuum}}} = \frac{n}{1}$$

$$\frac{\sin i}{\sin r} = n$$

where n is the refractive index of the denser medium.

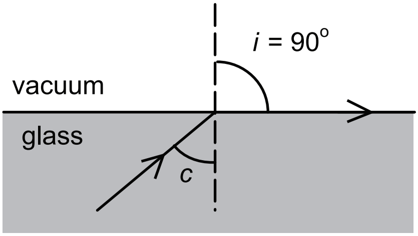
***E.g.* 2**: For the light ray passing from a **denser** medium (such as glass to vacuum) to a **less dense** medium,



$$\frac{\sin i}{\sin r} = \frac{n_{\text{vacuum}}}{n_{\text{denser medium}}} = \frac{1}{n}$$

where n is the refractive index of the denser medium.

***E.g.* 3**: For light ray passing from a denser medium into a less dense medium at a critical angle, $i = c$,



$$\frac{\sin i}{\sin r} = \frac{n_{vacuum}}{n_{glass}}$$

$$\frac{n_{vacuum}}{n_{glass}} = \frac{\sin c}{\sin 90°} \text{ where } i = c \text{ and } r = 90°$$

$$n_{glass} = \frac{1}{\sin c}$$

$$\Rightarrow n = \frac{1}{\sin c}$$

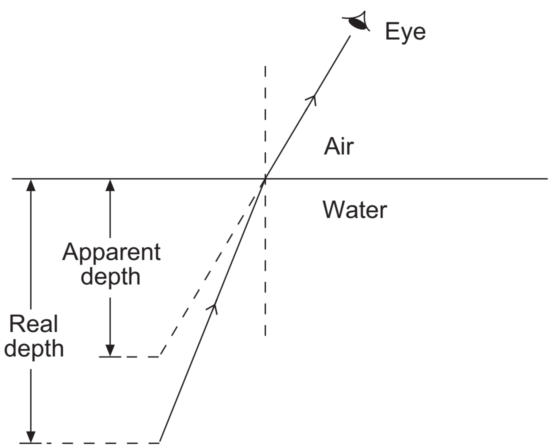
where n is the refractive index of the denser medium.

When other incident angles $i > c$, the incident ray will undergo total internal reflection.

Note that $n_{vacuum} = 1$ and $n_{air} = 1.0003$.

5. Refractive index, n, of a medium (i.e. water) can also be calculated as follows:

$$\frac{\text{real depth}}{\text{apparent depth}} = n$$



6. The speed of light is slower in a denser medium as compared to that in a less dense medium.

Example 13.1

A ray of light travels from within a piece of glass into air. The incident angle is 10^{o} and the refractive index of glass is 1.61. Calculate the angle of refraction.

Solution

Refractive index of glass, n_{glass} = 1.61

Refractive index of air, n_{air} = 1.0003

$$\frac{\sin i}{\sin r} = \frac{n_{air}}{n_{glass}} \quad (\textit{Common mistake}: \frac{\sin i}{\sin r} = n_{glass})$$

$$\frac{\sin 10°}{\sin r} = \frac{1.0003}{1.61}$$

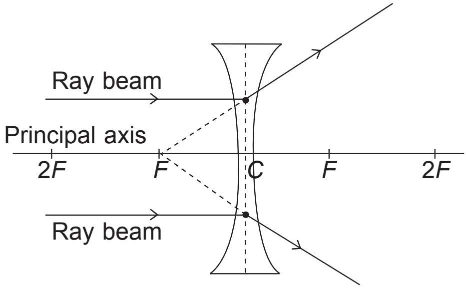
$$\sin r = \frac{1.61 \sin 10°}{1.0003}$$

Angle r = 16.2º (to 1 d.p.)

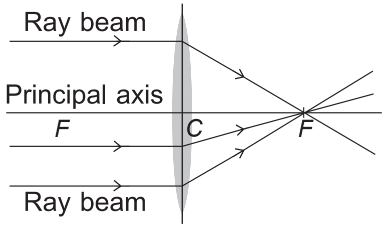
7. An application of total internal reflection: optical fibres to transmit data.
   Principle: The polished surfaces of the fibres are made of a material of suitable refractive index for total internal reflection of light.
   Advantages:
   1. Optical fibres have high electrical resistance, so it can be used near high-voltage equipment safely.
   2. Since optical fibres have lower density than copper, the mass is lower for the same volume of wires. Hence optical fibres are suitable for mobile vehicle applications such as aircrafts where mass and space are concerns.
   3. Optical fibres are resistant to chemical corrosion
   4. Optical fibres do not emit electric fields or magnetic fields since they carry light instead of electrical currents, hence they will not interfere with nearby electronic equipment or themselves be subject to electromagnetic interference.
   5. Since optical fibres are secured, it is difficult to intercept signals without disrupting them, unlike conventional current carrying copper cables.

13.3 Lenses

1. Actions of a thin lens: As shown in the following diagrams, a converging lens converges a beam of light whereas a diverging lens diverges a beam of light.



Diverging lens

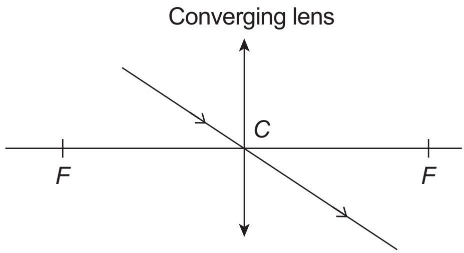
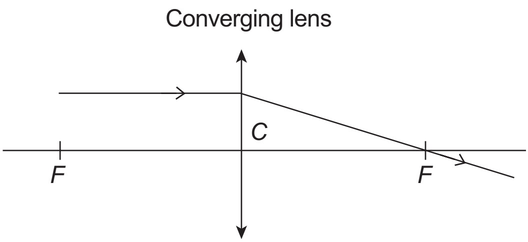
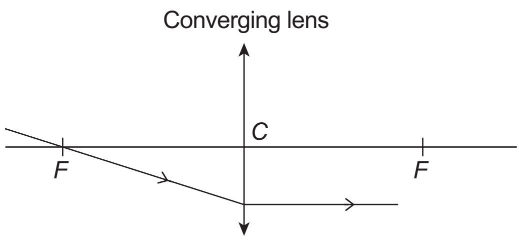


Converging lens

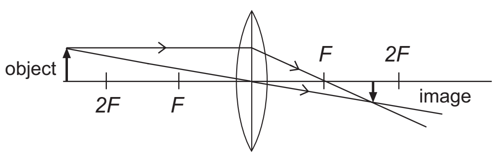
2. The following table summarises the main features of a lens:

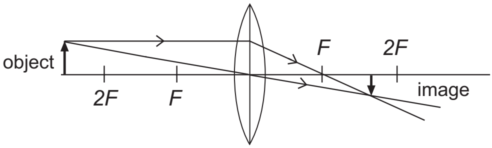
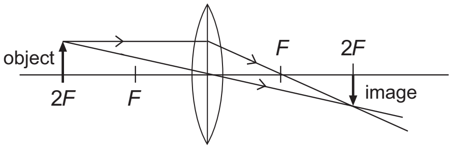
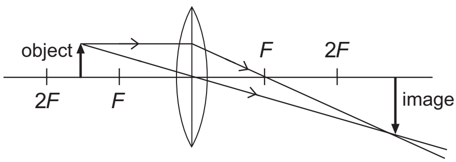
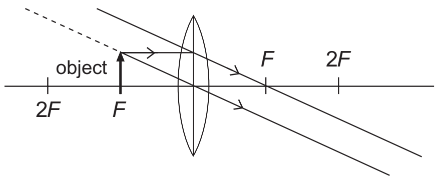
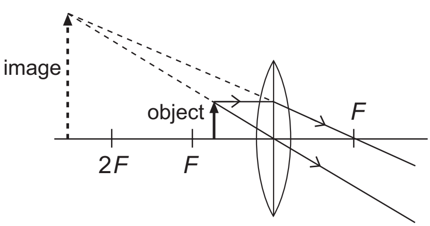
Term	Definition
Focal length, *f*	Distance between the optical centre, *C* and the principal focus *F*.
Optical centre, *C*	Midpoint between the lens' surface on the principal axis. Rays passing through optical centre are not deviated.
Principal axis	Line passing symmetrically through the optical centre of the lens.
Principal focus or Focal point, *F*	Point of convergence for all light rays refracted by the lens.
Focal plane	Plane which passes through *F* and perpendicular to the principal axis.

3. Ray diagrams are drawn to locate the position and the size of an image.

Action of incident ray	Diagram
Ray passing through *C* passes straight through without a change in direction.	
Ray parallel to principal axis passes through lens and changes direction and passes through *F*.	
Ray passing through *F* initially reaches lens and passes out parallel to principal axis.	

4. Types of images formed by a **thin** converging lens

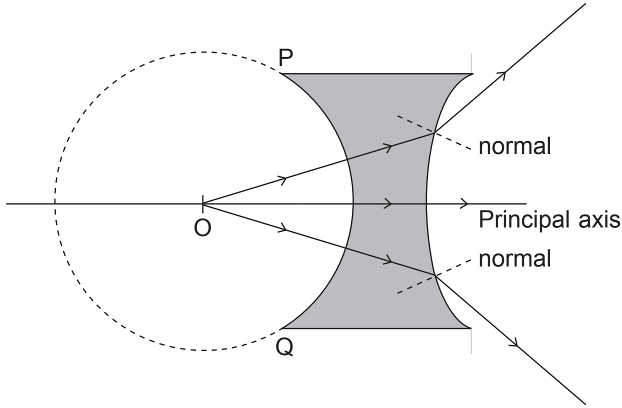
Object distance	Ray diagram	Image characteristics	Application
At infinity		• Real • At *F*	Telescope lens

Object distance	Ray diagram	Image characteristics	Application
Greater than 2*F*		• Inverted • Real • Diminished • Between *F* and 2*F*	Camera lens
At 2*F*		• Inverted • Real • Same size as object • At 2F	Photocopier
Between *F* and 2*F*		• Inverted • Real • Magnified	Projector
At *F*		• Image formed at infinity. (Light rays travel parallel to each other.)	
Less than *F*		• Upright • Enlarged • Virtual (On the same side of the lens as the object.)	Magnifying glass

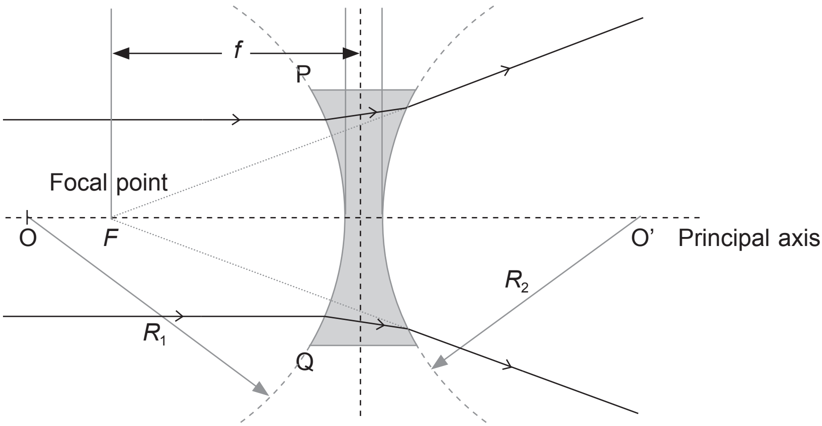
Note: Ray diagrams must ALWAYS have arrows to indicate direction of the ray.

5. Special cases

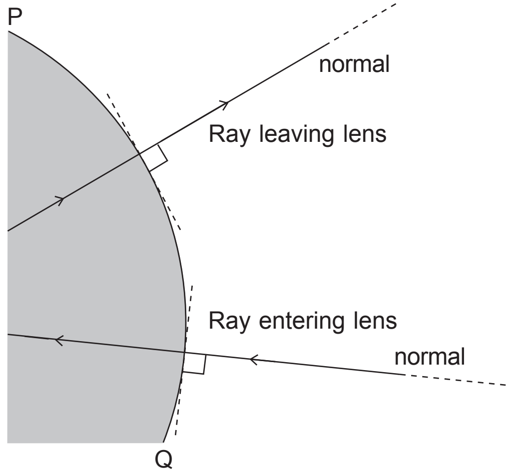
- Diverging lens: Light source from O, centre of curvature of the lens.
  The figure shows part of a diverging lens where one of the faces of the lens PQ is part of a circle with centre O.



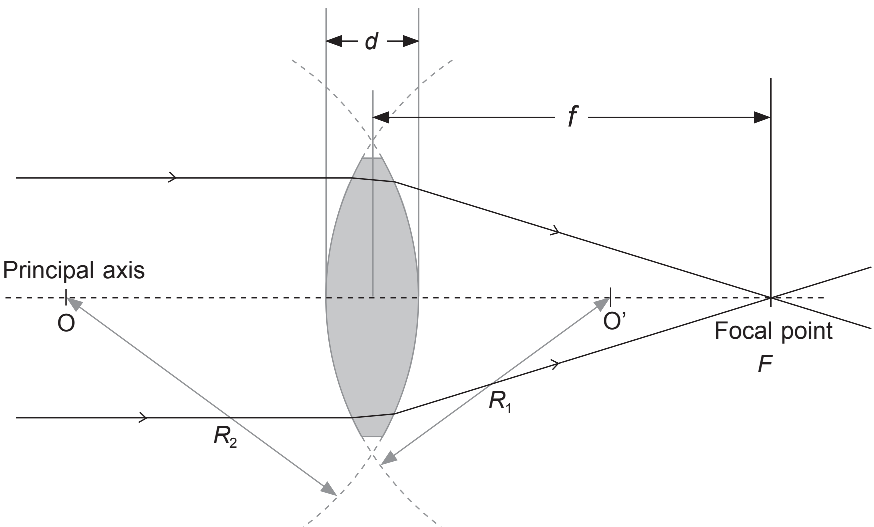
Any light rays drawn from O to PQ will be normal (90°) to the surface PQ because they are moving along the normal line.
Hence any light ray originated from O and entering into the lens PQ will be moving into the lens without changing direction.
A complete diverging lens is shown in the figure below, where O and O' are the centre of the circles (dotted), *F* is the focal point and *f* is the focal length. R_1 and R_2 are the radii of the circles with centres O and O' respectively.



- Converging lens: Light rays entering or leaving the lens will travel along the path of the normal to the lens surface which is a part of a circle. The figure shows part of a converging lens where PQ is part of a circle.



The rays will not change direction because they are moving along the path of the normal line. The path forms an angle of 90° to the surface of the lens.
A complete converging lens is shown in the figure below, where O and O' are the centre of the circles (dotted), F is the focal point and f is the focal length. R_1 and R_2 are the radii of the circles with centres O and O' respectively.



TOPIC 14 Electromagnetic Spectrum

Objectives

Candidates should be able to:

(a) state that all electromagnetic waves are transverse waves that travel with the same speed in vacuum and state the magnitude of this speed
(b) describe the main components of the electromagnetic spectrum
(c) state examples of the use of the following components:
   (i) radiowaves (e.g. radio and television communication)
   (ii) microwaves (e.g. microwave oven and satellite television)
   (iii) infra-red (e.g. infra-red remote controllers and intruder alarms)
   (iv) light (e.g. optical fibres for medical uses and telecommunications)
   (v) ultra-violet (e.g. sunbeds and sterilisation)
   (vi) X-rays (e.g. radiological and engineering applications)
   (vii) gamma rays (e.g. medical treatment)
(d) describe the effects of absorbing electromagnetic waves, e.g. heating, ionisation and damage to living cells and tissue

NOTES...

14.1 Components of the Electromagnetic Spectrum

1. All electromagnetic waves (EM waves) are transverse waves that travel at the speed of light (3×10^8 m/s) in vacuum and slow down in other media.

2. EM waves do not require a medium for propagation.

3. EM waves can be absorbed or emitted by matter.

4. The main components of the electromagnetic spectrum are as follows:

EM Wave	Order of Magnitude of Wavelength, λ/m	Application
γ-ray (Gamma ray)	10^{-3}	Manufacturing: Checking of cracks/ holes in metal plates. Medical: Radiotherapy.

EM Wave	Order of Magnitude of Wavelength, λ/m	Application
X-ray	10^{-10}	Medical: Inspection of bones for signs of fractures.
Ultraviolet (UV)	10^{-8}	Medical: Production of vitamin D in the body.
Visible light spectrum: *Violet* *Indigo* *Blue* *Green* *Yellow* *Orange* *Red* (In increasing order of λ ↓)	10^{-7}	
Infrared radiation (IR)	10^{-4}	Remote control for television sets.
Microwave	10^{-2}	Microwave oven for cooking.
Radio Wave	10^{-2} to 10^{3}	Telecommunication.

14.2 Harmful Effects of Absorbing EM Waves

1. EM waves transmit radiation energy from one region to another.
2. Radiation may damage living cells and tissues through heating and ionisation.
   (a) Heating: Organic molecules in tissue gain kinetic energy from incident radiation. The energy increase is detected by a temperature rise. When the temperature gets too high, the molecules break apart and the tissue gets cooked.
   (b) Ionisation: Organic molecules absorb energy to break molecular bonds to form ions which can react with neighbouring molecules. This results in destruction or changes to the tissue.
3. Mobile phones emit radiation in the form of electromagnetic waves which can heat up the brain.
4. Too much sun-tanning can lead to an overdose of ultraviolet radiation which can cause skin cancer (i.e. melanoma).

TOPIC 15 Sound

Objectives

Candidates should be able to:

(a) describe the production of sound by vibrating sources
(b) describe the longitudinal nature of sound waves in terms of the processes of compression and rarefaction
(c) explain that a medium is required in order to transmit sound waves and the speed of sound differs in air, liquids and solids
(d) describe a direct method for the determination of the speed of sound in air and make the necessary calculation
(e) relate loudness of a sound wave to its amplitude and pitch to its frequency
(f) describe how the reflection of sound may produce an echo, and how this may be used for measuring distances
(g) define ultrasound and describe one use of ultrasound, e.g. quality control and pre-natal scanning

NOTES

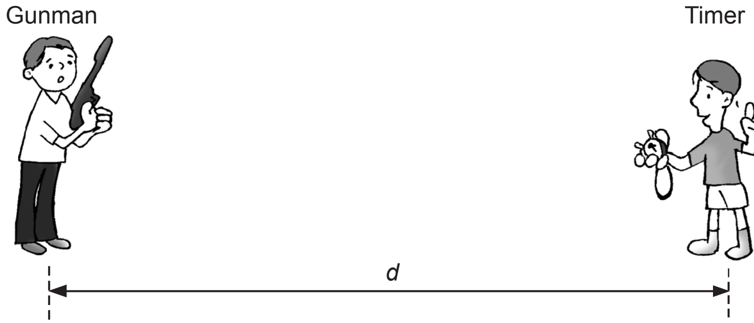
15.1 Production of Sound Waves

1. Sound waves are produced when objects vibrate in a medium.
2. Sound waves are longitudinal waves which require a medium for propagation.

15.2 Medium of Propagation for Sound

1. When sound waves travel in different media, the speed differs.
   Speed of sound in solids > speed of sound in liquids > speed of sound in air.
2. In solids, the atoms are more closely packed together, as compared to liquids and gases. Hence, sound travels the fastest in solids.

15.3 Determining the Speed of Sound



1. To determine the speed of sound, a gunman and a timer can stand apart from each other in an open field at a known distance *d*.

2. The gunman will fire a pistol into the air. The timer will start his stopwatch upon seeing the flash of the pistol and stop the stopwatch when he hears the sound of the pistol. The time interval is recorded as Δt.

3. The speed of sound is calculated as:

$$v = \frac{d}{\Delta t}$$

4. The speed of sound in air is about 330 m/s. Since the human reaction time is about $\frac{2}{3}$ of a second, *d* has to be sufficiently large for the experiment to be accurate.

Example 15.1

In a storm, an observer saw a lightning flash, followed by the sound of thunder 4.0 seconds later. Given that the speed of sound in air is approximately 330 m/s, find the observer's distance from where the lightning occurred.

Solution

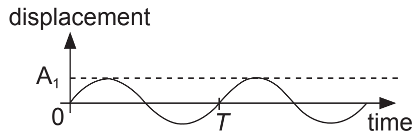
The lightning flash, which the observer sees, is assumed to reach him immediately after the lightning occurs (speed of light = 3.0×10^8 m/s).
Let the distance of the observer from the lightning be *d*.

$$\Delta t = 4.0 \text{ s}$$
$$330 = \frac{d}{\Delta t} = \frac{d}{4}$$
$$d = 1320 \text{ m}$$

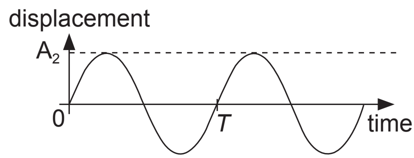
15.4 Characteristics of Sound

1. The following table shows the main characteristics of sound and the factors affecting these characteristics:

<table>
<tr><th>Characteristics</th><th>Factors</th></tr>
<tr><td>Loudness</td><td>Amplitude of a sound wave
(a higher amplitude leads to a louder sound)



soft

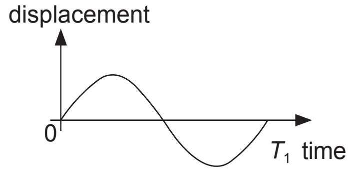


loud

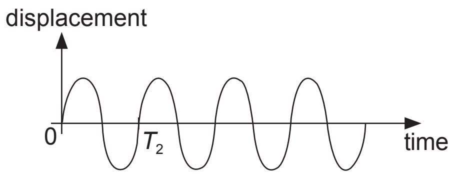
Note: amplitude $A_1 < A_2$</td></tr>
<tr><td>Pitch</td><td>Wavelength of a sound wave
(a shorter wavelength leads to a higher pitch)

Frequency of a sound wave
(a higher frequency leads to a higher pitch)

From the equation, $v = f\lambda$, since v is constant, we observe that when the wavelength, λ, decreases, the frequency, f, increases. As such, a shorter wavelength leads to a higher frequency which leads to a higher pitch.



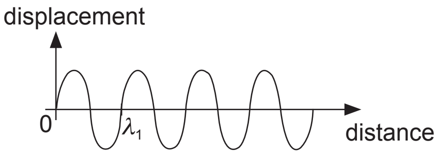
low pitch



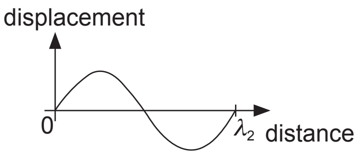
high pitch</td></tr>
</table>

<table>
<tr><th>Characteristics</th><th>Factors</th></tr>
<tr><td></td><td>Note: $T_1 > T_2$

From the equation, $T = \frac{1}{f}$, we observe that when the period, T, increases, the frequency, f, decreases. As such, a longer period leads to a lower frequency which leads to a lower pitch.



high pitch



low pitch

Note: $\lambda_1 < \lambda_2$</td></tr>
</table>

15.5 Echoes

1. Echoes are produced when a sound wave is reflected from a surface.
2. The reflected sound (echo) can be heard separately from the original sound if the source of the sound is much closer to the observer than to the reflecting surface.
3. To reduce the effect of echoes in buildings, walls are roughened up with padding and the floors are covered with rugs or carpets. This is to scatter the incident sound wave so that the reflected sound is reduced.
4. Using echo to measure distance.

Example 15.2

A man stood in front of a tall cliff. He fired a pistol into the air and started his stopwatch simultaneously. After 3.0 s, he heard the echo of the pistol shot. Given that the speed of sound is 330 m/s, find his distance from the cliff.

Solution

Let distance of man from cliff be d.

$2d = 330 \times 3.0$

$d = 495$ m

(We used $2d$ because 3.0 s is the time taken for the sound to hit the cliff and be reflected back to the man.)

15.6 Ultrasound

1. Ultrasound is the sound with frequencies that are greater than 20 000 Hz.
2. The audible range of sound for humans is between 20 Hz and 20 000 Hz. Hence humans cannot hear ultrasound.
3. Some applications of ultrasound:
   (a) Pre-natal scan to check the development of babies in womb.
   (b) Used by ships to find depth of seabed.
   (c) Check for cracks in metal pipes that are too small for the naked eye to see.

TOPIC 16 Static Electricity

Objectives

Candidates should be able to:

(a) state that there are positive and negative charges and that charge is measured in coulombs
(b) state that unlike charges attract and like charges repel
(c) describe an electric field as a region in which an electric charge experiences a force
(d) draw the electric field of an isolated point charge and recall that the direction of the field lines gives the direction of the force acting on a positive test charge
(e) draw the electric field pattern between two isolated point charges
(f) show understanding that electrostatic charging by rubbing involves a transfer of electrons
(g) describe experiments to show electrostatic charging by induction
(h) describe examples where electrostatic charging may be a potential hazard
(i) describe the use of electrostatic charging in a photocopier, and apply the use of electrostatic charging to new situations

NOTES...

16.1 Atomic Structure

1. Matter is made up of small units called atoms.
2. An atom consists of a positively-charged nucleus surrounded by negatively charged electrons orbiting around the nucleus. The overall charge of an atom is zero.
3. The positively-charged nucleus consists of positively-charged protons held together by neutral particles called neutrons.
4. When excess electrons are added to an atom, the atom becomes negatively charged.
5. When electrons are removed from an atom, the atom becomes positively charged.

16.2 Electric Charges

1. Electric charges are either positive or negative.
2. Like charges repel each other; unlike charges attract each other.
3. Rubbing (charging by friction) causes electrons to be transferred from one object to another. Charge transfer between two objects only involves electron transfer. There is NO MOVEMENT of positive charges (which are the nuclei of the atoms). Otherwise, the solid will deform.
4. Insulators can be charged by rubbing, unlike conductors (metals), because **electrons** are not free to move about in an insulator and thus charges are localised to the surfaces where rubbing occurs.
5. Examples of insulators and the types of charges they gain from rubbing:

Type of insulator rod	Type of cloth used for rubbing	Charges gained by cloth	Charges gained by rod
Cellulose acetate	wool	$-Q$	$+Q$
Glass	silk	$-Q$	$+Q$
Ebonite	fur	$+Q$	$-Q$
Polythene	wool	$+Q$	$-Q$

6. The excess charge, Q, carried away by one body must be equal to the number of electrons removed from the other body. The charges are in multiples of an electron charge, e (-1.6×10^{-19} C) according to the equation:

$$Q = Ne$$ where N is a whole number.

7. The unit of charge is the coulomb (Symbol: C).
8. Electric charge Q is related to current I and time t by the equation:

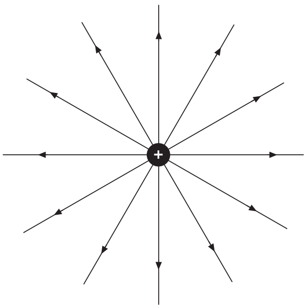
$$Q = It$$

16.3 Concept of Electric Field

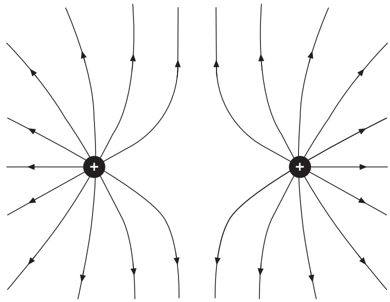
1. An electric field is a region in space in which a unit positive charge experiences a force.
2. Electric field is a vector quantity. The direction of the field is determined by the direction of the force acting on the unit positive charge.
3. An electric field is set up by a charge. When a unit positive charge is brought near a negative charge, the positive charge will experience a force of attraction towards the negative charge and vice versa.

Example 16.1: Examples of field patterns set up by point charges

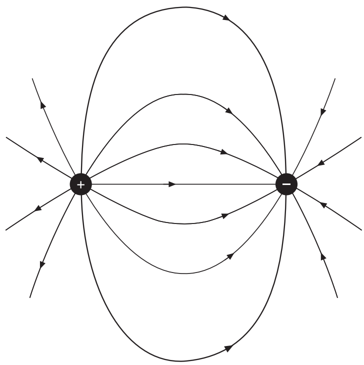
(a) Isolated positive charge



(b) Two equal magnitude, positive charges close to each other



(c) Two charges with equal magnitude but opposite signs



16.4 Hazards of Electrostatic Charging

1. Lightning: A large charge build-up in the clouds due to the friction between water and air molecules results in the ionisation of the air. The ionised air provides a path for conduction of electrons to the ground through tall, pointed objects.
   Remedy: Lightning conductors can be placed at the top of tall buildings to allow electrons to flow steadily from the air to the ground.

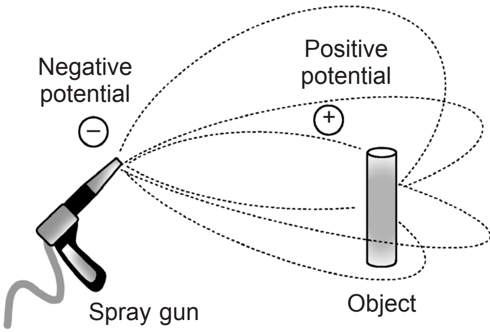
2. Fire: An excessive build up of charges due to friction with air can lead to an explosion or a fire in aircrafts.
   Remedy: Tyres are made of slightly conductive rubber to discharge the aircraft when it touches down.

16.5 Some Applications of Electrostatics

1. Spray painting:

   Steps:

   (1) A fixed electric potential difference is maintained between the paint spray nozzle and the object to be painted. (i.e. the nozzle is negatively-charged and the object is positively charged)

   (2) As the paint leaves the nozzle, the droplets are charged.

   (3) Since the droplets all have the same charge, they repel each other so that the paint spreads out evenly.

   (4) The paint droplets are all attracted to the positively-charged object and stick strongly to its surface.

2. Photocopier:

   Steps:

   (1) Positive charges are arranged in a pattern to be copied on the surface of an insulator drum.

   (2) Negatively-charged toner powder is sprinkled on the drum.

   (3) Only the portions of the drum with positive charges allow the toner powder to stick to it to form the image.

   (4) The resultant pattern is then transferred onto the paper and fixed permanently by heat.

TOPIC 17 Current of Electricity

Objectives

Candidates should be able to:

(a) state that current is a rate of flow of charge and that it is measured in amperes
(b) distinguish between conventional current and electron flow
(c) recall and apply the relationship charge = *current* × *time* to new situations or to solve related problems
(d) define electromotive force (e.m.f.) as the work done by a source in driving unit charge around a complete circuit
(e) calculate the total e.m.f. where several sources are arranged in series
(f) state that the e.m.f. of a source and the potential difference (p.d.) across a circuit component is measured in volts
(g) define the p.d. across a component in a circuit as the work done to drive unit charge through the component
(h) state the definition that resistance = *p.d. / current*
(i) apply the relationship $R = V/I$ to new situations or to solve related problems
(j) describe an experiment to determine the resistance of a metallic conductor using a voltmeter and an ammeter, and make the necessary calculations
(k) recall and apply the formulae for the effective resistance of a number of resistors in series and in parallel to new situations or to solve related problems
(l) recall and apply the relationship of the proportionality between resistance and the length and cross-sectional area of a wire to new situations or to solve related problems
(m) state Ohm's Law
(n) describe the effect of temperature increase on the resistance of a metallic conductor
(o) sketch and interpret the I/V characteristic graphs for a metallic conductor at constant temperature, for a filament lamp and for a semiconductor diode

NOTES

17.1 Conventional Current and Electron Flow

1. Definition of current: the rate of flow of electric charges.

2. Equation: $$I = \frac{Q}{t}$$

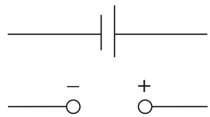
   I is the current (unit: A)
   Q is the charge (unit: C, or equivalent unit: A s)
   t is the time (unit: s)

3. Definition of ampere: 1 ampere is the current carried by 1 coulomb of charge flowing in a circuit in 1 second.

4. The flow of conventional current in a circuit arises from the flow of electrons (negative charges) in the opposite direction.

5. Direct Current (d.c.): A direct current only flows in one direction.

6. Alternating Current (a.c.): An alternating current periodically reverses its direction back and forth.

 d.c. source	 a.c. source

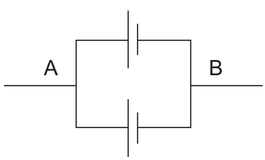
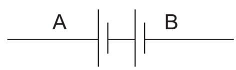
17.2 Electromotive Force (e.m.f.)

1. Definition of electromotive force: The electromotive force of a d.c. source is the work done by the source to drive a unit charge round a closed circuit.

2. Equation: $W = QV$

   W is the work done by source (unit: J)
   Q is the charge (unit: C)
   V is the e.m.f. (unit: V)

3. The following table shows some of the different types of arrangement of 1.5 V cells and the resultant e.m.f.:

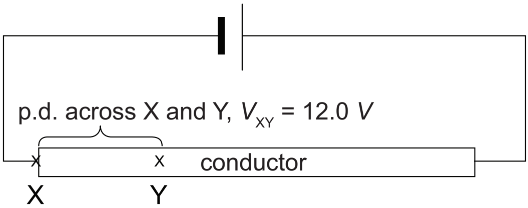
Two cells in parallel Overall e.m.f. across AB = 1.5 V	**Two cells in series** Overall e.m.f. across AB = 3.0 V
	

17.3 Potential Difference (p.d.)

1. Definition of potential difference: The potential difference across a circuit component is the work done to drive a unit charge through the circuit component.

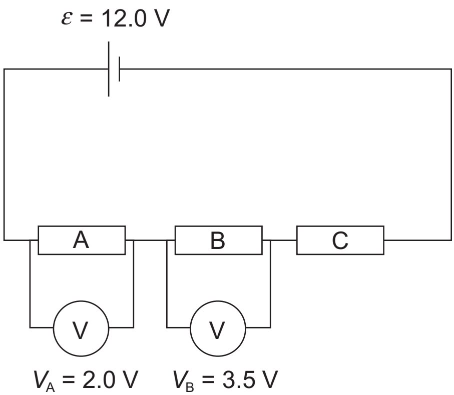
Example 17.1

For a conductor (resistor wire) connected in a closed circuit, the potential difference across two points, X and Y, in part of the conductor is the work done to drive a unit charge across the two points through that part of the conductor.



Example 17.2

The following circuit shows three resistors, A, B and C, connected in series. The potential difference across A and B are given as V_A = 2.0 V and V_B = 3.5 V. Given that the e.m.f. of the battery is 12.0 V, find the potential difference across resistor C.

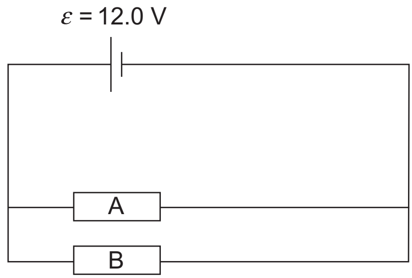


Solution

V_C = 12.0 – 2.0 – 3.5 = 6.5 V

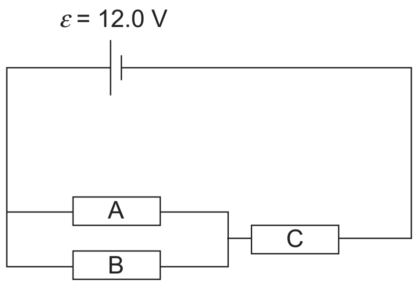
2. In a circuit with two resistors A and B, the potential difference across resistor A is the same as the potential difference across resistor B if the two resistors are arranged in parallel.

$V_A = V_B = 12.0$ V



Example 17.3

Given that $V_C = 5.0$ V, find the potential difference across A and B.



Solution

Since resistors A and B are arranged in parallel, $V_A = V_B = 12.0 - 5.0 = 7.0$ V.

17.4 Resistance

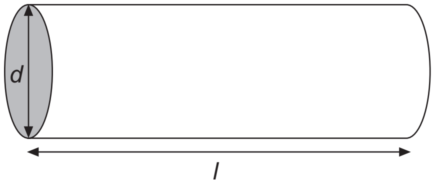
1. Definition of resistance: The ratio of potential difference (V) across the conductor to the current (I) flowing through it.

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

R is resistance of conductor (unit: Ω, equivalent unit: $1\ \Omega = 1\ \text{V A}^{-1}$)
V is potential difference across the conductor (unit: V)
I is current through the conductor (unit: A)

2. The resistance of a piece of cylindrical wire R is related to its length l, cross sectional area A and its resistivity, ρ (each type of material has its own resistivity):

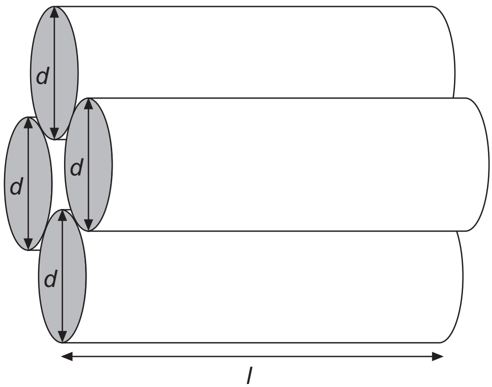
$$R = \frac{\rho l}{A}$$



d – diameter of wire
l – length of wire
Cross-sectional area of wire,

$$A = \pi\left(\frac{d}{2}\right)^2$$

3. Parallel resistors
4 identical resistors are connected in parallel as shown in the diagram.



Effective cross-sectional area = 4 × A = 4A

Effective length of bundle of 4 resistors = l

Effective resistance, R_{eff}

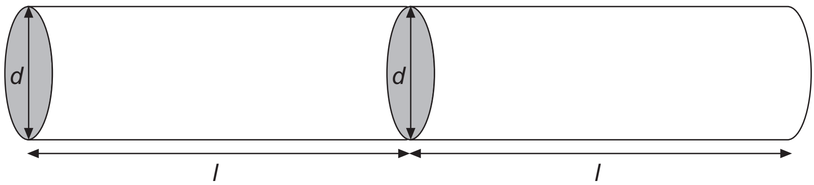
$$= \frac{\rho l}{4A} = \frac{1}{4}R$$

Formula:

$$\frac{1}{R_{elf}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \frac{1}{R_4}$$

4. Series resistors

2 identical resistors are connected in series as shown in the diagram.



Effective cross-sectional area = A

Effective length of 2 resistors = $2l$

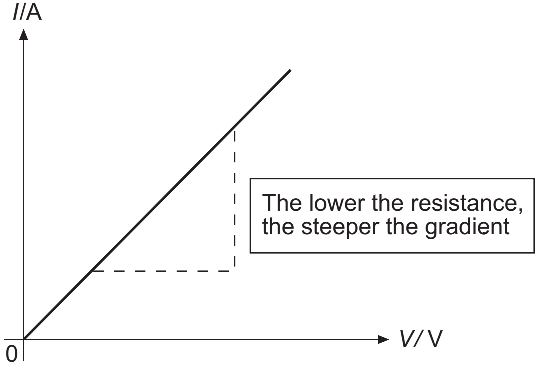
Effective resistance, $R_{eff} = \frac{\rho(2l)}{A} = 2\frac{\rho l}{A} = 2R$

Formula:

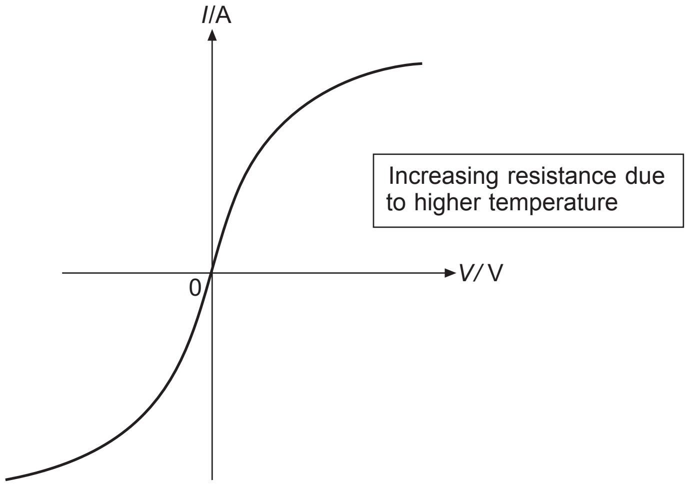
$$R_{eff} = R_1 + R_2$$

5. Ohm's Law: Ohm's law states that the current flowing in a conductor is directly proportional to the potential difference applied across it when all other physical conditions such as temperature are constant.

The I-V graph of an ohmic conductor is as follows:



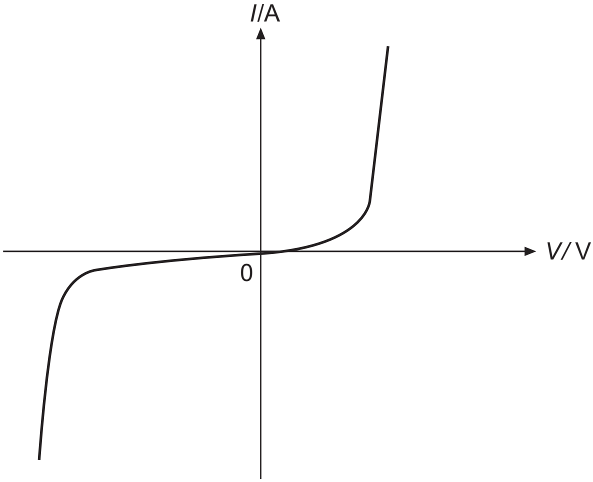
6. For a filament lamp (non-ohmic conductor), its *I-V* graph is not a straight line. As such, it does not obey Ohm's Law. As more current flows in a lamp, its metal filament becomes hotter and atoms in the filament vibrate faster, moving further away from their positions. This leads to an increase in the frequency of collisions with the travelling electrons that hinder their flow, causing more resistance. Hence, the gradient of its graph is fairly constant at low current *I* and potential difference *V*, but with increasing current, the resistance increases (gradient decreases).



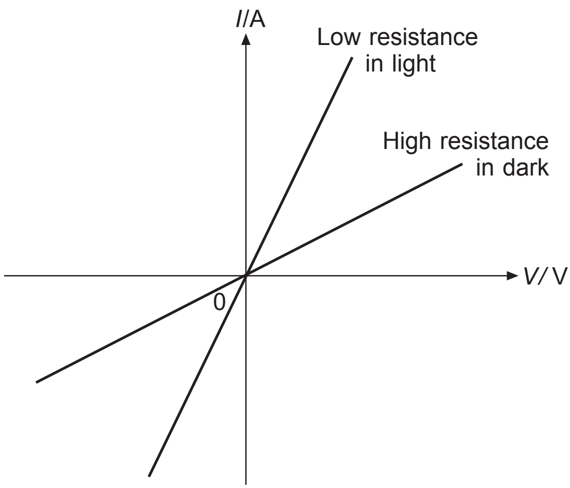
17.5 Diode and Light-dependent Resistor

1. A diode can be used to convert a.c. to d.c. in a process called rectification. A diode is a semiconductor device that allows current to only flow in one direction.

2. The *I-V* characteristic graph for the semiconductor diode is shown:



3. A light dependent resistor (LDR) is a semiconductor. When light shines onto the LDR, electrons are released. This increases the number of current-carrying electrons. As the light intensity increases, the current also increases, resulting in a fall in resistance. In the dark, there are no electrons and the current experiences a greater resistance.



TOPIC 18 D.C. Circuits

Objectives

Candidates should be able to:

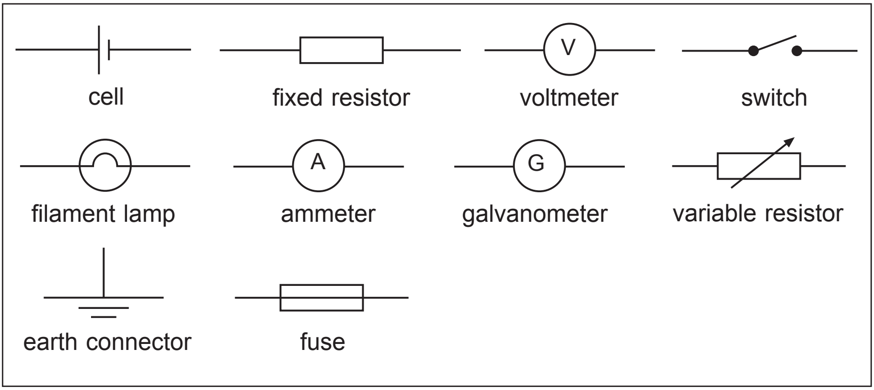
(a) draw circuit diagrams with power sources (cell, battery, d.c. supply or a.c. supply), switches, lamps, resistors (fixed and variable), variable potential divider (potentiometer), fuses, ammeters and voltmeters, bells, light-dependent resistors, thermistors and light-emitting diodes
(b) state that the current at every point in a series circuit is the same and apply the principle to new situations or to solve related problems
(c) state that the sum of the potential differences in a series circuit is equal to the potential difference across the whole circuit and apply the principle to new situations or to solve related problems
(d) state that the current from the source is the sum of the currents in the separate branches of a parallel circuit and apply the principle to new situations or to solve related problems
(e) state that the potential difference across the separate branches of a parallel circuit is the same and apply the principle to new situations or to solve related problems
(f) recall and apply the relevant relationships, including $R = V/I$ and those for current, potential differences and resistors in series and in parallel circuits, in calculations involving a whole circuit
(g) describe the action of a variable potential divider (potentiometer)
(h) describe the action of thermistors and light-dependent resistors and explain their use as input transducers in potential dividers
(i) solve simple circuit problems involving thermistors and light-dependent resistors

NOTES

18.1 Current and Potential Difference in Circuits

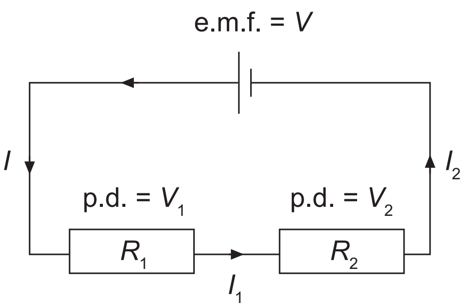
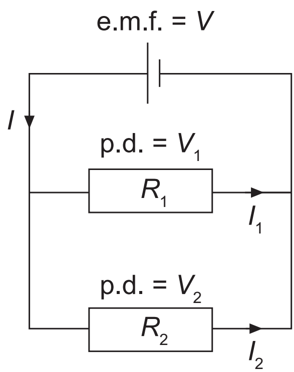
1. Current can only flow in a **closed** circuit.

2. The following table shows some of the electrical symbols used in circuit diagrams:

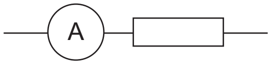
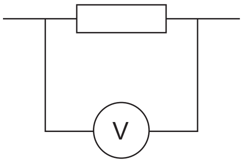


18.2 Series and Parallel Circuits

1. Comparison between a series circuit and a parallel circuit:

Series Circuit	Parallel Circuit
 • Only 1 path for current flow • The current is the same at all points in a series circuit. $I = I_1 = I_2$ • The potential difference across each resistor is different based on their resistance. • The sum of the potential differences across the resistors gives the e.m.f. of the cell. $V = V_1 + V_2$ • Effective resistance: $R_{eff} = R_1 + R_2$	 • There is more than 1 path for the current to flow. • Current: $I = I_1 + I_2$ • The potential difference across each resistor is the same and is equal to the e.m.f. of the cell. $V = V_1 = V_2$ Effective resistance: $\frac{1}{R_{elf}} = \frac{1}{R_1} + \frac{1}{R_2}$

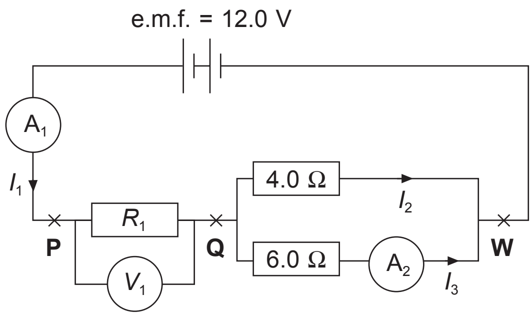
2. Ammeter and Voltmeter

Component	Use	Characteristic
Ammeter	Measures the current flowing through resistor. To be connected in series. 	Very small resistance (so that the potential difference aross it is negligible).
Voltmeter	Measures the potential difference across resistor. To be connected in parallel. 	Very high resistance (so that negligible amount of current will flow through it).

Example 18.1

In the following circuit diagram, the effective resistance of the circuit is 5.4 Ω. Find:

(a) the resistance of R_1
(b) the reading of ammeter 1
(c) the voltmeter reading
(d) the reading of ammeter 2



Solution

(a) Effective resistance across **QW** = $\left(\frac{1}{4.0} + \frac{1}{6.0}\right)^{-1}$ = 2.4 Ω

Hence, R_1 = 5.4 – 2.4 = 3.0 Ω

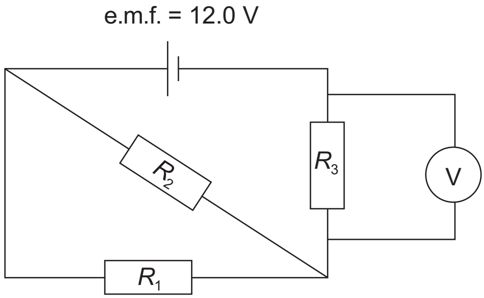
(b) Let the current reading in A_1 be I_1:
Using Ohm's Law: $V = IR$
$12.0 = I_1(5.4)$
$I_1 = 2.222$ A
$= 2.22$ A (to 3 s.f.)

(c) Current through $R_1 = I_1 = 2.222$ A
Potential difference (p.d.) across $R_1 = V$
$V = I_1R_1 = 2.222 \times 3.0$

(d) Let the current reading in A_2 be I_3:
p.d. across **QW** = 12.0 – 6.67 = 5.33 V
$5.33 = I_3(6.0)$
$I_3 = 0.888$ A (to 3 s.f.)

Example 18.2

Three resistors are connected to a 12.0 V battery as shown in the circuit below:

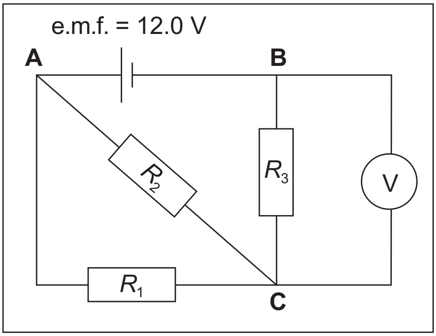


Given that $R_1 = 4.0\ \Omega$, $R_2 = 1.0\ \Omega$, $R_3 = 3.0\ \Omega$, find the voltmeter reading.

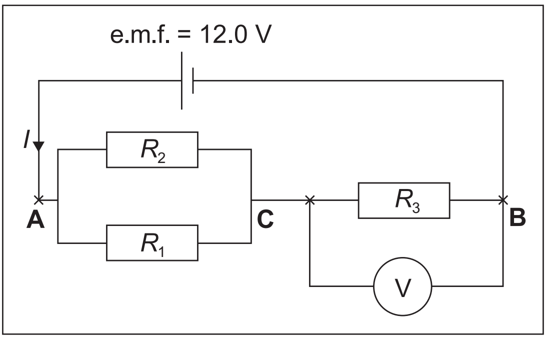
Solution

Let us add points **A**, **B**, **C** to the circuit diagram and redraw it.

Observe that R_1 and R_2 are parallel across points **A** and **C**:



Original



Redrawn

Effective resistance across **AC** = $\left(\frac{1}{4.0} + \frac{1}{1.0}\right)^{-1}$ = 0.8 Ω

Effective resistance of the whole circuit = 0.8 + R_3 = 0.8 + 3.0 = 3.8 Ω

Let the current through whole circuit be I.

Using Ohm's Law,

12.0 = I × 3.8

I = 3.158 A (to 4 s.f.)

p.d. across R_3 = IR_3 = 3.158 × 3.0 = 9.47 V

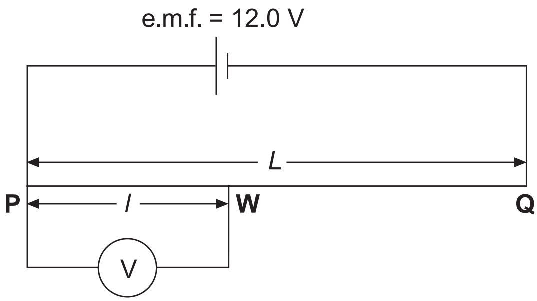
Voltmeter reading = 9.47 V (to 3 s.f.)

18.3 Potential Divider Concept

1. Recall that resistance is directly proportional to length:

   $R = \frac{\rho l}{A}$.

2. Let us use a uniform wire *PQ* of length *L* to replace the box resistors for the circuit below:



Let the resistance of the wire **PQ** be $R_{PQ} = \frac{\rho l}{A}$ --------- Equation (1)

Take a point **W** which is the distance *l* from **P**:

$R_{PW} = \frac{\rho l}{A}$ --------- Equation (2)

From Equation (1), $\frac{\rho}{A} = \frac{R_{PQ}}{L}$. Substitute into Equation (2).

$$R_{PW} = \left(\frac{R_{PQ}}{L}\right)l = \left(\frac{l}{L}\right)R_{PQ}$$

$$\left(\frac{R_{PW}}{R_{PQ}}\right) = \left(\frac{l}{L}\right)$$

Current *I* through a series circuit is the same.

$$V_{PW} = IR_{PW} = \left(\frac{l}{L}\right)IR_{PQ}$$

Thus,

$$V_{PW} = \left(\frac{l}{L}\right)V$$

When $l = L$, $V_{PW} = V$,

which tells us that (i) as *l* decreases, V_{PW} also decreases,

(ii) as *l* increases, V_{PW} also increases,

(iii) $\frac{V_{PQ}}{L}$ = constant.

Example 18.3

The wire PQ used in the circuit below has a length of 3.0 m. The resistance of PQ is 4.0 Ω. Find *l* for the voltmeter to register a reading of 4.0 V.

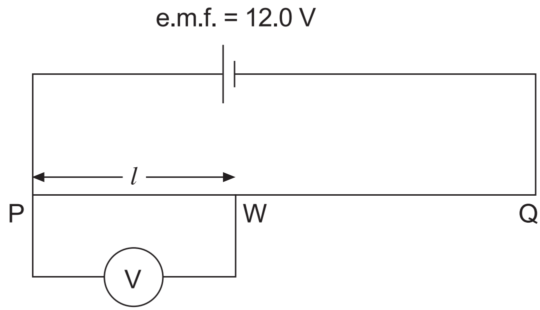
Solution

$$\frac{R_{PW}}{R_{PQ}} = \left(\frac{l}{L}\right)$$

$$\frac{R_{PW}}{R_{PQ}} = \frac{IR_{PW}}{IR_{PQ}} = \left(\frac{l}{L}\right)$$

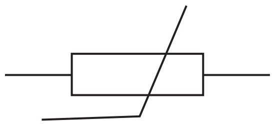
$$\frac{4.0}{12.0} = \left(\frac{l}{3.0}\right)$$

$$l = 1.0 \text{ m}$$



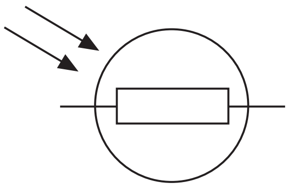
18.4 Thermistors and Light-Dependent Resistors (LDR)

1. A thermistor is a non-ohmic conductor. As it gets hotter, its resistance decreases. Thermistors are used for the control of temperature.



thermistor

2. An LDR is a semiconductor device (cadmium sulphide). Its resistance decreases as the intensity of light on it increases. LDRs are used in illumination control.



LDR

TOPIC 19 Practical Electricity

Objectives

Candidates should be able to:

(a) describe the use of the heating effect of electricity in appliances such as electric kettles, ovens and heaters
(b) recall and apply the relationships $P = VI$ and $E = VIt$ to new situations or to solve related problems
(c) calculate the cost of using electrical appliances where the energy unit is the kW h
(d) compare the use of non-renewable and renewable energy sources such as fossil fuels, nuclear energy, solar energy, wind energy and hydroelectric generation to generate electricity in terms of energy conversion efficiency, cost per kW h produced and environmental impact
(e) state the hazards of using electricity in the following situations:
  (i) damaged insulation
  (ii) overheating of cables
  (iii) damp conditions
(f) explain the use of fuses and circuit breakers in electrical circuits and of fuse ratings
(g) explain the need for earthing metal cases and for double insulation
(h) state the meaning of the terms live, neutral and earth
(i) describe the wiring in a mains plug
(j) explain why switches, fuses, and circuit breakers are wired into the live conductor

NOTES

19.1 Application of Heating Effects of Electricity

1. Household appliances such as kettles, irons and rice-cookers make use of the heating effect of electric current.
2. Nichrome is chosen as a heating element due to the following advantages:
   (a) cheap
   (b) high resistance
   (c) high melting point
   (d) does not oxidise easily

19.2 Electrical Energy and Power

1. Recall: $W = QV$
   W is the work done by source (unit: J)
   Q is the charge (unit: C)
   V is the e.m.f. (unit: V)

2. Since $Q = It$, we have $W = (It)V = VIt$
   I is the current (unit: A)
   t is the time taken (unit: s)

3. The following table summarises the different forms of the electrical energy equation:

Equation 1	$W = VIt$	
Equation 2	$W = I^2Rt$	by substituting $V = IR$ into (1)
Equation 3	$W = \frac{V^2}{R}t$	by substituting $I = \frac{V}{R}$ into (1)

4. Power, $P = \frac{\text{Work time, } W}{\text{Time, } t}$
   Rearranging, we have $W = Pt$
   Compare with Equations 1, 2 and 3 in the above table:

Equation 1	$P = VI$
Equation 2	$P = I^2R$
Equation 3	$P = \frac{V^2}{R}$

5. SI unit for power: W or J/s

19.3 Calculating Cost of Using Electricity

1. The unit for measuring electrical consumption is the kilowatt-hour (kWh), which is the energy used by an electrical device at a rate of 1000 W in 1 hour.

   1 kWh = 1000 W × 1 h
   = 1000 × 60 × 60
   = 3 600 000 J
   = 3.6×10^6 J

   Example 19.1

   Given that electrical energy costs $0.25 per kWh, find the total cost of running eight 60 W lamps and a 3 kW electrical kettle continuously for 8 minutes.

   Solution

   Total power = (8 × 60) + (1 × 3000) = 3480 W = 3.48 kW

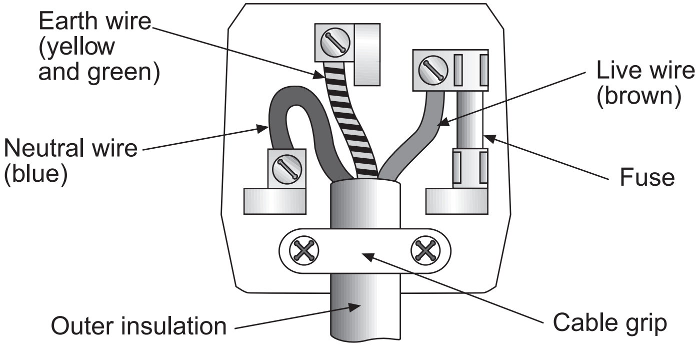
   No. of hours of operation = $\frac{8}{60} = \frac{2}{15}$ h

   Total cost = $3.48 \times \frac{8}{60} \times 0.25$ = \$0.116 = \$0.12 (to 2 d.p.)

19.4 Hazards of Using Electricity

1. Electricity is dangerous and can harm people if it is not used properly.
2. Some of the common dangers involved are:
   (a) Handling electrical appliances with wet hands can lead to electric shock.
   (b) Overheated cables can lead to fire.
   e.g. Plugging many appliances to one power point using multiplugs.
   (c) Electrical cables with damaged insulation, especially the live wire, can lead to an electric shock.

19.5 Safe Use of Electricity in the House



1. There are three wires in the household electric cable: live (L), neutral (N) and earth (E).
   (a) All appliances need at least 2 wires (live and neutral) to form a complete circuit.
   (b) The live (L) wire (brown) delivers the current at high voltage from the supply to the appliance. It is the most dangerous, thus switches, fuses and circuit breakers are wired to it instead of the other wires.
   (c) The neutral (N) wire (blue) completes the circuit by forming a path for the current back to the supply. It is usually at 0 V.
   (d) The earth (E) wire (yellow and green) is a low-resistance wire, usually connected to the metal casing of the appliance.
   (e) Earthing (use of earth wire) protects the user from an electric shock if the metal casing should accidentally become live (contacted with bare live wire).
   (f) The large current that flows from the loose live wire through the metal casing and the earth wire will blow the circuit fuse and cut off the supply to the appliance.

2. Fuse
   (a) A fuse is a safety device that is connected to the live wire of an electrical circuit to protect the equipment and wiring against any excessive current flow.
   (b) Characteristics:
   Made of tin-lead alloy with a low melting point.
   Common fuse ratings: 1 A, 2 A, 5 A, 10 A and 13 A.

(c) How does a fuse work?

1. Fuse rating for a fuse in a device must be slightly higher than the current through the device.
2. When the current is too large, the fuse becomes hot and melts (blown fuse), thus cutting off the current flow from the live wire to the device.
3. The blown fuse will have to be replaced by a new one for the device to work again.

3. Switches are used to close and open a circuit. Switching off disconnects the high voltage from an appliance.

4. Double insulation

(a) Double insulation is a safety feature in an electrical appliance that can substitute for an earth wire.

(b) It means that in addition to the first insulation covering the wires, there is a second insulation (**e.g.** plastic casing of a hair dryer).

TOPIC 20 Magnetism

Objectives

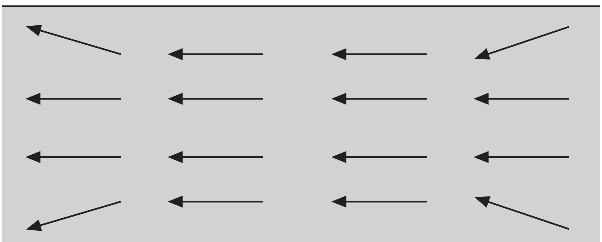
Candidates should be able to:

(a) state the properties of magnets
(b) describe induced magnetism
(c) describe electrical methods of magnetisation and demagnetisation
(d) draw the magnetic field pattern around a bar magnet and between the poles of two bar magnets
(e) describe the plotting of magnetic field lines with a compass
(f) distinguish between the properties and uses of temporary magnets (e.g. iron) and permanent magnets (e.g. steel)

NOTES

20.1 Laws of Magnetism

1. Properties of Magnets:
   (a) A magnet has two poles where the magnetic forces are the strongest: North pole and South pole.
   (b) Magnets DO NOT exist as monopoles (unlike electric charges).
   (c) We can use arrows to indicate magnetic dipoles in a magnet. The arrowhead indicates North pole.

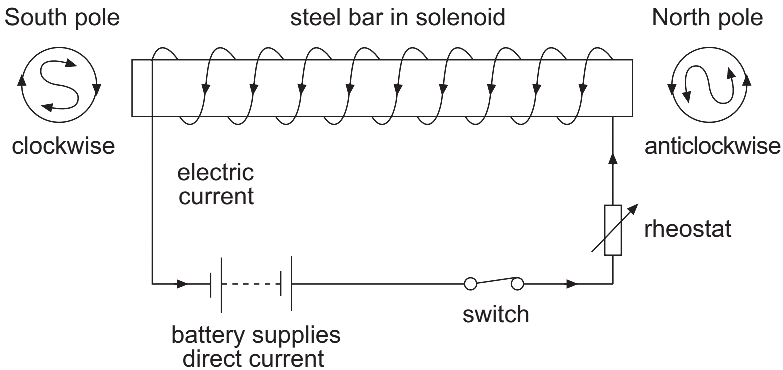


The arrows nearer to the edge are not exactly parallel due to repulsion of like poles.

   (d) The law of magnetism states that like poles repel and unlike poles attract.
   (e) Repulsion is the only way to test if an object is a magnet.

2. Induced magnetism: A magnetic material becomes an induced magnet when placed in a magnetic field, i.e. near a permanent magnet. The magnetic field from the magnet aligns the randomly arranged dipoles in the material.

3. Magnetisation using electricity:
To magnetise a steel bar, one can place it in a solenoid connected to a d.c. source.
   (a) The magnetic field produced by the solenoid magnetises the steel bar.
   (b) The polarities of the magnetised steel bar depend on the direction of the current.
   (c) If the bar is viewed from one end and the current flows in an anticlockwise direction, then that end will be the North-pole; if clockwise, then that end will be the South-pole.



20.2 Magnetic Properties

1. Examples of magnetic materials: iron, steel, nickel and cobalt.

2. Permanent magnets are magnets that do not lose their magnetism easily. They are made from materials like steel. Steel is an alloy of carbon and iron.

3. The differences between the magnetic properties of iron and steel can be summarised in the table below:

Properties	Iron	Steel
Material	soft	hard
Magnetisation	easy	difficult
Demagnetisation	easy	difficult
Magnetic field strength in solenoid	strong	weak
Magnetism	temporary	permanent

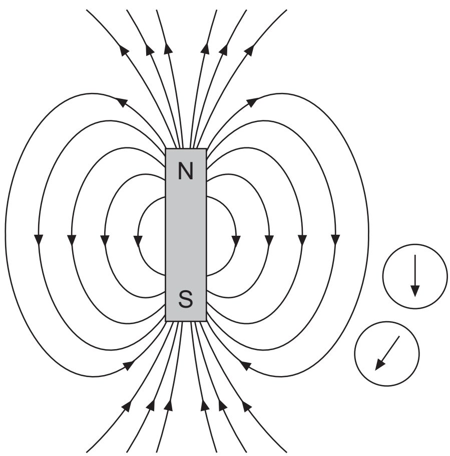
4. Comparison between electromagnet and permanent magnet:

Electromagnet	Permanent magnet
Made of a coil of wire (often with a soft iron core).	Made of hard magnetic material like steel.
Magnetism is temporary. Requires a current through the coil to sustain the magnetic field strength.	Magnetism is permanent. Does not require any electric current to retain magnetic field strength.
Applications: telephone receivers, electric relays, electric bells, circuit breakers and loudspeakers*.	Applications: magnetic doorstops, compasses, motors, dynamos and loudspeakers*

* A loudspeaker uses both an electromagnet and a permanent magnet.

20.3 Magnetic Field

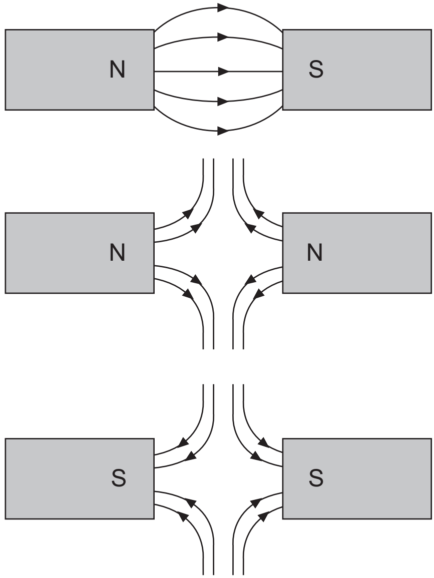
1. A magnetic field is a region in space where magnetic materials experience a force.
2. Magnetic field lines: We draw magnetic field lines to help us visualise the direction of the magnetic forces.
3. A compass can be used to plot the magnetic field lines around a magnet by marking each end of the compass needle with a dot as it is moved from the North pole to the South pole and linking up the dots together to form a solid line. The arrow on the line indicates the direction the compass needle points.



Important:

1. Magnetic field lines always start from North and end at South.
2. Each line is always in a complete closed loop (no matter how big the loop is) unlike electric field lines which can point to infinity.
3. Strength of a magnetic field depends on how close the lines are spaced together. (Closer ⟶ Stronger)

4. The magnetic field lines between like poles and unlike poles are as follows:



TOPIC 21 Electromagnetism

Objectives

Candidates should be able to:

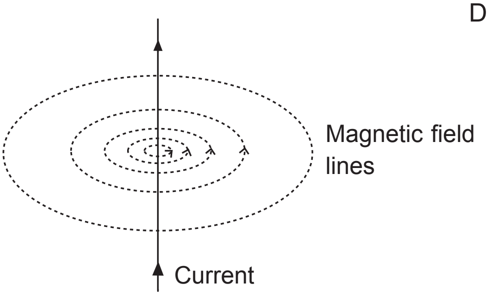
(a) draw the pattern of the magnetic field due to currents in straight wires and in solenoids and state the effect on the magnetic field of changing the magnitude and/or direction of the current
(b) describe the application of the magnetic effect of a current in a circuit breaker
(c) describe experiments to show the force on a current-carrying conductor, and on a beam of charged particles, in a magnetic field, including the effect of reversing
  (i) the current
  (ii) the direction of the field
(d) deduce the relative directions of force, field and current when any two of these quantities are at right angles to each other using Fleming's left-hand rule
(e) describe the field patterns between currents in parallel conductors and relate these to the forces which exist between the conductors (excluding the Earth's field)
(f) explain how a current-carrying coil in a magnetic field experiences a turning effect and that the effect is increased by increasing
  (i) the number of turns on the coil
  (ii) the current
(g) discuss how this turning effect is used in the action of an electric motor
(h) describe the action of a split-ring commutator in a two-pole, single-coil motor and the effect of winding the coil on to a soft-iron cylinder

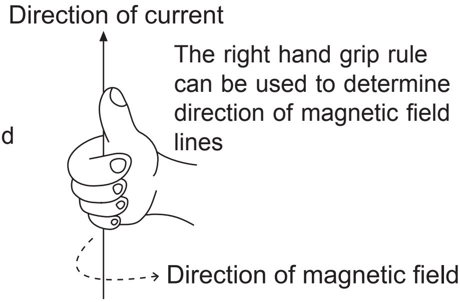
NOTES...

21.1 Magnetic Effect of a Current

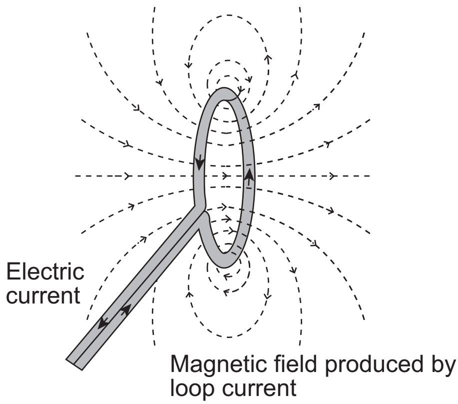
1. A current-carrying wire will produce a magnetic field around it. The pattern of the field lines depends on how the wire is shaped.

2. For a straight wire, the field lines form concentric circles around the wire as shown (note direction of arrows on field lines):

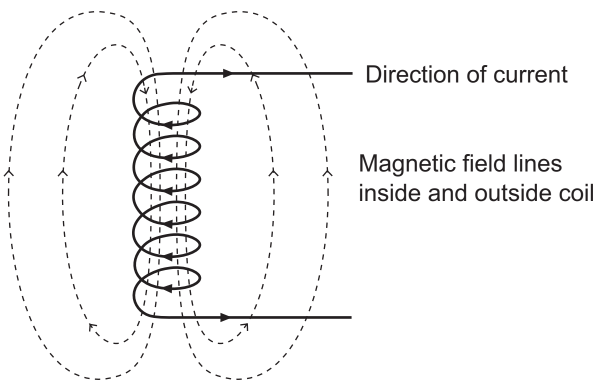




3. A higher current will result in a stronger magnetic field around the wire.
4. The field pattern of a single turn of circular wire carrying current is as shown:



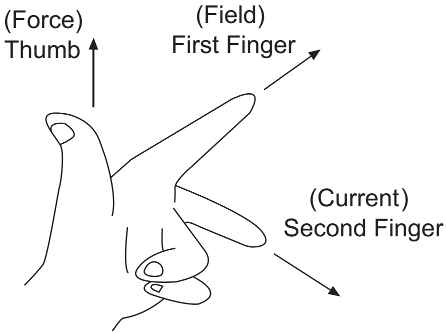
5. A solenoid's magnetic field pattern is as shown:



21.2 Force on a Current-carrying Conductor

1. When a current carrying wire is placed in a magnetic field, it will experience a magnetic force.

2. The direction of the force can be found using Fleming's Left Hand Rule:



Thumb: Direction of force

First Finger: Direction of field

Second Finger: Direction of current in wire

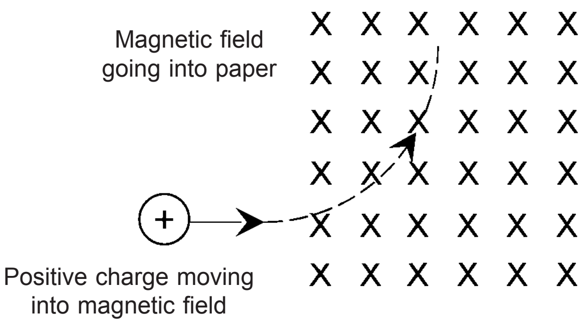
Note: The three fingers must be held at 90° to each other.

3. For a positive charge moving in space, it will behave like a current-carrying wire.

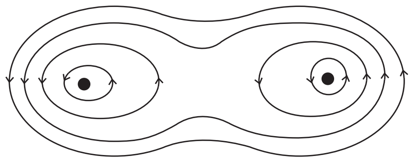
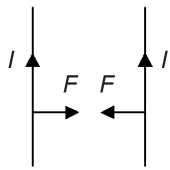
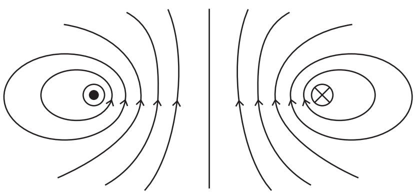
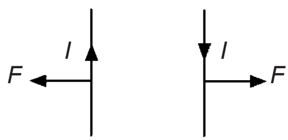
4. For a negative charge, the direction of the current will be **opposite** to its direction of travel.

Example 21.1

For a positive charge moving into a magnetic field as shown, it will experience a force to its left; hence its path is curved.



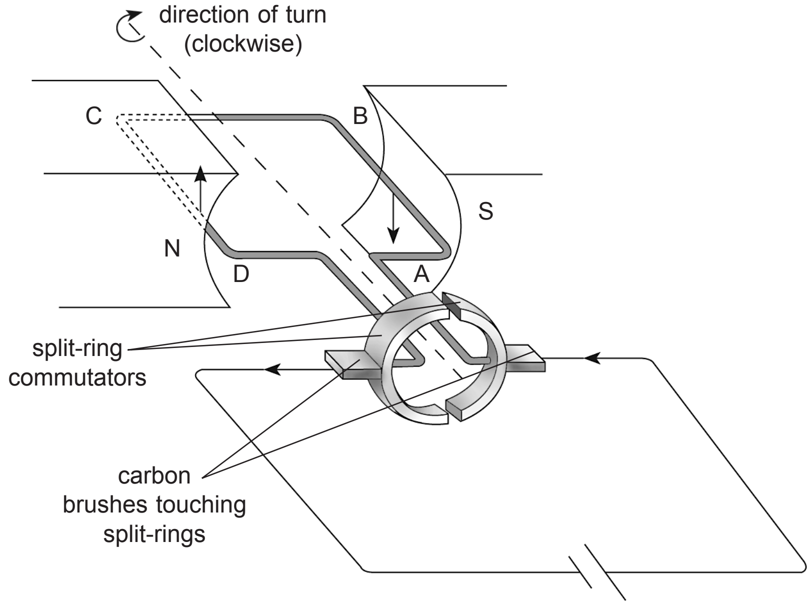
5. Force between two current-carrying wires.
When two wires are carrying current, they will experience mutual forces of attraction or repulsion because each of them will produce a magnetic field which will affect the other. If the currents flow in the same direction, the wires will attract each other; if the currents flow in opposite directions, the wires will repel.

1. Currents in same direction  ● Current coming out of paper	Notice that the field lines are only crowded outside and not in the middle? That is because the field lines cancel out in the middle of the wires. Hence there is an attractive force pulling the two wires together. 
2. Currents in opposite directions  ● Current coming out of paper ⊗ Current going into paper	Notice that the field lines are crowded between the wires. Crowded field lines exert a force sideway against each other. Hence there is a repulsive force pushing the wires apart. 

21.3 D.C. Motor

1. The behaviour of a current-carrying conductor in a magnetic field can be applied in electric motors which convert electrical energy into kinetic energy (i.e. fans).

2. The electric motor makes use of the principle that a current carrying coil will experience a turning effect inside a magnetic field.



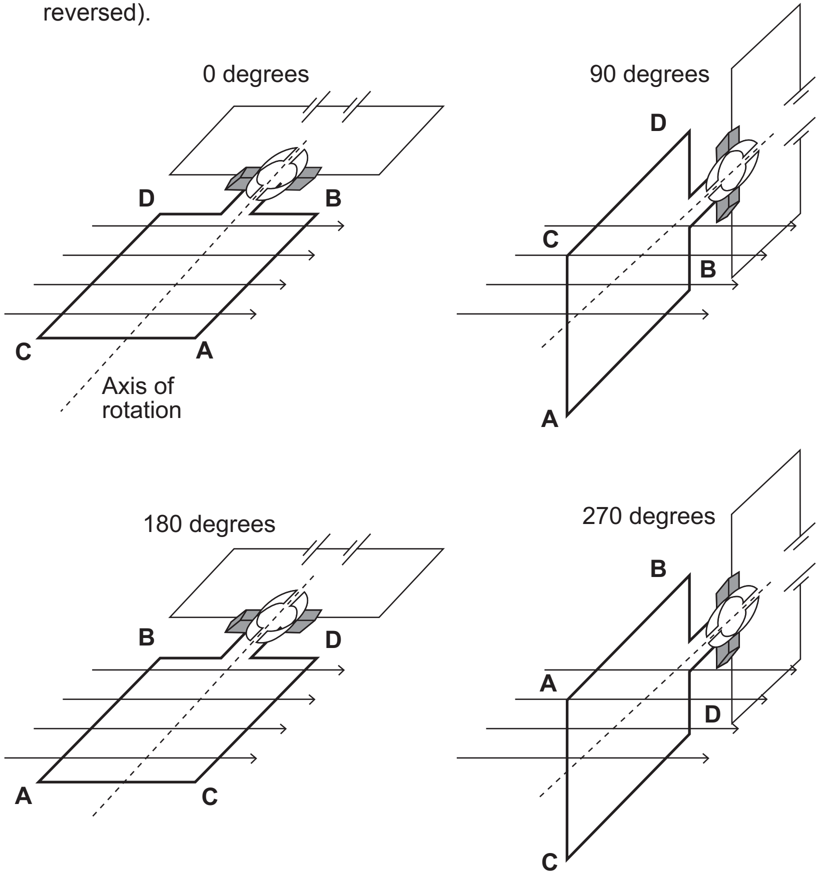
3.

Features	Role
Split-ring commutator	The split in the ring allows direction of current to be reversed in the coil to allow the coil to always rotate in one direction.
Carbon brushes	Carbon (graphite) can conduct electricity and is also a lubricant. It allows the commutator to turn smoothly with minimal friction.

4. Stages of operation
   (a) The carbon brushes make a connection with the coil every 180^{o} turn for current to flow through the coil. In the 0^{o} diagram, the brushes are in contact with the voltage source.
   (b) Current through wire segment C-D interacts with the magnetic field resulting in an upward force (left hand rule). Similarly, current that flows through segment A-B produces a downward force. Both forces are of equal magnitude,but opposite directions (currents in different direction). Thus a turning effect about the axis in the middle of the coil is created.

(c) In the 90° and 270° diagrams, the brushes are not in contact with the voltage source and no force is produced. In these two positions, the rotational kinetic energy of the coil keeps it spinning until the brushes regain contact.

(d) In the 180° diagram, the same thing occurs, but the force on **A-B** is upwards and force on **C-D** is downwards (direction of currents has reversed).



5. The strength of the turning effect can be increased by:
   (a) Increasing strength of magnetic field (use stronger magnets).
   (b) Increasing number of turns of wires in the coil.
   (c) Increasing the area of the coil (Area **ABDC**).
   (d) Increasing the current.
   (e) Adding a soft iron core around which the wires are coiled.

TOPIC 22 Electromagnetic Induction

Objectives

Candidates should be able to:

(a) deduce from Faraday's experiments on electromagnetic induction or other appropriate experiments:
   (i) that a changing magnetic field can induce an e.m.f. in a circuit
   (ii) that the direction of the induced e.m.f. opposes the change producing it
   (iii) the factors affecting the magnitude of the induced e.m.f.

(b) describe a simple form of a.c. generator (rotating coil or rotating magnet) and the use of slip rings (where needed)

(c) sketch a graph of voltage output against time for a simple a.c. generator

(d) describe the use of a cathode-ray oscilloscope (c.r.o.) to display waveforms and to measure potential differences and short intervals of time (detailed circuits, structure and operation of the c.r.o. are not required)

(e) interpret c.r.o. displays of waveforms, potential differences and time intervals to solve related problems

(f) describe the structure and principle of operation of a simple iron-cored transformer as used for voltage transformations

(g) recall and apply the equations $V_P / V_S = N_P / N_S$ and $V_P I_P = V_S I_S$ to new situations or to solve related problems (for an ideal transformer)

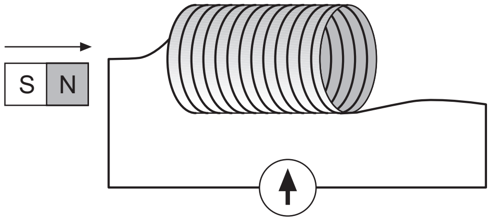
(h) describe the energy loss in cables and deduce the advantages of high voltage transmission

NOTES...

22.1 Principles of Electromagnetic Induction

1. Electromagnetic induction: When there is a change in the magnetic flux (magnetic field) linking the conductor, an e.m.f. and hence a current is induced between the ends of the conductor.

2. When the North pole of the bar magnet is moved towards the solenoid, an induced current is generated which produces a North pole at the end of the solenoid facing the magnet. The induced North pole is to oppose the motion of the magnet's North pole. Once the magnet stops moving, the induced current dies down to zero.



3. Faraday's Law of electromagnetic induction:
   The magnitude of the induced e.m.f. is directly proportional to the rate of change of magnetic flux linking the coil.

4. A larger e.m.f. is produced when:
   (a) the number of turns of wire in solenoid is increased.
   (b) a stronger magnet is used.
   (c) the speed with which magnet is moved towards or away of the solenoid is increased.
   (d) a soft iron core is placed inside the solenoid.

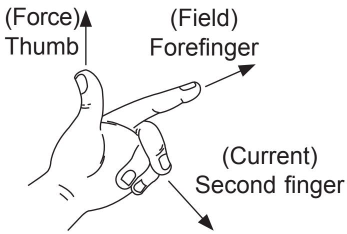
5. Lenz's Law: The direction of induced current sets up a magnetic field to oppose the change in the magnetic flux producing it.

6. Fleming's left hand rule and Fleming's right hand rule

<table>
<tr><th>Left Hand</th><th>Right Hand</th></tr>
<tr><td>

Quantities involved:
• Direction of force on conductor
• Direction of current
• Direction of magnetic field.

Given directions of any two of the above three quantities, it is possible to find the direction of the third quantity.

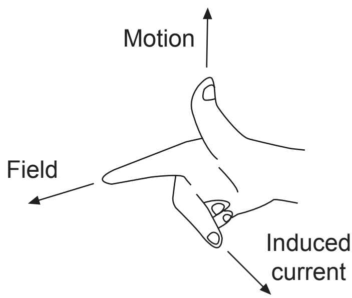


Thumb: Direction of force
Forefinger: Direction of field
Second Finger: Direction of current in wire
Note: The three fingers must be held at 90° to each other.

</td><td>

Quantities involved:
• Direction of induced current
• Direction of magnetic field
• Direction of motion

Given directions of any two of the above three quantities, it is possible to find the direction of the third quantity.



Thumb: Direction of motion
First Finger: Direction of field
Second Finger: Direction of induced current in wire
Note: The three fingers must be held at 90° to each other.

</td></tr>
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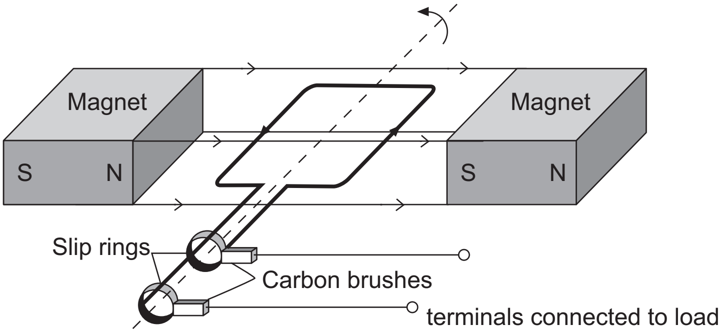
7. Energy Conversion Process

Dynamo, Generator	Kinetic Energy to Electrical Energy
Motor	Electrical Energy to Kinetic Energy

22.2 A.C. Generator

1.



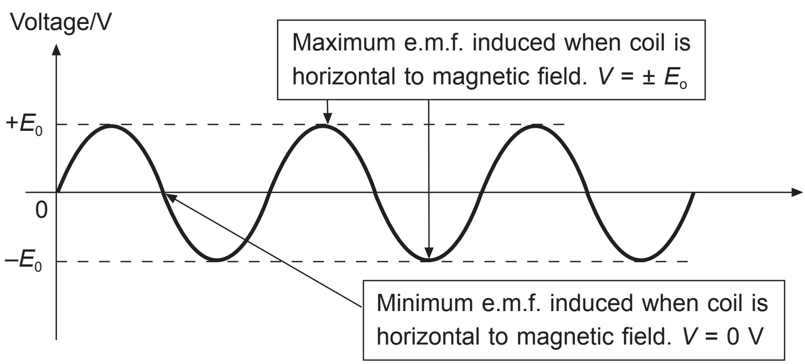
2. An a.c. generator is used to generate electricity. It consists of a coil of rectangular wires situated between two magnets as shown above.

3. When the coil is rotated, it cuts the magnetic field and causes a change in the magnetic flux linkage. As long as the coil keeps on rotating, the rate of change of magnetic flux linking the coil is non-zero and hence, an e.m.f. will be induced in the coil. By Faraday's Law of electromagnetic induction, the magnitude of the e.m.f. that is induced in the coil is directly proportional to the rate of change of magnetic flux linking the coil.

4. Kinetic energy (rotation) is converted into electrical energy.

5. The a.c. generator's coil is connected to two slip-rings which make sliding contact with the carbon brushes at all times (unlike the split-ring commutator used by d.c. motors).

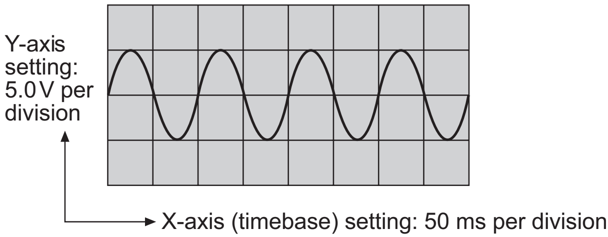
6. The voltage-time graph of the induced e.m.f. is as follows:



22.3 Uses of Cathode-Ray Oscilloscope (c.r.o.)

1. Measure p.d.
2. Display waveforms
3. Measure short time intervals

Example 22.1



Amplitude = one division = 5.0 V

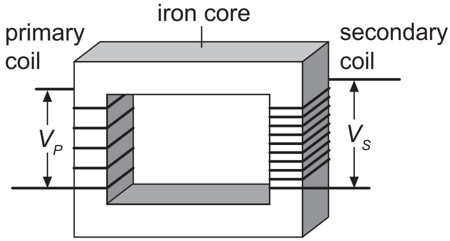
Period, T = 2 divisions = 100 ms = 0.1 s

Frequency, $f = \frac{1}{T} = \frac{1}{0.1}$ = 10 Hz

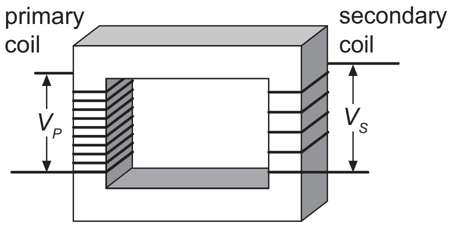
22.4 Principles of Operation of a Transformer

1. The advantage of producing a.c. instead of d.c. at power plants is that a.c. can be stepped up or down to suit household and industries' needs. Household a.c. voltage is stepped down to 240 V.

2. The following diagram shows a step-up and a step-down transformer:



Step-up transformer
$V_P < V_S$
$N_P < N_S$



Step-down transformer
$V_P > V_S$
$N_P > N_S$

3. Principle of operation of a transformer:
   a.c. will produce a changing magnetic field. By coiling a primary coil of wires and a secondary coil around an iron core, the changing magnetic field produced by the primary coil will induce an e.m.f. in the secondary coil.

4. For an ideal transformer, we have:
$P_P = P_S \Rightarrow I_P V_P = I_S V_S$

$$\frac{I_P}{I_S} = \frac{N_S}{N_P}$$

Also, $$\frac{V_S}{V_P} = \frac{N_S}{N_P}$$

Note:
1. For practical transformers, if the load on the secondary circuit increases in resistance (more devices connected to the secondary terminals in series), then the amount of power output required will also increase.
2. The power input ($P = I_P V_P$) from the generator is NOT FIXED. Only V_P and V_S are fixed.
For N2013/P1/Q40, the 230 V has been transmitted over a long distance without transformers.
3. The amount of I_p depends on consumption.

5. Power plants transmit electricity through thick cables at high voltages for the following reasons:
(a) A higher voltage will mean a lower current travelling in the cable.
(b) Thick cables (large cross-sectional area) mean the cables have low resistance.

$$\left(R = \frac{\rho l}{A} \right)$$

In this way, less power is lost as heat due to heating effect in the cables.

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