Physics Cheatsheet

Start

1. Measurements

Physical Quanitites:
Quantities that can be measured, consists of a numerical magnitude and a unit.

Prefixes:

Prefix	Order of magnitude	Symbol
nano-	10^{-9}	n
micro-	10^{-6}	μ
milli-	10^{-3}	m
centi-	10^{-2}	c
deci-	10^{-1}	d
kilo-	10^{3}	k
mega-	10^{6}	M
giga-	10^{9}	G

Great Majestic kings drink cold milk μntil nine

Conversion of km/h to m/s:
km/h ÷ 3.6 = m/s

Sizes of well-known objects:
Radius of Earth: 6378000m (6.378×10^{6})
Size of atom: 0.0000000001m (10^{-10})

Instrument	Measuring Range	Precision
Measuring Tape	More than 1 m	1 cm or 10 mm
Metre Rule	10 cm to 1 m	0.1 cm or 1 mm
Vernier Calipers	~2 cm to ~10 cm	0.01 cm or 0.1 mm
Micrometer Screw Gauge	Less than 2 cm	0.001 cm or 0.01 mm

Vernier Calipers:
Precision: 0.01cm
Read the main scale until the immediate left of the zero mark on the vernier scale, then add the marking which coincides with the marking on the main scale.
Zero Errors for Vernier Calipers:
Positive: Zero mark of Vernier is slightly to the right of the main scale.
Negative: Zero mark of Vernier is slightly to the left.

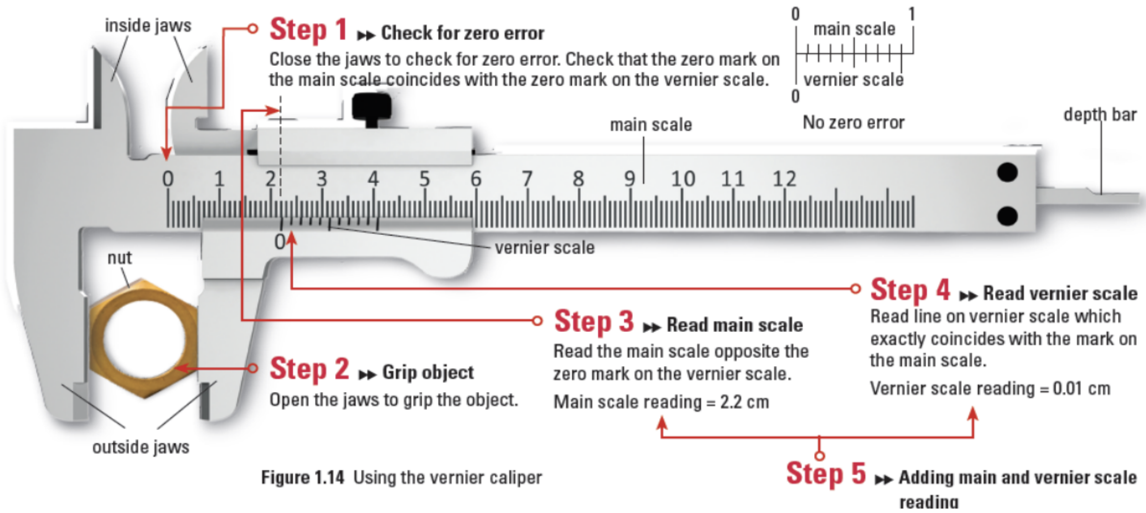
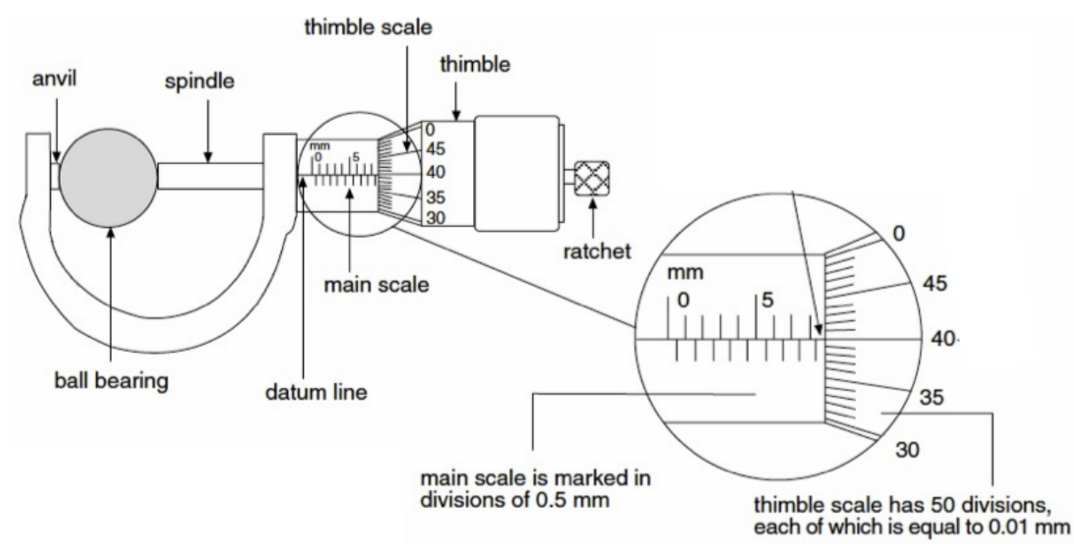
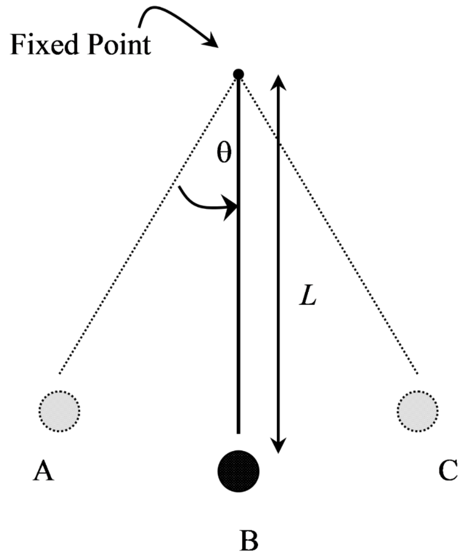


Figure 1.14 Using the vernier caliper

Micrometre Screw Gauge
Precision: 0.01mm
Read main scale, then read thimble reading
Zero Errors:
Positive: Zero marking on thimble scale is below datum (centre) line.
Negative: Zero marking on thimble scale is above datum line



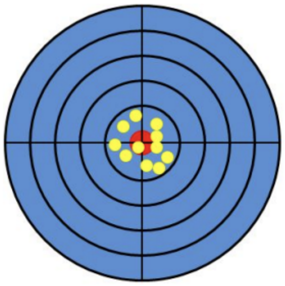
Pendulums:
Oscillation: One complete to-and-fro motion (A to C to A)/(B to C to B to A to B)



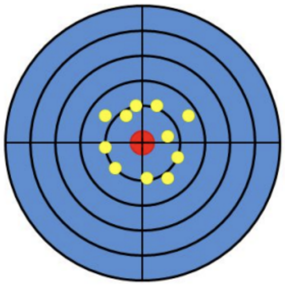
Period: Time taken for one complete oscillation

Precision vs Accuracy:

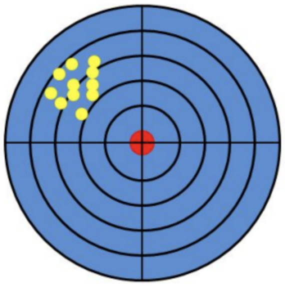
Accuracy of measurement	Precision of measurement
Accuracy refers to the closeness of a measured value to a standard or known value. Example: You obtain a mass measurement of 3.2kg for a given substance, but the actual (known) mass is 10 kg, then your measurement is not accurate.	Precision refers to the closeness of two or more measurements to each other. Example: If you measure the mass of a given substance five times, and get 3.2 kg each time, then your measurement is very precise.



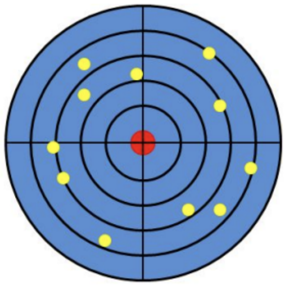
accurate and precise



accurate and not precise



not accurate and precise



not accurate and not precise

Errors:

<table>
<tr><th>Random Error</th><th>Systematic Error</th></tr>
<tr><td>

It occurs in all measurements.
It occurs when an observer estimates the last figure of a reading on an instrument.

Causes:

Human reaction time
Background noise
Mechanical vibrations

It cannot be predicted.

It can be reduced by taking a large number of readings and averaging them.
</td><td>

It is not random but constant.
It may cause an observer to consistently underestimate or overestimate a reading.

Causes:

Zero error of an instrument: Any indication that a measuring system gives a false reading when the true value of a measured quantity is zero

It can be eliminated if we know the sources of the errors.
</td></tr>
</table>

2. Kinematics

Formulas:

Average velocity [ms^{-1}]	$v = \frac{s}{t}$
Acceleration [ms^{-2}]	$a = \frac{v-u}{t}$
Acceleration of free fall	$g = 10\ ms^{-2}$

Scalar Quantities:
Quantities with only magnitude
Distance, Speed, Mass, Energy, Time

Vector Quantities:
Quantities with both magnitude and direction
Displacement, Velocity, Acceleration, Force

Distance:
Total distance travelled

Displacement:
Total distance travelled in a straight line

Speed:
The distance moved per unit time (m/s)

Velocity:
The rate of change of displacement (m/s)

Acceleration:
The rate of change of velocity (m/s^2)

***Acceleration due to freefall:**
The acceleration due to freefall varies based on the distance from the centre of the planet (e.g. Equators vs Poles, height from ground)

3. Dynamics, Mass Weight and Density

Formulas:

Resultant force [N]	$F = ma$
Weight	$W = mg$
Density [kg m^{-3}]	$\rho = \frac{m}{V}$

Contact and Non-contact Forces:

Normal Contact Force	• Contact force • The push experienced when two objects are pressed together • Acts perpendicular to and outward from the contact surface
Friction	• Contact force • Opposes relative motion between two objects that are in contact with one another
Tension	• Contact force • The force due to a taut spring, string or rope which pulls on the objects attached to both its ends • The direction of this force is along the string
Drag Force [Air Resistance]	• Contact force • When an object moves through a fluid (liquid or gas), the drag force is a force by the fluid on the object. • The drag force of an object moving through the air is known as air resistance. • The direction of the drag force is opposite the direction of the motion (velocity) of the object. • The greater the speed of the object, the greater the magnitude of the drag force. • The drag force is zero when the object is at rest
Weight/Gravitational Force	• Non-contact force • In a gravitational field, a mass experiences weight due to gravitational attraction • On Earth, the weight of an object is directed toward the centre of the Earth

Electric Force	● Non-contact force ● The push (repulsion) or pull (attraction) between electric charges.
Magnetic Force	● Non-contact force ● The push or pull between two magnets, magnets on magnetic materials. ● Moving electric charges in a magnetic field may also experience a magnetic force.

Mass:
The amount of matter in a body
Measured with a beam balanced
Kilograms (kg)

Weight:
The gravitational force, or gravity, acting on an object
Measured with spring balance
Newton (N)

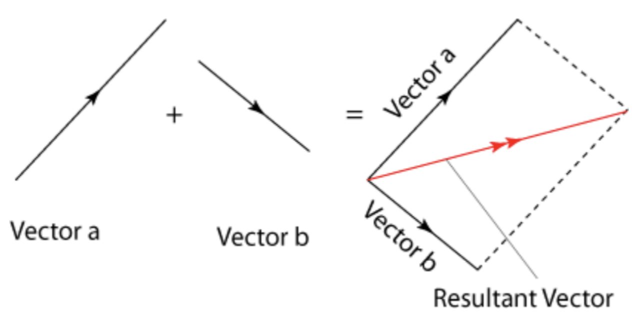
Gravitational Field:
A region in which a mass experiences a force due to gravitational attraction.

Gravitational Field Strength:
The gravitational field strength, g, is the gravitational force acting per unit mass on an object.
Near the surface of the Earth, g ≈ 9.81 N/kg ≈ 10 N/kg.
SI unit of gravitational field strength: newton per kilogram (N/kg) or metre per square second (m/s^2); 1 N/kg = 1 m/s^2

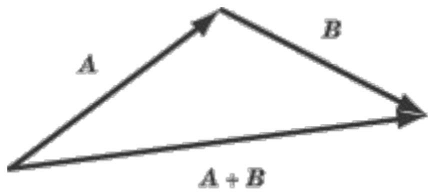
Inertia:
The reluctance of the object to change its state of motion due to its mass.

Vector Diagrams:
In a vector diagram, if all 3 arrows form a complete loop, the forces are in equilibrium

Parallelogram Method:



Tip to Tail Method:



Newton’s Law of Motion:

1. **1st Law:** In the absence of a net force acting on it a stationary object remains stationary, whereas a moving object continues moving at constant speed in the same direction.
2. **2nd Law:** When a net force, Fnet, acts on an object of a constant mass, the direction of the acceleration of the object is the same as the direction of the net force. The product of the mass and acceleration of the object gives the resultant force.
3. **3rd Law:** For every action, there is an equal and opposite reaction.
    - If one object exerts a force on a second object, the second object exerts a force on the first object. These two forces have equal magnitudes and opposite directions.

Free Body Diagram:

Include **all forces acting on** the **object** in its free-body diagram.

(a) A force is represented by a straight arrow.

(b) The **larger magnitude** of the force, the **longer** the **arrow**.

(c) The direction of the force is the **same** as the **direction** of the arrow.

(d) If the object is not represented by a point, each **arrow** is **drawn from** the **location** where the **force** is **applied**.

- **Weight**: Arrow is drawn from the **centre of gravity**.
- **Normal contact force**: Arrow is drawn from the **contact surface** and is **perpendicular** to it.
- **Tension**: Arrow is drawn from the point where the **string** is **attached** to the object and points **parallel** to the string.
- **Friction**: Arrow drawn from the **contact surface** and is **parallel** to it.

Friction:

Friction is a contact force that opposes relative motion between two objects that are in contact with one another.
Friction is the result of irregularities of the surfaces that are in contact.

Positive and Negative Effects of Friction:

Positive Effects of Friction	Negative Effects of Friction
(a) Prevents food from slipping when gripping food between chopsticks (b) Friction by the brake pads on bicycle tyres decreases the speed of a bicycle (c) Friction between rubber tires and tar roads allows car to grip the roads properly. ● To enhance this positive effect, car tyres have grooves that channel water under the tyre away. This helps prevent skidding. (d) Rock climbers use chalk powder that absorbs sweat on their palms. This improves their grip of the rock surface. (e) Rubbing of hands during cold weather or rubbing two pieces of wood to start a fire.	(a) When engines operate, friction causes some input energy to be converted into sound or thermal energy. The useful output energy is less than the total input energy. Overheating may be dangerous. (b) Causes wear and tear of moving parts of shoes, engines, motors and machines.
	Reducing the Negative Effects of Friction
	(a) Polishing surfaces to make them smooth reduces friction, e.g. the pistons and cylinders of an engine are made of highly polished steel or aluminium (b) Lubricants like oil or grease are applied to moving parts to prevent wear and tear. They help smooth over surface irregularities. (c) Ball bearings placed between two moving parts ensure the machines do not rub against each other. They can be found in the wheels of cars, bicycles, skates. (d) The layer of air in an air cushion between moving surfaces reduces friction, e.g. hovercrafts and magnetic levitation (Maglev) trains float slightly above the surface so that they can move faster.

Free Fall:
If the only force acting on an object is its weight, it is said to be undergoing free fall.

This is regardless of which direction the object is moving

e.g. In a vacuum on earth, a ball that is moving upwards just after being thrown is still undergoing free fall.

An object undergoing free fall experiences a downward acceleration that equals the gravitational field strength,

Since at free fall F=W,
F=ma
mg = ma
g = a

Air Resistance and Terminal Velocity:
An object moving through a fluid experiences a drag force. If the fluid is air, the drag force is called air resistance.

When an object moves through air, air resistance is a force that acts opposite of direction in which the object is moving.

The greater the speed of the object, the greater the magnitude of air resistance.

The greater the surface area of the object, the greater the magnitude of air resistance.

The greater the density of the air, the greater the magnitude of air resistance.

When the forces on an object are balanced, the object experiences zero acceleration. Thus, its velocity remains constant (Newton’s first law).

Thus, when the air resistance balances the weight of a falling object, its velocity no longer changes. This is its terminal velocity.

Density:
Density is defined as mass per unit volume.

When an insoluble solid is placed in a liquid, the solid will
(a) float if its (average) density is less than that of the liquid.
(b) sink if its (average) density is greater than that of the liquid.
(c) be suspended if its (average) density is equal to that of the liquid.

4. Turning Effect of Forces

Formulas:

Moment [Nm]	$M = Fd_{\perp}$

Moments:
Moment of a force (torque, Nm): The product of the force F and the perpendicular distance from the pivot to the line of action of the force.

Principle of Moments:
When an object is balanced, it is in a state of equilibrium

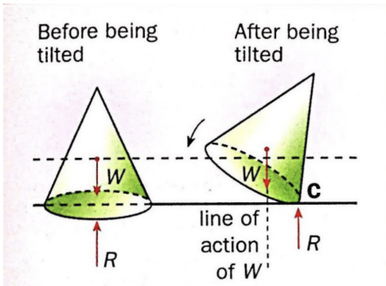
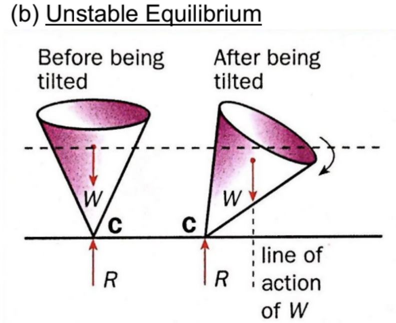
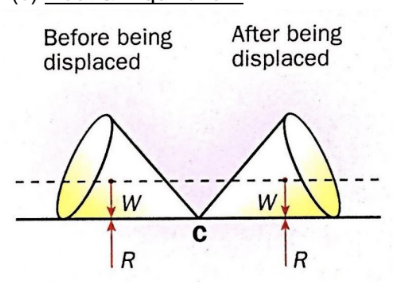
When an object is in equilibrium,
1. the resultant force must be zero (Translational Equilibrium)
2. the resultant moment must be zero (Rotational Equilibrium)

The Principle of Moments states that when an object is in equilibrium, the sum of clockwise moments is equal to the sum of anticlockwise moments about any axis.

Centre of Gravity:
The centre of gravity of an object is defined as the point through which its weight appears to act through.

Stability:
The stability of an object is essentially related to 2 factors:
● The base area of the object,
● The position of the centre of gravity of the object

To increase the stability of an object,
1. Keep the base area of the object as large as possible;
2. Keep the centre of gravity of the object as low as possible.

Type of Equilibrium	Descriptions
(a) <u>Stable Equilibrium</u>  	● When the cone is tilted slightly, the centre of gravity …rises… but …falls… to its original position due to the …moment… produced by its weight (**anticlockwise**) about the contact point C (pivot).
(b) <u>Unstable Equilibrium</u>  	● When the cone is tilted slightly, the centre of gravity …falls… and the cones …topples… due to the …moment… produced by its weight (**clockwise**) about the contact point C (pivot).
(c) <u>Neutral Equilibrium</u>  	● When the cone is displaced horizontally, the centre of gravity remains at the same …height.…

5. Pressure

Formulas:

Pressure [Nm^{-2} or Pa]	$P = \frac{F}{A}$
Fluid pressure	$P = \rho g h$
Hydraulic pressure	$\frac{F_1}{A_1} = \frac{F_2}{A_2}$

Pressure:

Pressure is defined as the force acting per unit area.

Pascal's Principle:

When pressure is applied to an enclosed incompressible liquid, the pressure is transmitted equally to all other parts of the liquid.

Hydraulic Press:

(a) A force F_X is exerted on piston 1. The pressure exerted at point X is $p_X = \frac{F_X}{A_X}$.

(b) This pressure is transmitted equally to every part of the liquid, including to point Y.

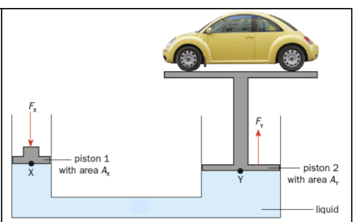
(c) A force, F_Y, is applied onto the base of piston 2.

(d) Thus,

$$\boxed{\begin{gathered} p_X = p_Y \\ \frac{F_X}{A_X} = \frac{F_Y}{A_Y} \end{gathered}}$$

Equivalently, $\frac{F_X}{F_Y} = \frac{A_X}{A_Y}$.

(e) Since $A_X < A_Y$, $F_X < F_Y$.

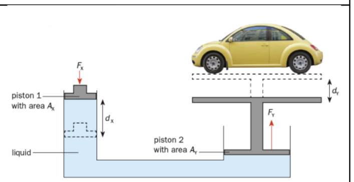


(f) Since the liquid is incompressible, the volume displaced at point X is equal to the volume displaced at point Y.

$$\boxed{\begin{gathered} V_X = V_Y \\ A_X\, d_X = A_Y\, d_Y \end{gathered}}$$

Equivalently, $\frac{A_X}{A_Y} = \frac{d_Y}{d_X}$.

(g) Since $A_X < A_Y$, $d_X < d_Y$.



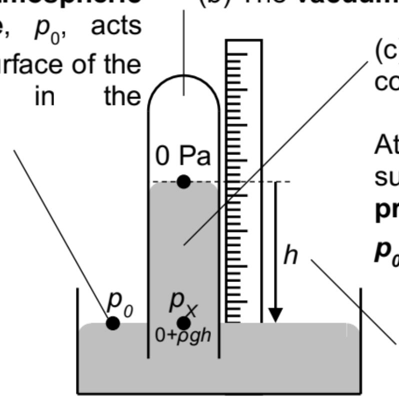
Pressure Due to a Liquid Column [Fluid Pressure]:

Refer to formula

Barometer:

(a) **Atmospheric pressure**, p_0, acts on the surface of the mercury in the **trough**.

(b) The **vacuum** exerts no pressure on the mercury in the tube.



(c) The thick glass tube, which is about 1 m long, contains mercury.

At point X, which is at the **same level** as the surface of the trough, the **mercury** exerts a **pressure, p_X,** that **equals atmospheric pressure**, p_0.

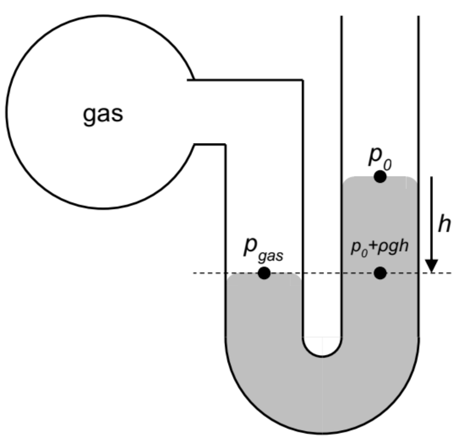
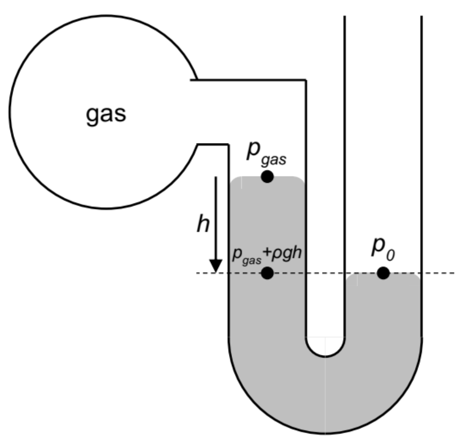
(d) The **distance** h of between the mercury levels in the tube and in the trough is measured with a metre rule.

Mercury:

1m Hg (one meter of mercury) = 136000Pa

Density of mercury = 13600kg/m^3

Manometer:

$p_{gas} > p_0$ The pressure of the gas, p_{gas}, is **greater than** atmospheric pressure.	$p_{gas} < p_0$ The pressure of the gas, p_{gas}, is **less than** atmospheric pressure.
 $p_{gas} = p_0 + \rho g h$	 $p_{gas} + \rho g h = p_0$ $p_{gas} = p_0 - \rho g h$

6. Energy, Work & Power

Formulas:

Kinetic Energy [J]	$KE = \frac{1}{2}mv^2$
Gravitational Potential Energy	$GPE = mgh$
Work Done [J or Nm]	$WD = Fs$
Power [W]	$P = \frac{WD}{t} = Fv$
Efficiency	$\mu = \frac{output}{input} \text{x}100\%$

Types of Energy:

1. Kinetic energy:
    - Is the energy of an object due to its motion. It can be used to do work. E.g. The kinetic energy of moving air (wind) can be used to turn turbines, which converts the kinetic energy to electrical energy.
2. Potential energy:
    - Is the stored energy in a system, due to the position, shape or state of the system. In general, there are gravitational potential energy, elastic potential energy, and chemical potential energy.
3. Electrical energy:
    - Is the energy of an electrical charge due to its motion and position.
4. Light energy:
    - Is a form of electromagnetic wave that is visible to the eye. It is made up of oscillating electric and magnetic fields, and it is a part of the electromagnetic spectrum.
5. Thermal energy:
    - Is the energy stored in a body due to its thermal properties. The thermal energy of a body represents the total internal kinetic energy of the atoms or molecules in the body.
6. Nuclear energy:
    - Is the energy released during a nuclear reaction, of which there are two types: (a) Nuclear fission and (b) Nuclear fusion.

Conservation of Energy:
The Principle of Conservation of Energy states that energy cannot be created or destroyed but can be converted from one form to another. The total energy in an isolated system is constant.

Efficiency:
Refer to formula

Work Done:
Work done by a constant force on an object is the product of the force and the distance moved by the object in the direction of the force.

7. Kinetic Model of Matter

Solid, Liquid and Gas:

	Solid	Liquid	Gas
Visible Physical Properties			
Shape	Fixed shape	No fixed shape, takes the shape of the container	No fixed shape, takes the shape of the container
Volume	Fixed volume	Fixed volume	No fixed volume, assumes the volume of the container
Compressibility	Incompressible	Incompressible	Highly compressible
Density	High density	High density	Low density
Explanation of Physical Properties			
Intermolecular Forces	Very strong Thus, solids have fixed shapes and volumes, and are incompressible.	Strong Thus, liquids have fixed volumes and are incompressible.	Very weak / negligible Thus, gases have no fixed volumes and are highly compressible.
Separation of Particles	Very closely packed Thus, solids have high densities and are incompressible.	Closely packed Thus, liquids have relatively high densities and are incompressible.	Spaced very far apart from one another. Thus, gases have low densities and are highly compressible.
Arrangement of Particles	Regular pattern	Randomly arranged	Randomly arranged
Motion of Particles	Vibrate randomly about fixed positions Thus, solids have a fixed shape.	Slide past one another randomly Thus, liquids have no fixed shape.	Move quickly, randomly and continuously in all directions Thus, gases have no fixed shape and occupy a container of any volume.

Brownian Motion:
The air (fluid) is made up of small, invisible particles that undergo continuous and random motion.

The air molecules (fluid particles) collide with the smoke particles (suspended particles) continuously, randomly and from all directions.

This results in Brownian motion. Brownian motion is the continuous and random motion of particles that are suspended in a fluid (e.g. air, water).

Motion of molecules vs temperature:
The average kinetic energy of the gas particles is directly proportional to the absolute temperature of the gas.

$$\boxed{KE_{\text{av, particles}} \propto T}$$

Gas Pressure [Motion of molecules]:
How does a gas exert a pressure?

Gas particles move about randomly, continuously and in all directions

They collide with the inner walls of the container and exert a force on them.

The average force exerted per unit area is the gas pressure.

Gas Laws:

	Pressure Directly Proportional to Temperature for Constant Mass and Volume		Pressure Inversely Proportional to Volume for Constant Mass and Temperature		Volume Directly Proportional to Temperature for Constant Mass and Pressure	
	As °C Increases	As °C Decreases	As Volume Increases	As Volume Decreases	As °C Increases	As °C Decreases
Avg KE	Increases	Decreases	Constant	Constant	Increases	Decreases
Avg Force Per Collision	Increases	Decreases	Constant	Constant	Increases	Decreases
Avg Time to Move Between Inner Walls	Decreases	Increases	Increases	Decreases	Increases	Decreases
Freq of Collisions	Increases	Decreases	Decreases	Increases	Decreases	Increases

8. Transfer of Thermal Energy

Thermal Energy Movement:
Thermal energy always flows from a region of higher temperature to a region of lower temperature.

A net flow of thermal energy in the form of heat occurs only when there is a difference in temperature.

Thermal energy is transferred through three different processes.

There is no net heat flow between two regions they reach the same temperature.

Conduction:
Conduction is the transfer of thermal energy through a medium from one particle to another particle.

Conduction takes place in all states of matter - fastest in solids, followed by liquids and gases.

1. Particles at the heated end gain kinetic energy and vibrate vigorously.
2. They collide with neighbouring particles, causing them to vibrate more vigorously as well.
3. This process continues until the particles at the cooler end are also set into vigorous vibration.

In metals, electrons at the heated end gain kinetic energy and move more rapidly.

They then collide atoms in the cooler parts of the metal and transfer their kinetic energy in the process.

This continues until the particles at the cooler end are also set into vigorous vibration.

Convection:
Convection is the transfer of thermal energy by means of convection currents in a fluid, due to a difference in density.

Convection only takes place in fluids (liquids and gases) and not solids.

1. When the water at the bottom of the flask is heated, it expands, becomes less dense than the surrounding water and rises.
2. The upper region of water is cooler, denser, and sinks to the bottom of the flask.
3. The process repeats and sets up a convection current due to the difference in the densities of water in the different regions until thermal equilibrium is reached.

Radiation:

Rate of heat transfer by radiation	*Surface temperature is **less than** the surrounding temperature*	*Surface temperature is **greater than** the surrounding temperature*
***High temperature difference** between the surface and the surroundings*	The object is a **good net absorber** of infrared radiation. There is a **high rate of heat transfer** by radiation from the **surroundings to the object.**	The object is a **good net emitter** of infrared radiation. There is a **high rate of heat transfer** by radiation from the **object to the surroundings.**
***Dark coloured / black** surface*		
***Dull / rough** surface*		
***Large** surface area*		
***Low temperature difference** between the surface and the surroundings*	The object is a **poor net absorber** of infrared radiation. There is a **low rate of heat transfer** by radiation from the **surroundings to the object.**	The object is a **poor net emitter** of infrared radiation. There is a **low rate of heat transfer** by radiation from the **object to the surroundings.**
***Light coloured / white** surface*		
***Polished / smooth / shiny** surface*		
***Small** surface area*		

Radiation is the transfer of thermal energy in the form of electromagnetic waves (e.g. infrared radiation) without the aid of a medium.

All bodies emit infrared radiation. Infrared radiation does not require a medium to be transmitted.

CRaB Framework:
1. Characteristic of item
2. Rate of transfer of thermal energy
3. Benefit/Purpose

9. Temperature

Thermometric Properties & Their Respective Thermometers:

Thermometric properties	Examples of thermometers
Volume of a fixed mass of liquid	Mercury-in-glass thermometer Alcohol-in-glass thermometer
Electromotive force (e.m.f.) between the junctions of two wires made of different metals	Thermocouple thermometer
Electrical resistance of a piece of metal	Resistance thermometer
Pressure of a fixed mass of gas at constant volume	Constant-volume gas thermometer

Formula for calculating unknown temperature in Liquid-in-glass Thermometer:

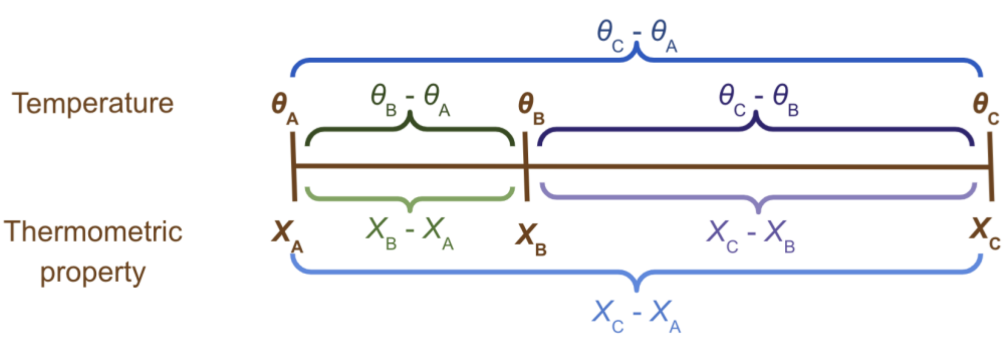
$$\theta = \frac{l_\theta - l_0}{l_{100} - l_0} \times 100$$

θ = temperature
ℓ_θ = length of the thread of the thermometer liquid at temperature θ
ℓ_0 = length of the thread of the thermometer liquid at 0°C
ℓ_{100} = length of the thread of the thermometer liquid at 100°C

Electrical resistance, <u>*R*</u>, of a piece of metal	Resistance thermometer	$\theta = \frac{R_\theta - R_0}{R_{100} - R_0} \times 100°C$

Change in Temperature & Thermometric Property:

Ratio of change of temperature = Ratio of change of thermometric property

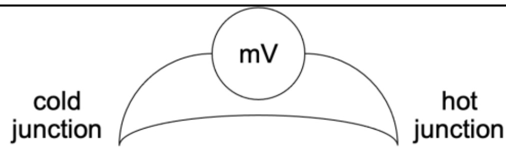


$$\frac{\theta_B - \theta_A}{\theta_C - \theta_A} = \frac{X_B - X_A}{X_C - X_A} \qquad \frac{\theta_C - \theta_B}{\theta_C - \theta_A} = \frac{X_C - X_B}{X_C - X_A}$$

Thermocouple Thermometer:

$\varepsilon \propto \Delta\theta$	$\varepsilon \propto (\theta_{hot} - \theta_{cold})$

ε = e.m.f. produced
$\Delta\theta$ = $\theta_{hot} - \theta_{cold}$ = temperature difference between the reference junction (cold junction) and the probe (hot junction)
θ_{hot} = temperature of the probe (hot junction)
θ_{cold} = temperature of the reference junction (cold junction)



melting ice (0°C) ←12.00 mV→ boiling water (100°C)

melting ice (0°C) ←4.20 mV→ liquid (θ = ?)

$\varepsilon \propto \Delta\theta$

Ratio of e.m.f. = Ratio of temperature difference

$$\frac{4.20}{12.00} = \frac{\theta - 0}{100 - 0}$$

$$\frac{4.20}{12.00} = \frac{\theta}{100}$$

$$\theta = \frac{4.20}{12.00} \times 100$$
$$= 35°C$$

Degrees Celsius to Kelvin:

[°C → Kelvin]	T / Kelvin = θ / °C + 273 Temperature in Kelvin = Temperature in degree Celsius + 273
[Kelvin → °C]	θ / °C = T / Kelvin – 273 Temperature in degree Celsius = Temperature in Kelvin – 273

10. Thermal Properties of Matter

Formulas:

Heat Capacity C [J K^{-1}]	$Q = C\Delta\theta$
Specific Heat Capacity c [J K^{-1} kg^{-1}]	$Q = mc\Delta\theta$
Specific latent heat of fusion L_f [J kg^{-1}]	$Q = mL_f$
Specific latent heat of vaporisation L_v [J kg^{-1}]	$Q = mL_v$

C: Heat capacity in J/K or J/°C
Q: Thermal energy absorbed or released by the object in J
Δθ: Change in temperature in K or °C
c: Specific heat capacity J/Kg K or J/Kg °C
m: kg
L: Specific Latent Heat in J/kg

Internal Energy:
The sum of molecular kinetic and potential energies of the particles of a substance.

Heat Capacity:
Heat capacity (C) is the amount of thermal energy required to increase the temperature of a substance by 1 K or 1°C.

Specific Heat Capacity:
The heat capacity of an object depends on its mass and material of the object.

The specific heat capacity (c) is the amount of thermal energy required toincrease the temperature of a unit mass of a substance by 1 K or 1°C.

Melting and Freezing:
When a solid is heated, its temperature rises until it starts to melt.

The temperature at which the solid changes its state from a solid to liquid is called the melting point.

During melting, the temperature of the object remains constant as the thermal energy supplied is used to overcome the intermolecular forces of attraction.

The energy that is absorbed during melting is called latent heat of fusion.

The same thermal energy is released in the reverse process called solidification or freezing.

The melting point of a substance is also its freezing point.

Boiling and Condensation:
When a liquid is heated, its temperature rises until it starts to boil.

The temperature at which the liquid changes its state from a liquid to gas is called the boiling point.

During boiling, the temperature of the object remains constant as the thermal energy supplied is used to

1. overcome the intermolecular forces of attraction, and
2. do work against the surrounding atmosphere – this is due to the large increase in volume when a liquid turns into a gas.

The energy that is absorbed during boiling is called latent heat of vaporisation.

The same thermal energy is released in the reverse process called condensation.

The boiling point of a substance is also its condensation point.

Boiling VS Evaporation:

Boiling	Evaporation
Occurs only at boiling point.	Occurs at any temperature.
Relatively fast.	Relatively slow.
Takes place throughout the liquid.	Takes place only at the surface.
Temperature remains constant.	Temperature usually decreases.
Bubbles formed in the liquid.	No bubbles formed in the liquid.
External thermal energy source needed.	External thermal energy source not needed.

Latent Heat:
Latent heat (L) is the amount of energy absorbed or released by a substance during a change in state , without a change in temperature.

Latent heat of fusion (Lf) is the amount of thermal energy required to change a substance from solid state to liquid state, without a change in temperature. This applies to melting and freezing/solidification.

Latent heat of vaporisation (Lv) is the amount of thermal energy required to change a substance from liquid state to gaseous state, without a change in temperature. This applies to boiling and condensation.

Specific Latent Heat:
As latent heat depends on the mass and material of a substance, it is fairer to compare the latent heat per 1kg of different substances. This is formally known as the specific latent heat (of fusion or vaporisation).

Evaporation:

1. Particles in a liquid are always moving randomly at different velocities.
2. The more energetic liquid particles at the surface overcomes the attractive forces of the other liquid particles and atmospheric pressure and escapes into the surrounding atmosphere.
3. The particles with lower kinetic energies are left behind. This causes the average kinetic energy of the liquid particles to decrease and the average temperature to decrease as well.

Factors affecting the rate of evaporation:

✓ temperature of the evaporating liquid ✓ surface area of the evaporating liquid ✓ movement of surrounding air	✓ atmospheric pressure ✓ humidity of surrounding air ✓ boiling point of the evaporating liquid

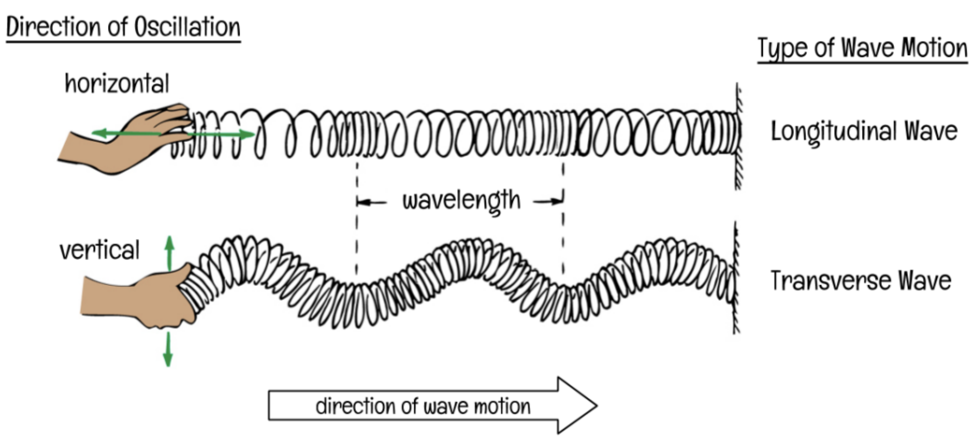
11. General Wave Properties

Formulas:

Wave equation	$v = f\lambda$
Period [s]	$T = \frac{1}{f}$

v = wave speed (in m/s)
f = frequency (in Hz)
λ = wavelength (in m)

Type of Waves:



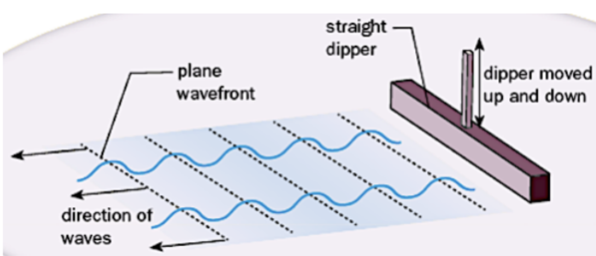
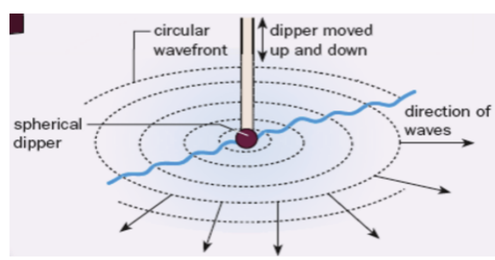
Transverse Waves	Longitudinal Waves
1. Rope Waves 2. Water Waves 3. Electromagnetic Waves 4. Earthquake S Waves 5. Rayleigh Waves 6. Love Waves	1. Sound Waves 2. Earthquake P Waves

Definitions:

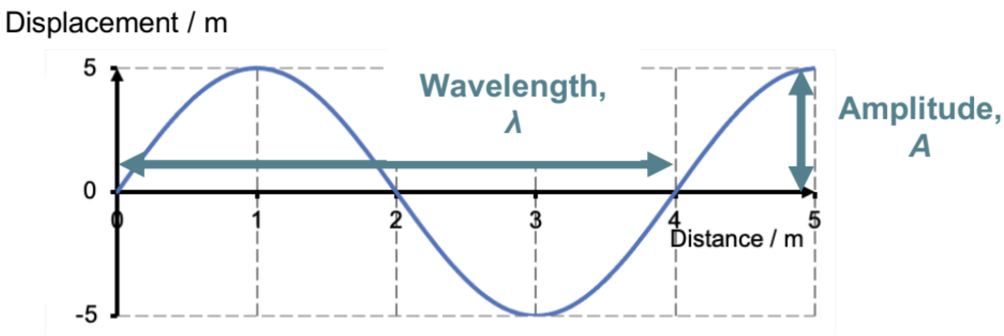
Wave terms	Description
Crests	The **highest** points on a **transverse** wave. • A particle at a crest is momentarily at rest.
Troughs	The **lowest** points of a transverse wave. • A particle at a trough is momentarily at rest.
Compressions and rarefactions	(Centres of compression, centres of rarefaction: terms used for **longitudinal** waves).
Amplitude	The **maximum** displacement of a point (or wave particle) from its **rest** position.
Wavelength	The **shortest** distance between any 2 points (or wave particles) that are **in phase**.
Phase	Points along a wave **in phase** if they have the **same** • **displacement** from their rest positions • **direction of travel** and • **speed**. E.g. Particles A, E and J are in phase with one another (λ, 2 λ, 3 λ … apart at a given time), whereas particles C and E are in **anti-phase**, (½ λ, 1½ λ, 2½ λ … apart at a given time).
Period	The **time** taken to produce one **complete** wave. SI unit: second (s)
Frequency	The number of **complete** waves produced **per unit time**. • It is also the number of crests or troughs that move past a certain point waves per unit time. • The frequency is equal to the **reciprocal** of the period. $f = \frac{1}{T}$ SI unit: **Hertz (Hz), 1 Hz = 1 cycle per second**

Wavefront:

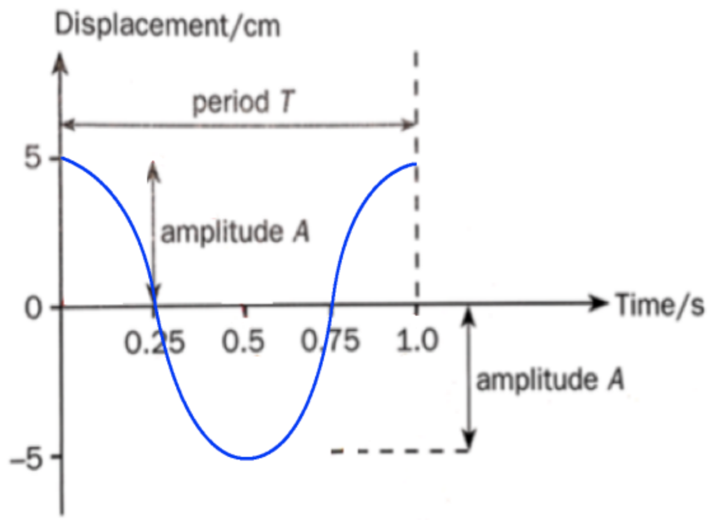
Imaginary line on a wave that joins all adjacent points that are in phase.

	
Plane Waves The wavefronts of plane waves are straight lines.	Circular Waves Circular waves have circular wavefronts.

Displacement-distance Graph:

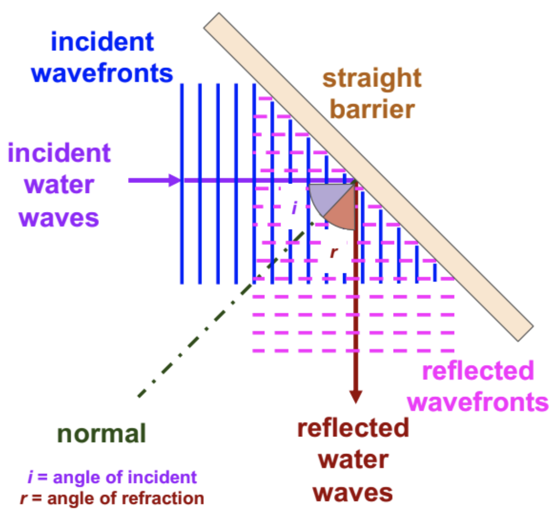


Displacement-time Graph:

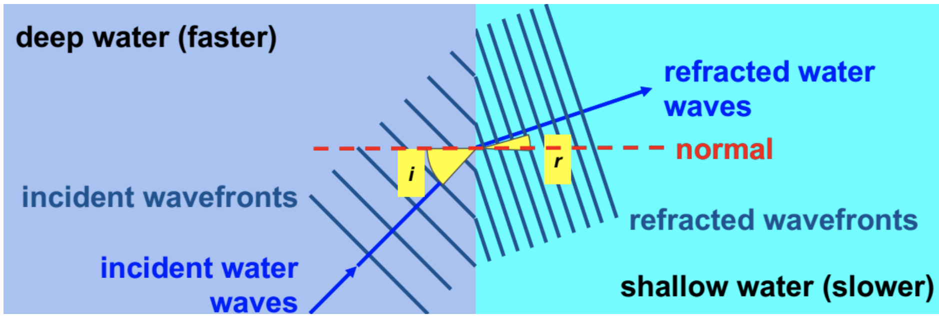


Reflection of Waves:

Angle of incidence = Angle of reflection



Refraction of Waves:



As the water wave crosses the interface from the deep region to the shallow region, the speed, v, decreases.

Water waves travel at a higher speed in deep water than in shallow water.

The frequency, f, remains unchanged since the wave is produced at its source.

The wavelength, $\lambda = v / f$, decreases.

The wavefronts are more closely spaced.

The wave bends towards the normal.

The angle of refraction, r, is smaller than the angle of incidence, i.

The wavefronts are connected at the interface (boundary).

12. Light

Formulas:

$$\text{refractive index} = \frac{\text{speed of light in a vacuum}}{\text{speed of light in the medium}}$$

$$n = \frac{c}{v}$$

n = refractive index of the medium (**no unit**)
c = **3.0×10^8 m/s** = speed of light in a vacuum (unit: m/s), and
v = speed of light in the vacuum (unit: m/s)

$$n_i \sin i = n_r \sin r$$

n_i = refractive index of the medium that the **incident ray** travels in
n_r = refractive index of the medium that the **refracted ray** travels in

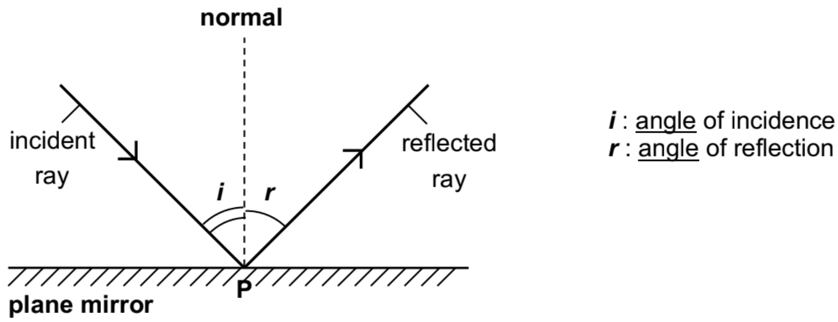
$$\text{refractive index, } n = \frac{\text{real depth}}{\text{apparent depth}}$$

In a **vacuum**,

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

n = refractive index of medium
c = critical angle

Angle of Incidence and Angle of Reflection:



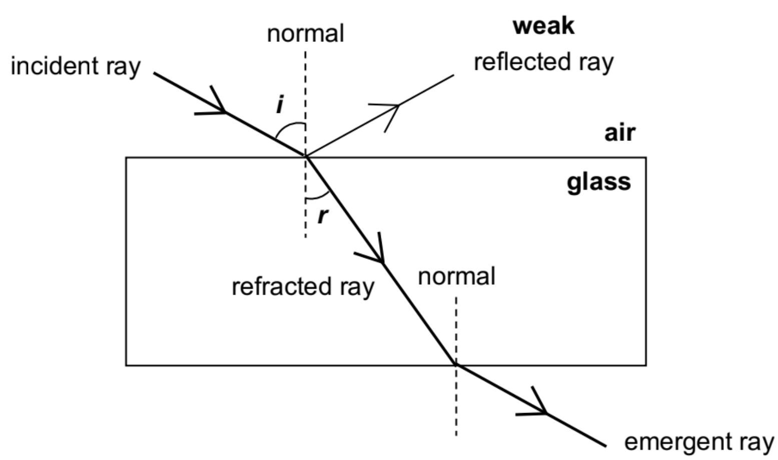
- The incident ray is the light ray coming towards the surface.
- The reflected ray is the light ray reflecting off the surface.
- The **normal** is an imaginary straight line that is perpendicular (90°) to the surface of the mirror.

- The **point of incidence P** is the point where the incident ray, reflected ray and the normal meet.

- The **angle of incidence** (***i***) is the angle between the incident ray and the normal.
- The **angle of reflection** (***r***) is the angle between the reflected ray and the normal.

Angle of incidence = Angle of reflection

Angle of Incidence and Angle of Refraction:
Refraction is the bending of light as light passes from one optical medium to another.

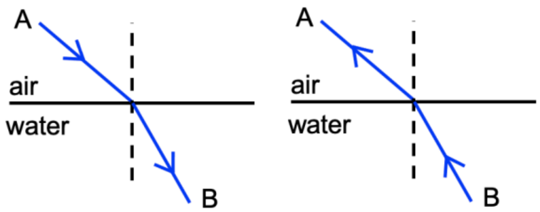


- **Normal** is an imaginary straight line that is perpendicular (90°) to the surface of the medium.
- **Angle of incidence** (***i***) is the **angle** between the **incident ray** and the **normal**.
- **Angle of refraction** (***r***) is the **angle** between the **refracted ray** and the **normal**.

- The **incident ray**, the **refracted ray** and the **normal at the point of incidence** all lies in the **same plane**.

Speed at which light travels:
Light travels at a speed of 3.0×10^8 m/s in a vacuum.

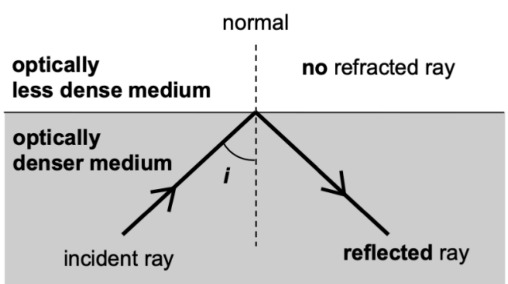
Principle of Reversibility of Light:



- The principle of reversibility of light states that the path of a light ray is reversible.
- If a ray of light travels from A to B along a certain path, it will follow the same path when travelling from B to A.

Refractive Index:
Ratio of speed of light in vacuum to the speed of light in medium.

Critical Angle:
The angle of incidence in an optically denser medium for which the angle of refraction is perpendicular to the plane.



- The **critical angle** is defined as the **angle of incidence** in the **optically dense medium** for which the **angle of refraction** in the **optically less dense medium** is **90°.**

Total Internal Reflection:
The complete reflection of a light ray inside an optically denser medium at its boundary with an optically less dense medium.

Both these conditions must be satisfied for **total internal reflection (TIR)** to occur:

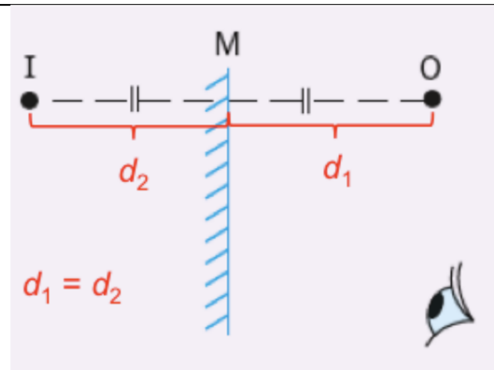
1. The incident ray must travel from an optically denser medium to an optically less dense medium.
2. The **angle of incidence** must be **greater** than **critical angle**, i.e. $i > c$.

Characteristics of an Image formed by a Plane Mirror:

1. It is laterally inverted.
2. It is the same shape and same size as the object.
3. It is upright.
4. It is virtual.
5. Its image distance from the mirror is the same as the object distance from the mirror.

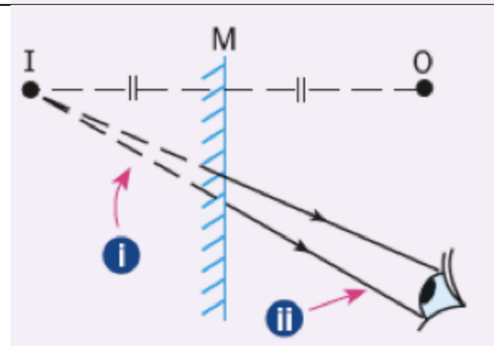
How to Draw Light Path Reflecting from a Mirror:

<table>
<tr>
<td>
Step 1
Draw a dotted line from object O that is perpendicular to the mirror.

Step 2
Label image I, such that
object distance = image distance.
</td>
<td>


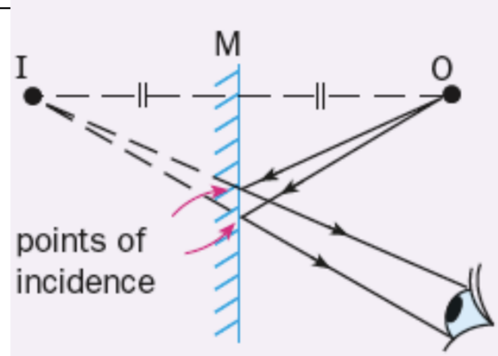
</td>
</tr>
<tr>
<td>
The virtual ray and the reflected ray lie along the same straight line.

Step 3(i)
Using a dotted line, draw the virtual ray from image I to the point of incidence

Step 3(ii)
Using a solid line with an arrowhead, draw the reflected ray from the point of incidence to the eye.
</td>
<td>


</td>
</tr>
<tr>
<td>
Step 4
Using a solid line with an arrowhead, draw the incident ray from object O to the point of incidence.

You may verify that
angle of incidence = angle of reflection
$i = r$

To the brain, the rays reflecting off the points of incidence seem to be coming from image I.
</td>
<td>


</td>
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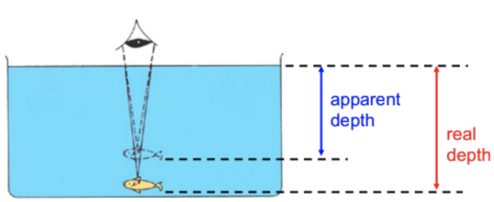
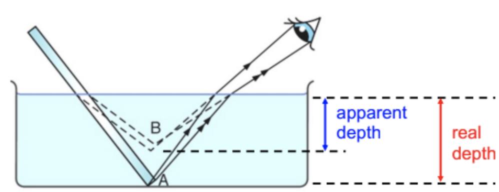
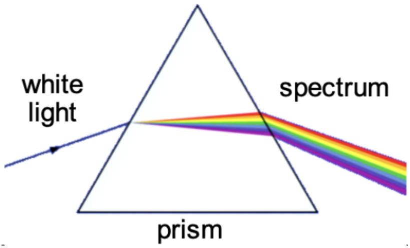
</table>

Real Depth vs Apparent Depth:





Chromatic Dispersion:

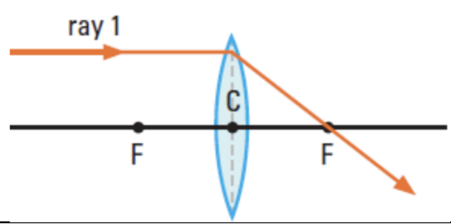
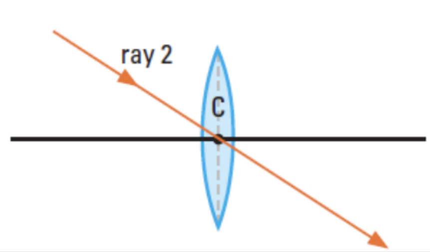
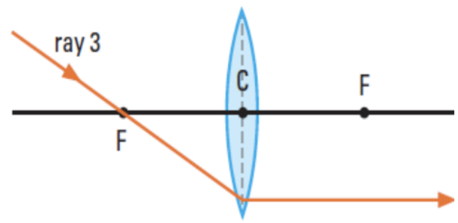


colour	violet	indigo	blue	green	yellow	orange	red
speed in glass	slowest						fastest
refractive index of glass	greatest						smallest
deflection	most						least

Definition for Terms in Lenses:

Term	Description
optical centre, C	▪ It is the **midpoint** between the lens surfaces for a symmetrical biconcave lens. ▪ It lies on the **principal axis**. ▪ Light ray passes through the optical centre of a converging lens will **not** be deflected.
principal axis	▪ It is an imaginary line that passes through the optical centre of the lens and is perpendicular to the vertical plane of the lens.
focal length, *f*	▪ It is the distance between the centre of the lens and the focal point (principal focus).
principal focus or focal point, F	▪ A point on the principal axis where **all** light rays **parallel** to the principal axis pass through after refracting through the lens. ▪ It is also known as the focal point. ▪ For a symmetrical biconvex lens, there will be two principal foci, one at each side of the lens.
focal plane	▪ A plane that passes through F and P where light rays will be focussed on the screen to produce an image. ▪ The focal plane is perpendicular to the principal axis.
object distance	▪ The distance between the object and the optical centre.
image distance	▪ The distance between the image and the optical centre.

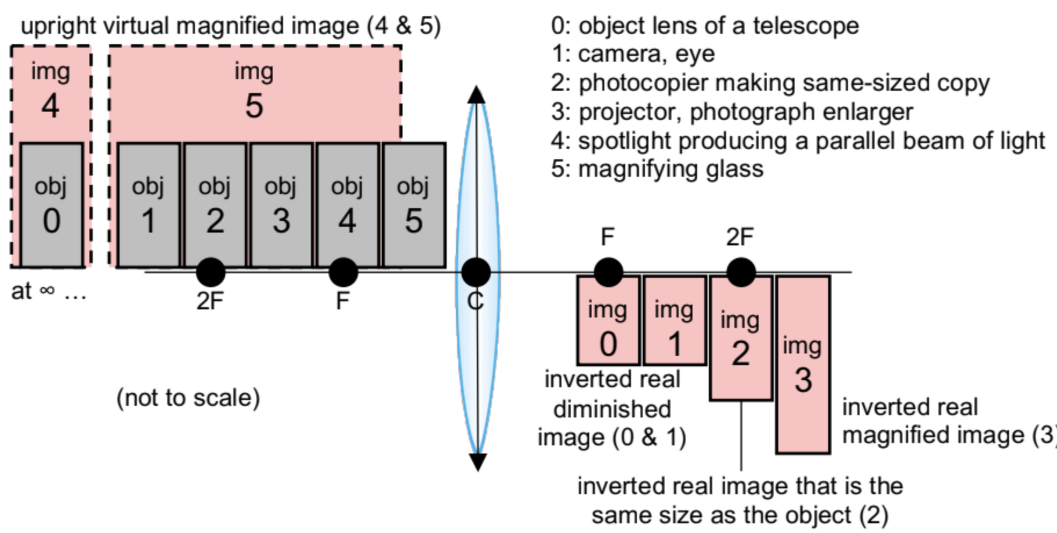
Drawing of Ray Diagrams:

Ray 1 Any incident ray traveling **parallel to the principal axis** of a converging lens will refract through the lens and pass through the **focal point** on the opposite side of the lens.	
Ray 2 An incident ray which passes through the **centre of the lens** (i.e. **optical centre**) will **continue in the same direction** as it did before it entered the lens. This is because near the centre, the 2 surfaces are almost parallel on both sides of the lens. As the lens is thin, the ray appears straight.	
Ray 3 Any incident ray traveling through the **focal point** on the way to the lens will refract through the lens and travel **parallel to the principal axis**	

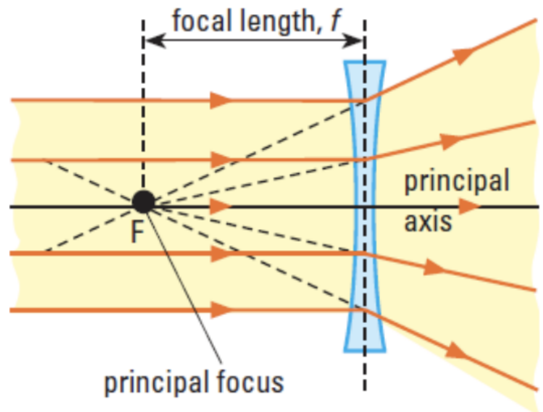
Terms Used to Describe the Images Formed by a Converging Lens

Type	Orientation	Size
▪ real ▪ virtual	▪ inverted ▪ upright	▪ diminished ▪ same size ▪ enlarged/ magnified

Summary: Thin converging lens



Diverging Lens:



Rule 1 Any incident ray traveling **parallel to the principal axis** of a diverging lens will refract through the lens and **travel in line with the focal point** (i.e. in a direction such that its extension will pass through the focal point).

Rule 2 Any incident ray traveling **towards the focal point** on the way to the lens will refract through the lens and travel **parallel to the principal axis**.

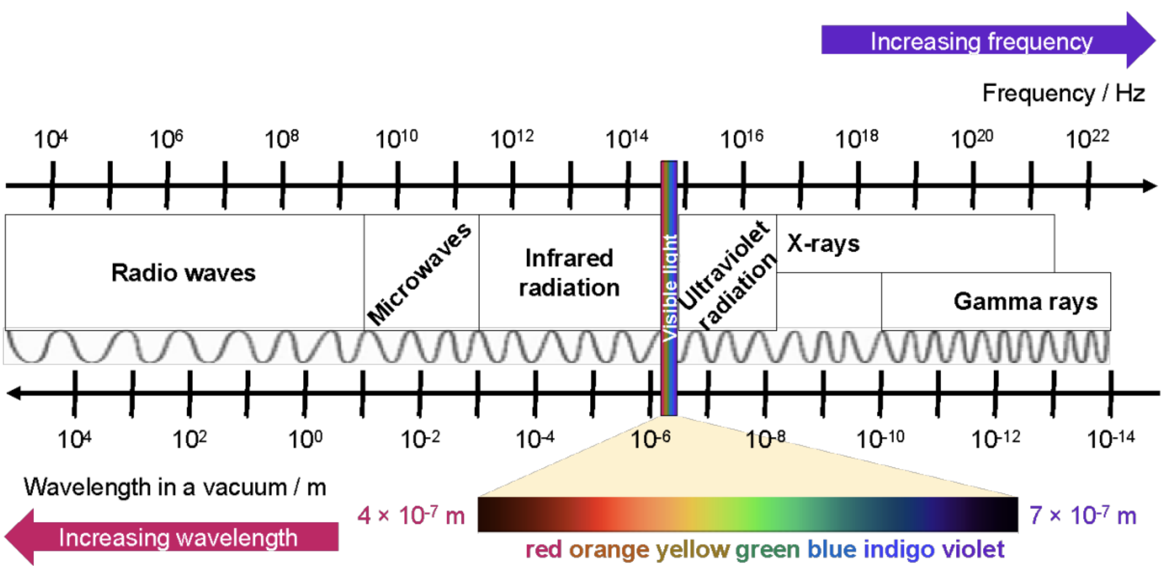
Rule 3 An incident ray which passes through the **center of the lens** will in **continue in the same direction** as it did when it entered the lens.

13. Electromagnetic Spectrum

Properties of Electromagnetic Waves:

1. They are transverse waves. They made up of electric and magnetic fields that oscillate perpendicular to each other.
2. They carry no electric charge, i.e. they are neither positively nor negatively charged.
3. They transfer energy from one place to another.
4. They do not require a medium to travel.
5. They travel at the speed of light in vacuum (3.0×10^8 m/s), but they slow down while travelling through other mediums like water or glass.
6. They obey the wave equation, $v = f \lambda$.
7. They obey the laws of reflection and refraction.
8. Their frequencies remain unchanged when they travel from one medium to another. Wave frequency depends only upon the source of the wave, while wave speed and wavelength changes when the wave enters a different medium.
9. The higher the frequency of an electromagnetic wave, the more energetic it is.

Electromagnetic Spectrum:



Increasing wavelength						Increasing frequency
Raging	**Martians**	**invaded**	**Venus**	**using**	**X-ray**	**guns**
Radio waves	Microwaves	Infrared radiation	Visible light	Ultraviolet radiation	X-rays	Gamma rays

Increasing wavelength			**ROY G. BIV**			Increasing frequency
Read	**out**	**your**	**good**	**book**	**in**	**verse**
Red	Orange	Yellow	Green	Blue	Indigo	Violet

Application of Electromagnetic Waves:

Component	**Uses**
Radio waves	Radio and television communication • Radio waves can go around obstructions better than microwaves due to their longer wavelengths Navigation systems Radar, to find the direction and distance of objects Wireless telegraphy
Microwaves	Can penetrate haze light rain, clouds and snow Satellite television Microwave oven • Causes water molecules in the food to vibrate more vigorously • Only the food gets cooked as microwaves interact less with the particles in glass, plastic and paper
Infrared (IR) radiation	Used in household electrical appliances such as Television remote controllers Ear thermometers Intruder alarms that can work in darkness (no visible light) • CCD camera
Visible light	Almost everything we need to do in daily life, e.g. reading • Detectable by the human eye Optical fibres in telecommunications • Digital signals are sent through using short pulses of light Medical uses, e.g. endoscope Light in the form of *laser light* can be used in • Eye surgery, cauterising or sealing blood vessels • Cutting through hard materials like steel
Ultraviolet (UV) radiation	Fluorescent tubes Sterilisation of medical equipment • Killing bacteria and viruses with germicidal lamps Forgery detection in banknotes • Fluorescent effect: anti-forgery marks on banknotes can be seen under UV Artificial tanning, e.g. sunbeds Stimulation of our bodies to produce vitamin D • However, prolonged exposure can lead to sunburn and cancer • Ozone in the upper atmosphere absorb a substantial amount of ultraviolet radiation from the Sun

X-rays	⚫ Can penetrate most materials, but not lead 💥 Produced when high-energy electrons lose their energy after striking a metal target 🏥 Radiation therapy (like gamma rays) 💼 Screening of luggage at checkpoints 💀 X-ray images to diagnose bone fractures and tooth decay ⚓ Detecting flaws in heavy metal equipment • X-ray of anchors for micro-cracks in metal parts 🎨 Detecting art forgery using X-ray photographs 💎 Analysis of crystal structure
Gamma rays (γ)	⚛️ Emitted as a result of the decay of radioactive nuclei ☢️ Released during nuclear reactions 🤒 Diagnosis of illness using I-131 as a tracer. 🏥 Radiation therapy (like X-rays) • Can penetrate deeply and kill cells as they have the highest energy • Gamma rays from a cobalt-60 source are used as surgical tools. While each individual beam is not strong enough to normal living tissue, when the many rays are focused on the tumour, the total energy kills the cancerous cells.

Ionising Radiation:

1. Ionising radiation is radiation that has the energy to ionize atoms or molecules (including those in living matter) by removing electrons from them.
2. High energy electromagnetic waves like ultraviolet radiation, X-rays and gamma rays can ionize atoms and molecules.
3. Exposure to ionising radiation can damage biological molecules (e.g. proteins, nucleic acids). This can lead to:
    a. abnormal cell division
    b. deformities in a developing foetus
    c. cancers, e.g. leukaemia
    d. premature ageing
    e. shortening of lifespan.

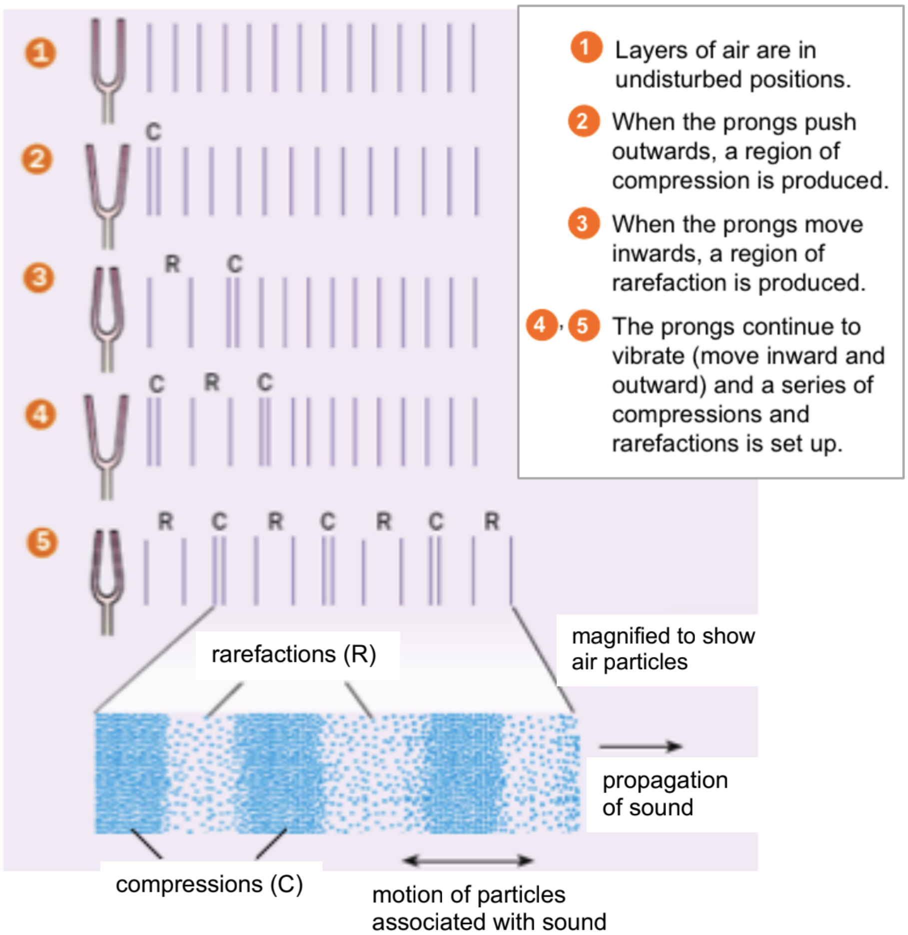
Infrared Heating:

Factors that affect the rate of heat transfer by radiation	**Good net emitter / absorber of infrared radiation** • High rate of heat transfer between object and surroundings by radiation	**Poor net emitter / absorber of infrared radiation** • Low rate of heat transfer between object and surroundings by radiation
Surface colour	black / dark coloured	white / silver / light-coloured
Surface texture	dull / rough	polished / shiny / smooth
Surface area	large	small
Temperature difference between surface of object and surroundings	large temperature difference	small temperature difference

14. Sound

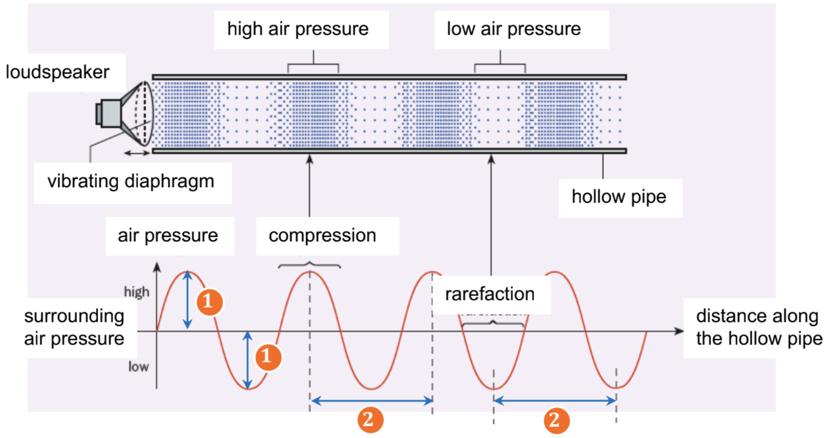
Production of sound by vibrating sources:

Prongs:



The vibrating bell causes layers of air particles around it to be displaced. This causes a series of alternate compressions and rarefactions that travel outwards through air and reach the ear of the person.

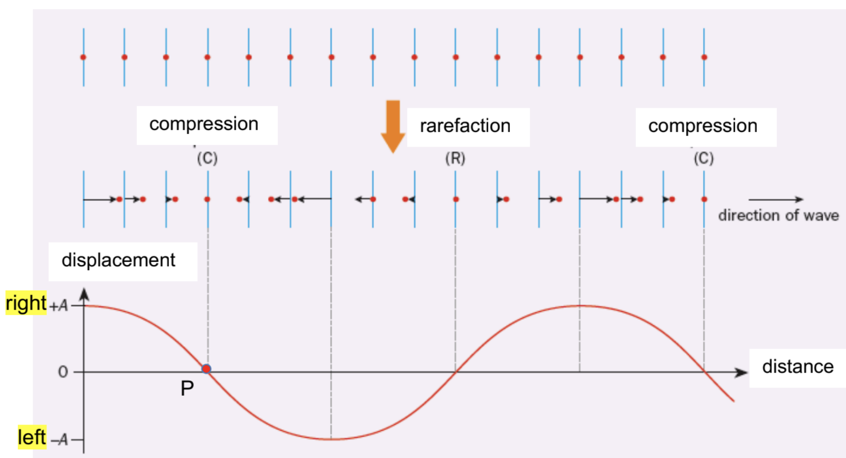
Pressure-distance Graph:



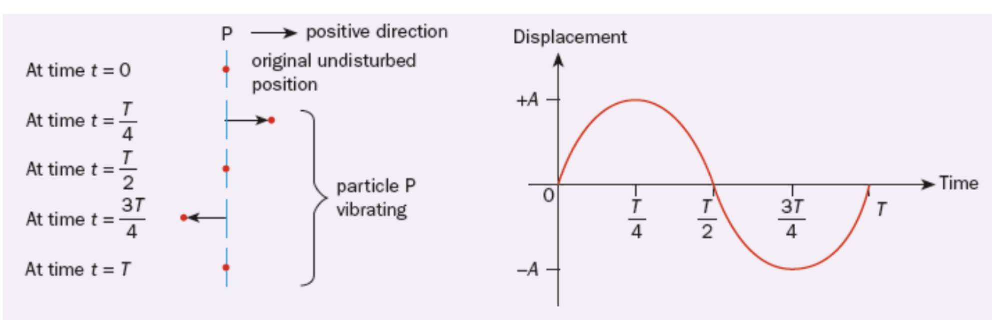
1 The **amplitude *A*** of a sound wave is the **maximum** pressure change.

2 The **wavelength *λ*** of the sound wave is the **distance** between the centres of two consecutive compressions or rarefactions.

Displacement-distance Graph:



Displacement-time Graph:



Speed of Sound in Different Mediums:

Medium	Air	Water	Glass	Iron	Aluminium
Approximate speed of sound / m/s	300	1500	4540	5000	6320

Briefly describe the differences.

- It travels at different speeds in different media.
- Speed of sound in solid …>… Speed of sound in liquid …>… Speed of sound in gas

In denser mediums, the particles are much closer together, and they can quickly transfer kinetic energy from one particle to the next.

When temperature increases, the speed of sound increases. At a higher temperature, particles have more kinetic energy and vibrate faster. Thus, sound waves can travel faster.

Increasing humidity increases the moisture (concentration of water vapour) in the air and the density of the medium. Thus, sound waves can travel faster.

How to calculate speed of sound:
Total distance/Total time required to hear echo

Pitch

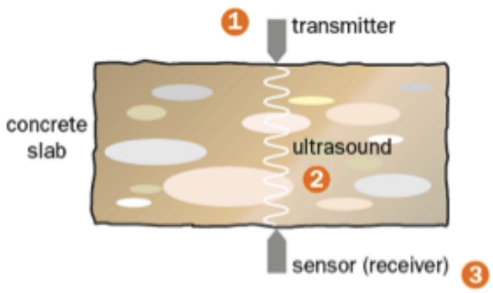
The pitch of a note depends on its frequency.
The higher the frequency, the higher the pitch of the sound.

Loudness

The loudness of sound depends on its amplitude.
The greater the amplitude, the louder is the sound.

Ultrasound:
Ultrasound and infrasound are sounds with frequencies higher than the upper limit and below the lower limit of the human range of audibility respectively. Ultrasound waves are sound waves with frequencies greater than 20 kHz. They are inaudible to humans.

Uses of Ultrasound:
Quality Control



1. Transmitter emits ultrasound
2. Ultrasound passes through the concrete and is received by a sensor.
3. The presence and location of defects are identified by **comparing** the ultrasound emitted with the ultrasound received.

Prenatal Scanning
When the source vibrates, body tissues are pushed and pulled repetitively to form regions of compression and rarefaction (longitudinal wave).

When the sound wave is incident on the denser body tissues, it is reflected through the body tissues and detected by the receiver.

The time taken for the ultrasound waves to be reflected is used to determine the depth of the reflecting surface within the body.

Why X-rays>Ultrasound:
X-rays during pregnancy don't increase the risk of miscarriage or cause problems in the foetus, such as birth defects and physical or mental development problems. However, repeated exposure to the high energy radiation can damage the body's cells, which can increase the risk of cancer developing in the foetus.

15. Static Electricity

Charge:

The SI unit of electric charge is the coulomb (C).

The amount of charge carried by an electron is 1.6×10^{-19} C.

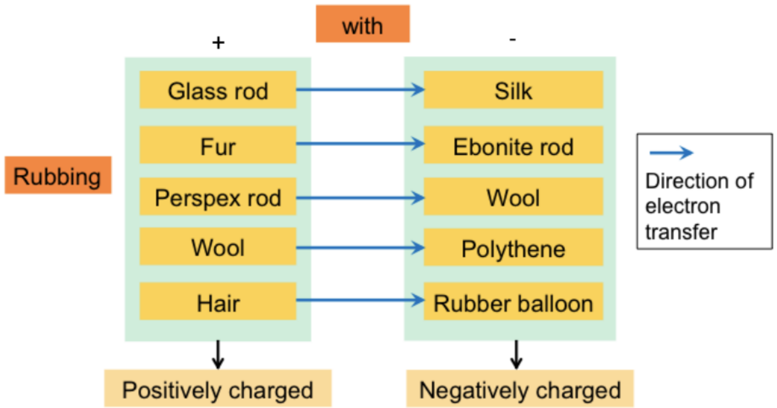
Electrical Insulators and Conductors:

	electrical insulators	**electrical conductors**
motion of charged particles	charged particles (electrons) are **not** free to move about	charged particles (electrons) are free to move about
ability to conduct electricity	low	high
method of charging	by friction (e.g. rubbing)	by induction
examples	glass, perspex, silk wool	copper, steel, fluids with mobile charged particles

Electric Field:

1. An electric field is a region in which an electric charge experiences an electric force.
2. An electric force is the attractive or repulsive force that electric charges exert on one another.
3. The direction of an electric field is represented by the direction of the electric force that would act on a small positive test charge.
4. Lines always go from positive to negative

Charging by Friction:



Before rubbing, the glass rod and the piece of silk are electrically neutral.

As different materials have different affinities (extent of attraction) for electrons, when the glass rod and the piece of silk are rubbed together, the atoms at their surfaces are disturbed and some electrons from the atoms at the surface of the glass rod are transferred to the piece of silk.

As the glass rod loses electrons, it becomes positively charged.

As the piece of silk gains electrons, it becomes negatively charged.

Charging by Induction:
Method 1: Charging two metal (conducting) spheres by induction

1. Two metal spheres (conductors), A & B, on insulating stands are placed side by side, touching each other.
2. A negatively-charged rod is brought near, but not touching, sphere A.
3. Electrons in both spheres A and B are repelled to the far end of sphere B.
4. Sphere A has excess positive charges, while sphere B has excess negative charges.
5. While holding the negatively charged rod in place (near sphere A), move sphere B away from sphere A.
6. The charged rod is removed making sphere A positively charged and sphere B negatively charged.

Note: If charged rod is removed before the 2 spheres move apart, electrons will be redistributed and sphere A & B will be neutral again.

Method 2: Charging a single conductor by induction

1. A positively-charged rod is brought near, but not touching, a metal conductor on insulating stand.
2. The electrons in the conductor are attracted towards the end near the positively-charged rod.
3. Without removing the positively-charged rod, the positively-charged end of the conductor is neutralised by touching it with a person's hand.
4. Free electrons move from earth to the conductor through the person, neutralising the positive charges on that end of the conductor.
5. With the positively-charged rod still in place, the person's hand is removed, stopping the earthing process
6. The positively-charged rod is removed, and the electrons in the conductor redistribute throughout the conductor.

Note: If the charged rod is removed before the earthing process is stopped, then excess electrons will flow to the earth and discharging occurs. The rod will then become electrically neutral.

Neutralising/ Discharging a Charged Insulator:
Method 1: Discharging through heating

1. The heat from the flame ionises the surrounding air particles.
2. For a positively-charged glass rod, the ions neutralise the excess charges on the glass rod.

Method 2: Discharging through humid conditions

1. Water molecules in air are electrical conductors.
2. For a negatively charged insulator, excess charges are transferred to the water molecule.

Neutralising/ Discharging a Charged Conductor:

1. A charged conductor can be discharged by earthing.
2. When we earth a charged conductor, we provide a path (usually lower resistance and connected to the earth) for:
    a. excess electrons to flow away from the charged conductor, or
    b. electrons to flow to the charged conductor if it has excess positive charges.

Hazards of Electrostatics:

1. **Lightning**
    a. The clouds are charged by friction between water molecules in the clouds and air molecules in the atmosphere.
    b. Negative charges accumulate at the bottom of the clouds.
    c. These repel the electrons near the surface of the Earth, causing the surface of the Earth to be positively charged.
    d. When the accumulation of charges is large, the air particles nearby are ionised.
    e. The ionised air particles provide a conducting path for the electrons in the clouds to reach the Earth.
    f. When the electrons travel down the conducting path to the Earth, lightning forms.
2. **Electrostatic Discharge**
    a. Excessive charges may build up on objects due to friction.
    b. Electronic equipment, such as computer boards and hard drives, can be easily damaged by electrostatic discharge.
    c. Such equipment is usually packed in antistatic packaging.
3. **Electrostatic Discharge of Vehicles**
    a. Electric charges can accumulate on trucks due to friction between
        1. The road and the rotating tyres of the truck.
        2. The moving air molecules and the body of the truck
    b. When a sudden discharge occurs, this may cause sparks and ignite any flammable items that the truck may be carrying.
    c. Gas tankers are equipped with a metal chain at the rear end hanging touching/ near to the ground to provide an earthing path for excess charges.
    d. During refueling, the gas tankers are also connected to an earth source to prevent static charges from accumulating on the body of the gas or fuel tanker.

Applications of Electrostatics:

1. **Photocopiers**
    a. The metal drum inside the photocopier is coated with selenium, a light sensitive semiconductor (photoconductor).
    b. It only conducts electricity in the presence of light.
    c. When no light shines on the selenium, it is a good insulator.
    d. The drum's surface is charged positively by a charged wire.
    e. The original image to be photocopied is placed on a sheet of clear glass above the drum and an intense light beam is shone onto the image.
    f. The darker areas of the image reflect less light and therefore, the corresponding regions on the drum remain positively charged.
    g. The regions on the drum corresponding to the lighter areas of become conductive.
    h. Electrons from the surroundings, which are attracted to these regions, discharge them.
    i. The drum continues turning, and the positively-charged image on the drum attracts the negatively-charged toner powder.
    j. A positively-charged sheet of paper is passed over the drum's surface.
    k. The paper attracts the negatively-charged toner and the image is formed on the paper.
    l. The paper is heated and pressed to fuse the toner powder to the paper permanently.

Note: Water molecules are present in abundance in humid air, and they can neutralise excess charges quickly. Printing quality may be reduced.

2. **Electrostatic Precipitator**
    a. The fly ash is passed through a negatively charged wire grid making the particles to become negatively charged.
    b. The negatively charged particles are passed through positively charged or earthed plates which attract the negatively charged particles.
    c. Hence, air emitted into the atmosphere is cleaner.
    d. The fly ash are collected and used in making cement.

3. **Spray Painting**
    a. As the paint leaves the nozzle, the droplets are charged by friction.
    b. These made all the paint droplets to have the same charge and repel each other.
    c. Hence, they spread evenly. Less paint is needed because the charged droplets are all attracted to the object.

16. Current of Electricity

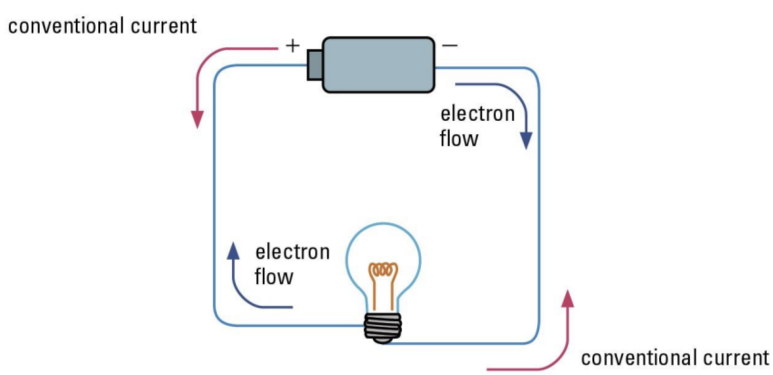
Formulas:

Current [A or Cs^{-1}]	$I = \frac{Q}{t}$
emf [V or JC^{-1}]	$emf = \frac{W}{Q}$
p.d [V or JC^{-1}]	$p.d = \frac{W}{Q}$
Resistance [Ω]	$R = \frac{V}{I}$
Resistivity [Ωm]	$R = \frac{\rho L}{A}$

Definitions:

1. Electric current: It is the rate of flow of electric charge.
2. EMF: The work done by the electrical energy source in driving a unit charge around a complete circuit.
3. P.D: The work done to drive a unit charge through the electrical component.
4. Resistance: The ratio of the potential difference across it to the current flowing through it.

Conventional Current vs Electron Flow:



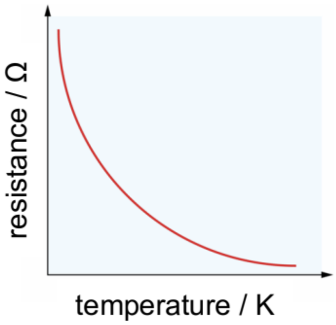
Factors affecting resistance:

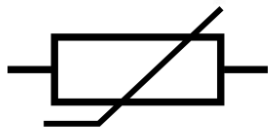
Factors	Relationship
Length (***L***)	• Resistance is ***directly proportional*** to length.
Cross-sectional area (***A***) or **thickness**	• Resistance is ***inversely proportional*** to cross-sectional area.
Type of material (resistivity *ρ*)	• Different types of materials have different resistivity. • Resistivity is a **physical property** of a material. Each material has its **constant value**. • S.I. Unit: ohm metre [Ωm] • The **lower** the resistivity of a material, the **better it conducts electricity**.
Temperature	• For **most metallic conductors**, the higher the temperature, the larger is its resistance. • For **carbon** and **semiconductors** (silicon, germanium), the higher the temperature, the lower is its resistance.

Ohm's Law:

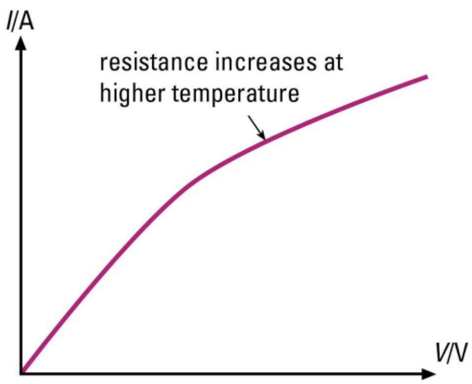
Ohm's Law states that the current passing through a metallic conductor is directly proportional to the potential difference across it, provided the temperature and other physical conditions remain constant.

Thermistor, Semiconductor diode & Filament Lamp:
A thermistor is a type of resistor whereby its resistance decreases as the temperature of the thermistor increases. Used in air conditioners and fire alarm.

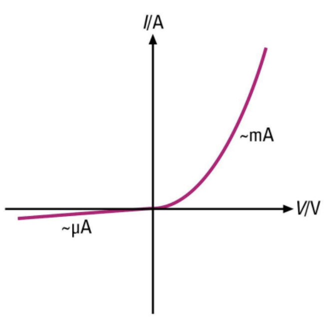


As the current increases, the temperature rises and the resistance of the filament lamp increases.



A semiconductor diode allows current to flow in one direction.




17. DC Circuits

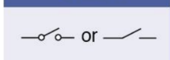
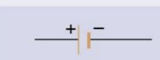
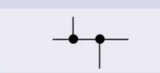
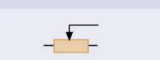
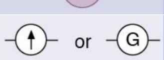
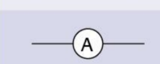
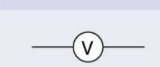
Formulas:

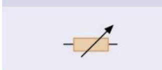
Series circuit	$I_T = I_1 = I_2$ $V_T = V_1 + V_2$ $R_T = R_1 + R_2$
Parallel circuit	$I_T = I_1 + I_2$ $V_T = V_1 = V_2$ $\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2}$

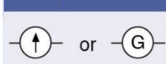
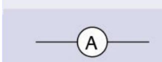
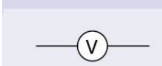
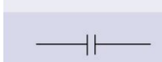
$$V_{out} = \frac{R_2}{R_1 + R_2} \times V_E$$

$$\frac{1}{R_{effective}} = \frac{1}{R_1} + \frac{1}{R_2} + \ldots + \frac{1}{R_n}$$

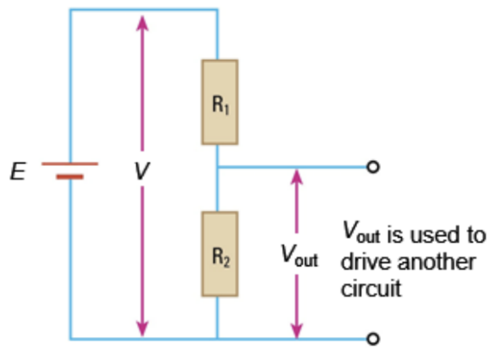
Circuit Diagram Stuff:

Symbol	Device
	switch
	cell
	battery
	power supply
	wires joined
	wires crossed
	potentiometer
	light dependent resistor
	galvanometer
	ammeter
	voltmeter
	2-way switch

Symbol	Device
	lamp
	fixed resistor
	variable resistor (or rheostat)

Symbol	Device
	galvanometer
	ammeter
	voltmeter
	2-way switch
	earth connector
	capacitor
	thermistor
	light emitting diode

Potential Divider:
A line of resistors connected in series. Used to provide a fraction of the voltage of a source to another part of the circuit.



Input Transducers:

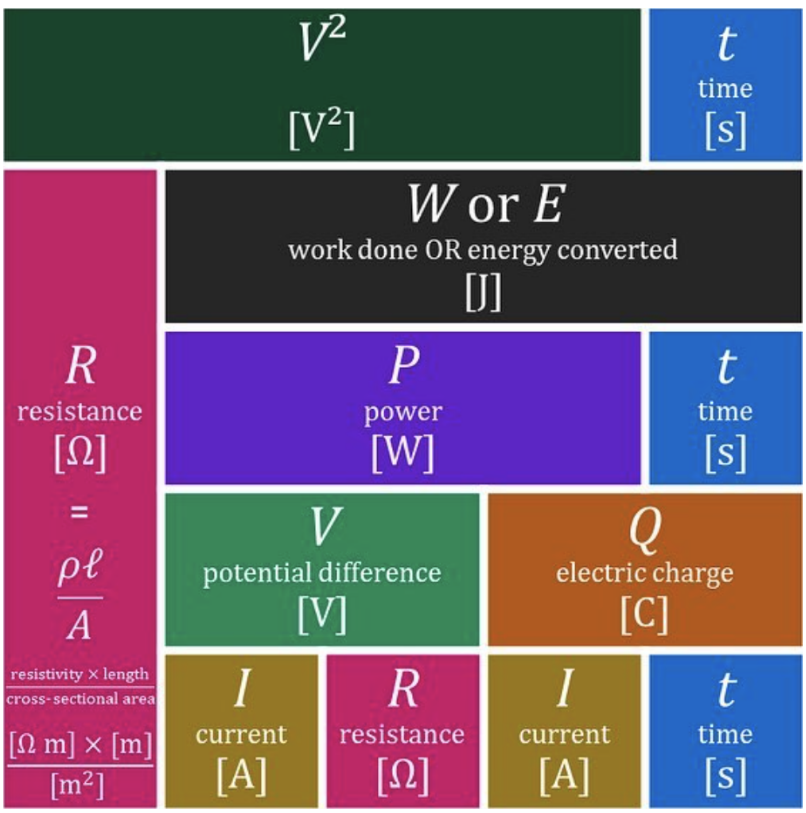
1. Thermistor
   a. When the temperature increases, the resistance of the thermistor decreases.
2. Light-Dependent Resistors
   a. When the light intensity increases, the resistance of the LDR decreases.

18. Practical Electricity

Formulas:

Electrical Power [W]	$P = VI = I^2R = \frac{V^2}{R}$

Power [W] = Work Done [J] / Time
Power [W] = Energy Converted [J] / Time
P.D = Work Done / Charge
EMF = Work Done / Charge
Work Done = (P.D / EMF)(Current)(Time)
Work Done = (Current)^2(Resistance)(Time)
(Work Done)(Resistance) = (P.D / EMF)^2(Time)



1 kWh = 1000 W x 1 h = 1000 (J/s) x (3600 s) = 3600 000 J = 3.6 MJ

Heating Effect:
Most household appliances that convert electrical energy to thermal energy have heating elements that are made of nichrome.

Nichrome is used because it has high resistivity and can withstand high temperatures.

Iron-chromium-aluminium alloys can also be used as heating elements.

When an electric current passes through these heating elements, electrical energy is converted into thermal energy rapidly.

Measuring Electricity Consumption:
The rating labelled as “240 V, 1200 W” means that when 240 V is supplied across the electric kettle, 1200 J of electrical energy is supplied to the kettle per second and converted into thermal energy.

Renewable and Non-renewable Energy:

Solar Power	Advantage	- Form of clean energy. - Source of energy is free.
	Disadvantage	- Generation of electricity is dependant on the availability of sunlight. - Cost of infrastructure is high.
Wind Power	Advantage	- Form of clean energy. - Source of energy is free.
	Disadvantage	- The construction of wind farms requires large, open areas. - It depends on the availability of wind.
Hydroelectric Power	Advantage	- It is an efficient method of generating electricity as water flow is easily controlled.
	Disadvantage	- It disrupts ecosystems.
Nuclear Power	Advantage	- It is highly efficient as a small amount of uranium is sufficient to generate a large quantity of energy.
	Disadvantage	- Nuclear waste may cause contamination of groundwater.
Fossil Fuels	Advantage	- Most countries have well-established technology and energy distribution systems.
	Disadvantage	- Extensive mining has a negative impact on the ecosystem.

Hazards of Electricity:

1. **Damaged insulation**
    a. It may cause a short circuit if an exposed live wire touches an exposed neutral wire, causing a large amount of current to flow through, producing a lot of heat which may start a fire.
    b. The exposed live wire may cause an electric shock if someone accidentally touches it.
2. **Overheating of cables**
    a. Causes a large current to flow through, producing a lot of heat which may start a fire.
3. **Damp environment**
    a. Impure or contanimated water conducts electricity. When water gets into electrical appliances, the water conducts electricity from the electrical element to the human body. This will cause an electrocution to the human using it.

Circuit Breakers:
Switch off energy supply when large current flows.

Can be reset without being replaced.

Fault can be located easily without having to inspect each plug.

Fuses:
Prevents excessive current flow.

Must be replaced after tripping.

Thin short wire in a casing (low resistance) blows when a large current passes through to open the circuit.

Slightly higher rated value than normal current.

Connected to live wire.

Casing will be disconnected from live wire, no current flows through person.

If on Neutral: Live wire causes metal casing to have high voltage as it is still connected to the metal casing, hence a person will get an electric shock if he touches the casing and a large current flows through him to the earth.

Mains should be switched off before replacing

Common fuse ratings: 1A, 2A, 5A, 7A, 10A, 13A, 15A.

Double Insulation:
No Earth wire

Two Levels of Insulation

Electric Cables insulated from internal components of appliance.

Internal Components insulated from external casing (e.g. plastic casing).

Earthing:
1. Without earthing
    - Electrical fault results in live wire touching metal casing.
    - Metal casing is at high potential (open circuit).
    - When a person touches the casing, circuit is complete and a large current flows through the person.
    - Person gets an electric shock
2. With earthing
    - Electrical fault results in live wire touching metal casing.
    - Large current flows to the ground through earth wire which has much lower resistance than the person, hence person does not suffer electric shock.
    - Large current exceeds rated value of fuse, hence fuse blows

Wires:

Live Wire [Brown]	Connected to high voltage, carries the current from the source to appliance; fitted with fuses, switches.
Neutral Wire [Blue]	Completes the circuit by providing a return path to the source.
Earth Wire [Green & Yellow]	Low-resistance wire that is usually connected to the metal casing of appliances.

Safety Features in the 3-Pin Plug:

Earth Wire	Allows any leakage current to flow away safely without causing harm to users by providing a path of much lower resistance.
Fuse	Melts and breaks the circuit when a large surge of current exceeding its fuse rating is passing through.
Cable Grip	Holds the wires in place and minimises unnecessary tensions.
Outer Insulation	Gives added protection to users from the wires.

Circuit Breakers:

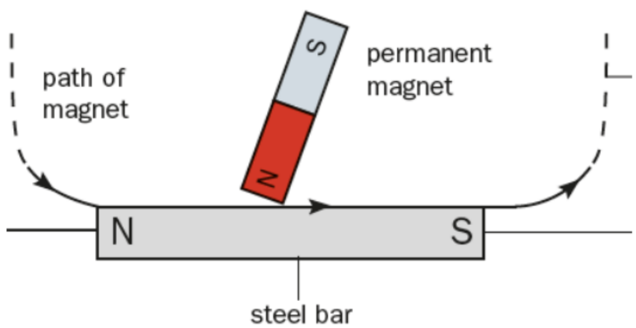
Type of Circuit Breaker	What does it do?
Miniature Circuit Breaker (MCB)	● Prevents **<u>excessive current flow</u>** through a circuit by breaking or tripping it. ● Usually, it is set at 10 A, 15 A or 20 A. ● When the MCB trips, it means that there is an **<u>overloading of devices</u>**. ● It is recommended that some devices are switched off before turning the MCB back on again.
Earth Leakage Circuit Breaker (ELCB)	● It monitors the **<u>current leakage</u>** (difference in current between the live and the neutral wire). ● When this difference in current is **greater than 30 mA**, the circuit breaker is tripped. ● When the ELCB trips, it means that there is a leakage of current through a **<u>faulty device</u>**. ● Identify the faulty device and get it repaired or stop using it. *Not connected to the earth

19. Magnetism

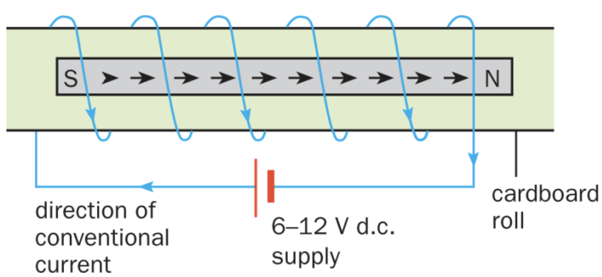
Identifying Magnets:
One side is attracted to a side of a known magnet, the other side is repelled from the side of the known magnet.

Induced Magnetism:
The process whereby an object made of a magnetic material becomes a magnet when it is near or in contact with a magnet.

Magnetisation by Stroking:



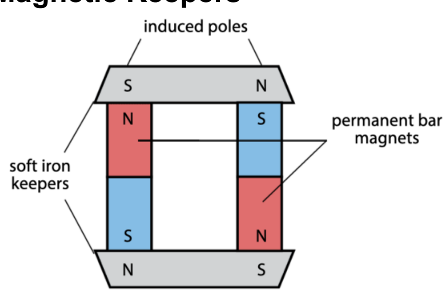
Magnetisation using an electrical method by a solenoid carrying a direct current:



Demagnetisation of magnetic materials:

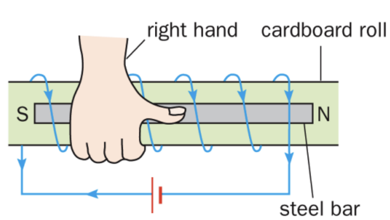
1. **Heating**
    a. As temperature increases during heating, atoms of the magnet vibrate more vigourously about their fixed positions. The atomic magnets lose their common alignment.
    b. Letting the hot demagnetized material cool in the east-west direction ensures that the magnetic domains do not re-align due to Earth's magnetic field.
2. **Hitting**
    a. Hammering a magnet in the east-west direction randomizes the alignment of the magnetic domains, causing the magnet to lose its magnetism
3. **Electrical Method**
    a. Place the magnet inside the solenoid with an alternating current (a.c.) along the east-west direction. (The alternating magnetic field due to the alternating current randomizes the alignment of the magnetic domains.)
    b. Gradually reduce the alternating current to zero or with the alternating current still flowing, slowly pull the demagnetized material out of the solenoid until it is far from the solenoid.

Preventing Demagnetisation:
Magnetic Keepers



Right-Hand Grip Rule:

(i) Grip the solenoid using the right hand.
(ii) Curl the fingers in the direction of the current flowing through the solenoid.
(iii) The thumb points in the same direction as the induced north pole.



Magnetic Fields:

The region surrounding a magnet in which a body of magnetic material experiences a magnetic force.

Plotted with sprinkling iron filings/compass.

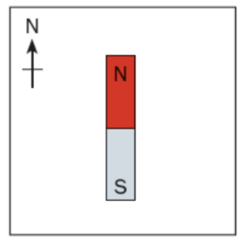
Closer lines = Stronger Magnetic Force.

Earth's geographical North is a magnetic South.

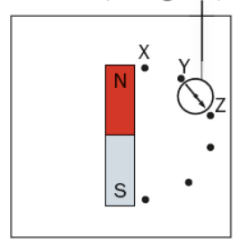
Plotting Magnetic Fields with Compass:

Plotting the magnetic field pattern with a **plotting compass**

1. Place the bar magnet at the centre of a piece of paper.
2. Ensure its N pole points to the Earth's N pole.
3. Place the compass at X and mark the S and N ends of the compass needle.
4. Move the compass to Y and repeat.
5. Repeat the process of marking the points until the S pole is reached.
6. Join the dots with a single line.
7. Repeat the process by starting from different points near the N pole until several lines are drawn.



plotting compass

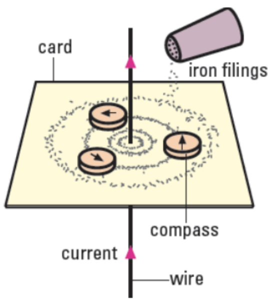


Temporary & Permanent Magnets:

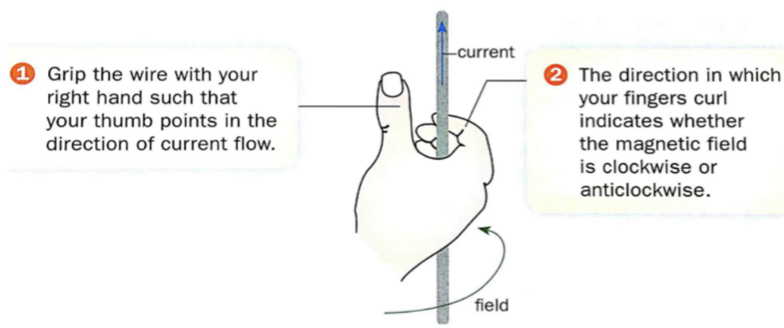
	Permanent Magnets [Hard magnetic material]	Temporary Magnets [Soft magnetic material]
Example	Steel	Iron
Definition	Permanent magnets (Hard magnetic material) do not require the presence of an electric current or a permanent magnetic field to retain their magnetism.	Temporary magnets (Soft magnetic material) retain their magnetism in the presence of an electric current or a permanent magnetic field.
Properties	Difficult to magnetise and demagnetise Have weaker induced magnetism	Easy to magnetise and demagnetise Have stronger induced magnetism
Applications	Magnetic recording media in hard disks. Magnetic door catch that ensures a fridge is airtight	Electromagnets separate magnetic materials from non-magnetic materials in a scrapyard

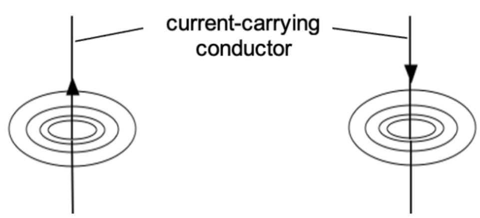
20. Electromagnetism

Properties of the Magnetic Field of a Current-carrying Conductor:
A current-carrying conductor produces a magnetic field around it.



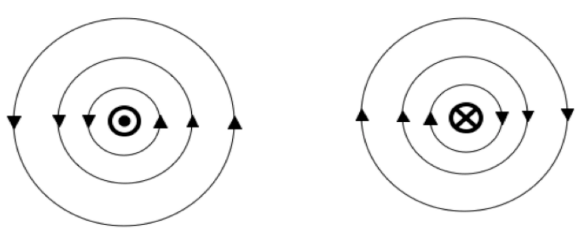
Right Hand Grip Rule [To determine the direction of the magnetic field around the wire]





Dot at the middle shows wire carrying current **out** of the

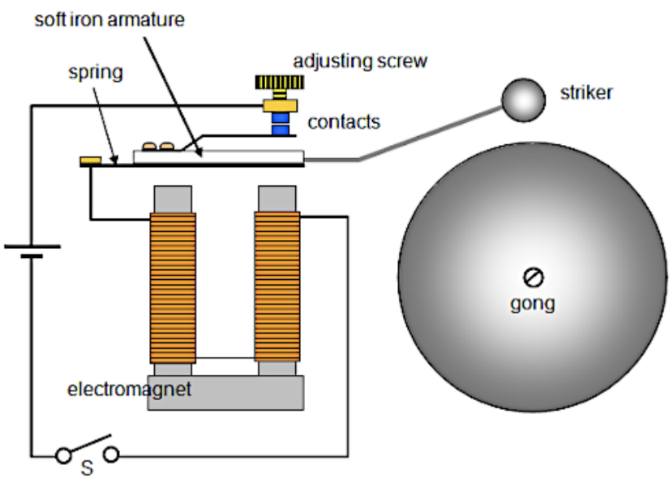
Cross at the middle shows wire carrying current **into** of



Factors affecting Magnetic Field Strength of a Solenoid:

1. Increase the magnitude of the current
2. Increase the number of turns per unit length of the solenoid
3. Placing a soft iron core within the solenoid

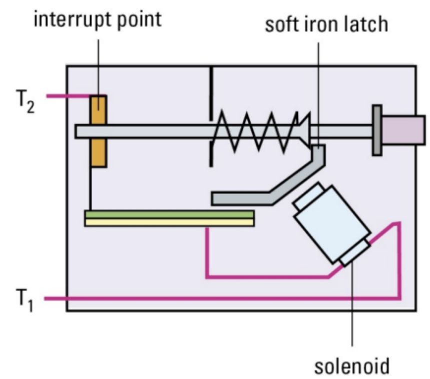
Applications of Magnetic Effect of Current in Daily Life:
Electric Bell



1. When the switch is pushed, the circuit is closed and current flow through the coils.
2. The soft iron cores becomes magnetized and the soft iron armature is attracted to the electromagnet.
3. The striker will then hit the gong.
4. When soft iron armature is attracted to the electromagnet, it breaks the contact and cuts off the current flow.
5. Hence, the soft iron cores lose their magnetism and the soft iron armature is not attracted to the iron core.
6. The spring allows the armature to return to its original position touching the contacts.

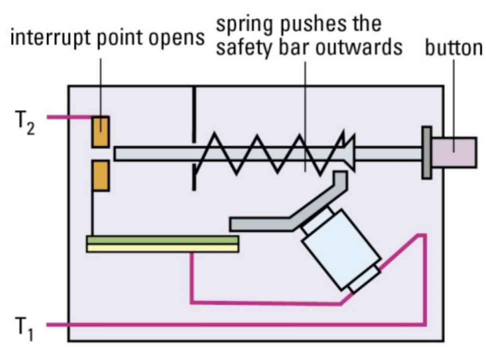
Circuit Breakers

Normal Condition



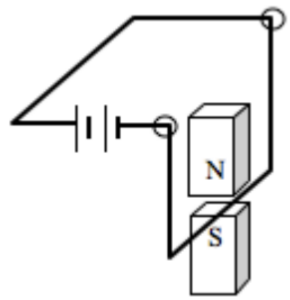
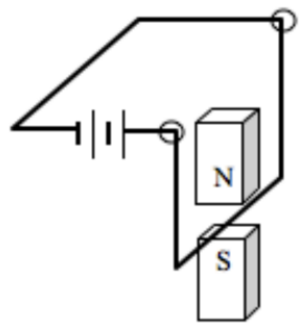
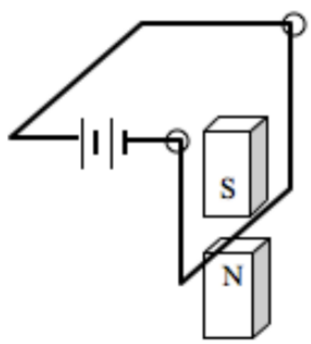
- Terminal T_1 and T_2 are connected to the live and neutral wires.
- When the current is within the limit (normal condition) the magnetic field produced by the solenoid is <u>not</u> strong enough to make the electromagnet to attract the soft iron latch.
- The circuit remains closed and current flows normally in the circuit.

Excessive Current Flow

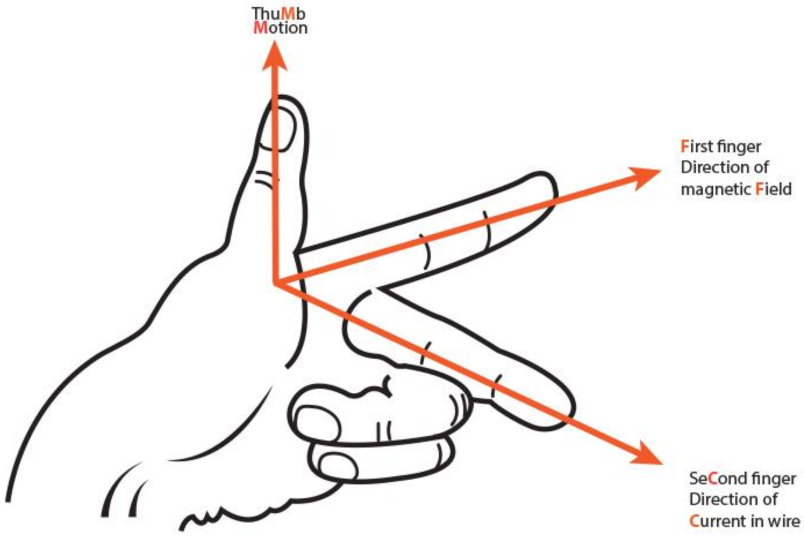


- A current surge may occur due to overloading or short circuit.
- The magnetic field produced by the solenoid is stronger due to the larger current and make the electromagnet stronger.
- Hence, the electromagnet is strong enough to attract the soft iron latch.
- The latch releases the spring which causes the safety bar to move outwards.
- The circuit is open and no current flows in the circuit.
- The circuit breaker can be reset by pushing the button of the safety bar

Force on a Current-carrying Conductor:

Cases	Diagram	Observations
Spacing Between Magnets (Field Strength)		The wire gets a larger force when the spacing decreases (magnetic field get stronger)
Reversing Current Flow Direction		The wire gets a force in the opposite direction when direction of the current is reversed.
Reversing Magnetic Field Direction		The wire gets a force in the opposite direction when direction of the magnetic field is reversed.

Fleming’s Left-Hand Rule:



Current is from + to -

Force on a Moving Charge in a Magnetic Field:

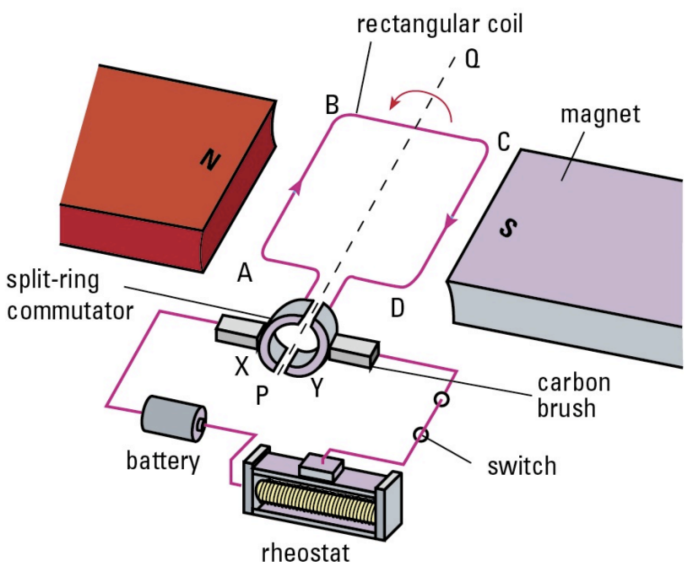
Thinking process to answer:

1. Find the electron flow [If its positive charge, electron flow is opposite of the way the positive charge goes]
2. Magnetic Field direction
3. Apply Fleming’s Left Hand Rule to find the Force
4. Particle will eventually U-turn/go in a circular motion [Usually draw U-turn is enough]

DC Motor:
A d.c. motor converts electrical energy into mechanical energy.

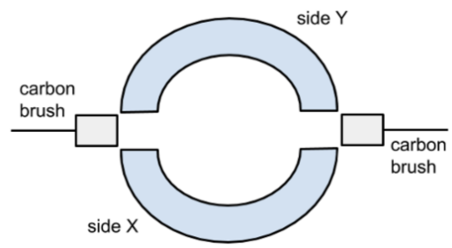
A d.c. motor consists of the following components:

1. Rectangular coil connected in series to a battery and rheostat
2. Permanent magnets
3. Spilt-ring commutator
   - The ends of the coil are fixed to the split-ring commutator (X and Y). The commutator rotates with the coil.
4. Two carbon brushes
   - The carbon brushes rub against the commutator and keep the coil connected to the battery.

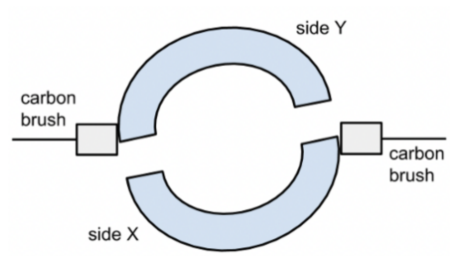


1. When the switch is closed, current will flow through the (rectangular) conducting coil.
2. The sides of the coil lie in between two permanent magnet.
3. Forces are produced on the current-carrying wires of the coil by the magnetic field (apply Fleming's left-hand rule), which cause the coil to rotate about its axle (along dotted line).
4. The ends of the rotating coil are connected to two halves of a copper ring (XY) known as the split ring commutator and they rotate together with the coil.
5. Electric current is passed from the circuit to the two halves of the copper ring via two separate carbon brushes.
6. The rheostat is used to control the amount of current in the coil, which affects the strength of magnetic forces produced on the sides of the coil (i.e. the rotating torque) and hence the rotational speed of the coil.
7. When an electric current flows through the coil ABCD, a downward force is produced on side AB and an upward force on side CD (using Fleming's left-hand rule).
8. This causes the coil to rotate anticlockwise about axis PQ.

But when the rotating coil reaches a **vertical position**, the split ring commutator (X and Y) **loses contact with the carbon brushes**, causing the current to be **cut off** and the forces to **disappear**.



However, the **inertia** of the rotating coil keeps it rotating and the commutator to make contact with the brushes again but in the reverse manner.



9. This reverses the current direction in the coil, and consequently side AB now gets an upward force while CD gets a downward force.
10. This allows the coil to continue rotating in the same anticlockwise direction.

The rotation speed (turning effect) of the coil (i.e. motor) can be increased by
1. Increasing the magnitude of the current in the coil
2. Increasing the number of turns per unit length of the coil
3. Inserting a soft iron core or cylinder into the coil
4. Using a stronger magnet.

21. Electromagnetic Induction

Lenz's Law:
The direction of the induced electromotive force (e.m.f.) (and hence the direction of the induced current in a closed circuit) is such that its magnetic effect opposes the change producing it.

Faraday's Law of EMI:
The magnitude of the electromotive force (e.m.f.) induced in a circuit is directly proportional to the rate of change of the magnetic flux linkage through the area bounded by the circuit.

(a) The magnetic flux through an area is the product of the area, A, and the magnetic field, B, passing perpendicular through this area.

The magnetic flux linkage of a solenoid with N identical turns is N times the magnetic flux through each coil of the solenoid.

(b) In diagrams, the magnetic flux through an area is directly proportional to the number of magnetic field lines passing through that area.

Thus, the magnitude of the electromotive force (e.m.f.) induced in a conductor is directly proportional to the rate at which magnetic field lines cut the conductor.

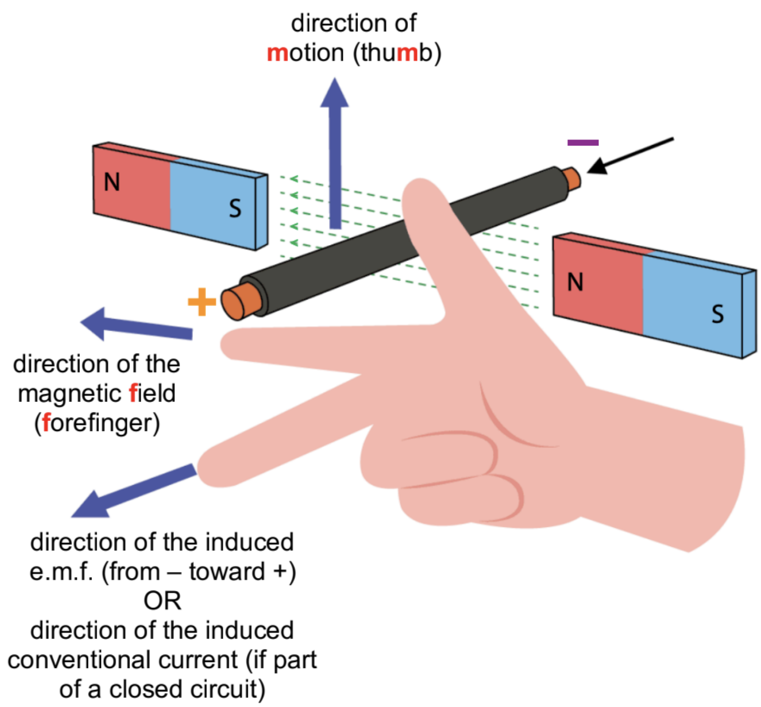
Factors affecting the magnitude of the induced e.m.f:

The magnet is moved faster toward/away from the solenoid	The magnitude of the induced e.m.f. is greater (because rate at which magnetic field lines cut the conductor is greater).
A stronger magnet is used	The magnitude of the induced e.m.f. is greater (because rate at which magnetic field lines cut the conductor is greater).
A solenoid with more coils is used	The magnitude of the induced e.m.f. is greater.

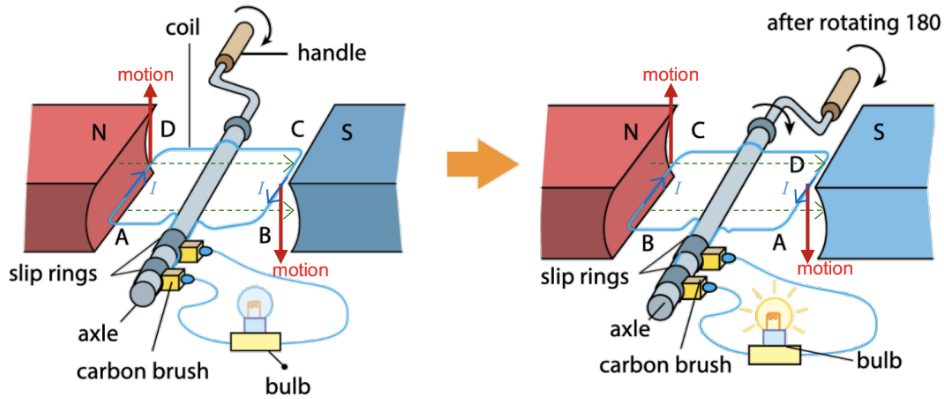
Steps to finding where the galvanometer points:

1. Find whether to magnet is moving towards or away from the solenoid
2. Find which poles is moving in or out.
    - If N pole moving in, N pole induced
    - If S pole moving in, S pole induced
    - If N pole moving out, S pole induced
    - If S pole moving out, N pole induced
3. Find the induced pole on the solenoid on the side the magnet moves
4. Galvanometer always points to the induced N pole of the solenoid.

Fleming's Right Hand Rule:



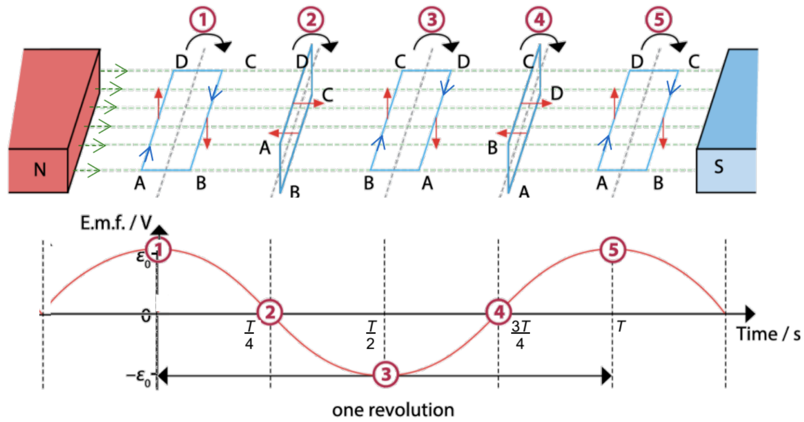
AC Generator:
An a.c. generator converts mechanical energy to electrical energy



(a) The coil is rotated by turning the handle.
(b) As the coil rotates between the two magnets, the magnetic flux through the coil changes at a non-uniform rate. The coil cuts the magnetic field lines ata non-uniform rate.
(c) By Faraday's law of electromagnetic induction, an e.m.f. is induced in the rotating coil. Fleming's right hand rule tells us the direction of the induced e.m.f. in sides AD and BC.
(d) The induced alternating current flows through the coil flows through the 2 slip rings and carbon brushes and the bulb.

Function of the 2 slip rings
The 2 slip rings maintain constant electrical contact with the carbon brushes as the coil rotates, ensuring that the induced current flows through the closed circuit.

The direction of the induced current through the coil reverses every half turn (alternating current).



position	position **#1**	position **#2**	position **#3**	position **#4**	position **#5**
angle of rotation	0°	90°	180°	270°	360° (1 complete cycle)
plane of the coil	The plane of the coil is **parallel** to the magnetic field lines.	The plane of the coil is **perpendicular** to the magnetic field lines.	The plane of the coil is **parallel** to the magnetic field lines.	The plane of the coil is **perpendicular** to the magnetic field lines.	The plane of the coil is **parallel** to the magnetic field lines.
Sides BA and DC	(Sides BA and DC do not cut the magnetic field lines.)				
Rate of sides AD and BC cutting the magnetic field lines	Sides **AD** and **BC** of the coil **cut the magnetic field lines** at the **greatest rate**.	Sides **AD** and BC of the coil **move parallel to** the **magnetic field lines** and **do not cut** them.	Sides **AD** and **BC** of the coil **cut the magnetic field lines** at the **greatest rate**.	Sides **AD** and BC of the coil **move parallel to** the **magnetic field lines** and **do not cut** them.	Sides **AD** and **BC** of the coil **cut the magnetic field lines** at the **greatest rate**.
Magnitude of induced e.m.f. (according to Faraday's law of electromagnetic induction)	The magnitude of the **induced e.m.f.** is **maximum**.	The **induced e.m.f.** is **zero**.	The magnitude of the **induced e.m.f.** is **maximum**.	The **induced e.m.f.** is **zero**.	The magnitude of the **induced e.m.f.** is **maximum**.
Magnitude and direction of induced current (according to Faraday's right hand rule)	The maximum **induced current** flows (**A→D→B→C**).	The **induced current** is **zero**.	Since sides AD and BC are moving in opposite directions compared to position #1, the maximum **induced current** flows in the **opposite direction** (**B→C→D→A**).	The **induced current** is **zero**.	The maximum **induced current** flows (**A→D→B→C**).

The amplitude of the induced e.m.f. of an a.c. generator can be increased by increasing the rate at which the coil cuts the magnetic field lines, e.g. by

1. Increasing the number of turns of the coil
2. Increasing the magnetic field strength (e.g. stronger magnets)
3. Increasing the speed of rotation of the coil
4. Winding the coil on a soft iron core (to strengthen the magnetic field passing through the coil)

The amplitude of the induced current can be increased by increasing the induced e.m.f. or by decreasing the resistance of the coil.

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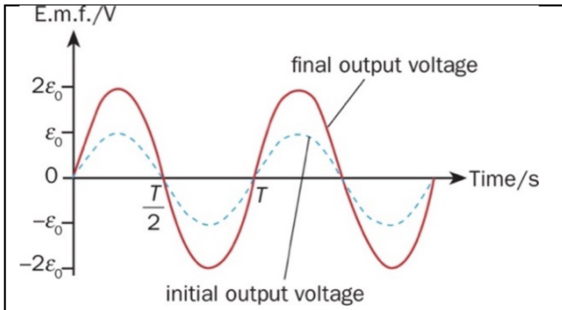

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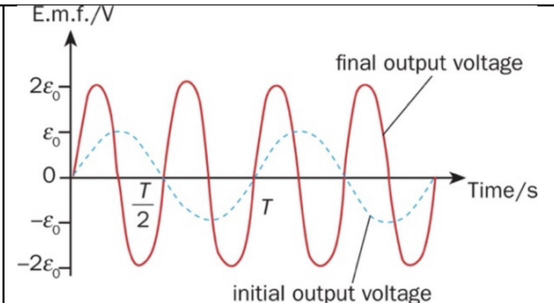

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<tr>
<td>Doubling the number of turns of the coil (without changing its frequency of rotation and the magnetic field strength) doubles the amplitude of the induced e.m.f.</td>
<td>Doubling the frequency of rotation (i.e. halving the period) of the coil (without changing its number of turns and the magnetic field strength)
• doubles the amplitude and
• doubles the frequency (i.e. halves the period)
of the induced e.m.f.</td>
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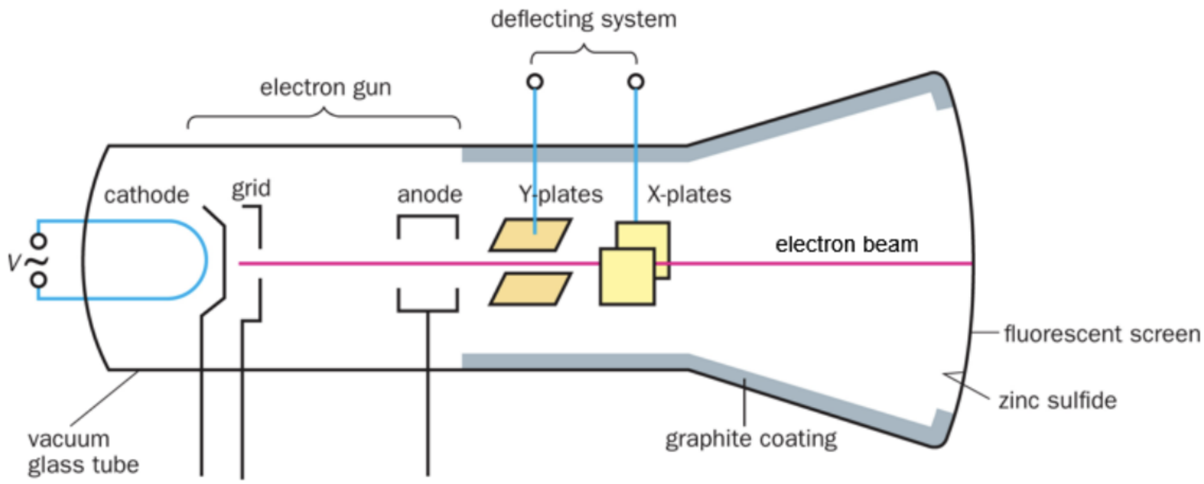
Cathode Ray Oscilloscope:
A cathode ray oscilloscope (CRO) is an electronic device that uses electron beam deflection to detect and show how voltages vary with time.



A c.r.o. has a cathode ray tube which has 3 main parts.

1. Electron gun
    - The electron gun emits a beam of electrons (thermionic emission) which is produced by the cathode.
2. Deflecting system
    - The deflecting system consists of two pairs of deflecting plates, X plates and Y plates.
    - Voltage can be applied across the deflecting plates.
    - The extent of deflection of the spot is proportional to the voltage applied.
    - X plates can make the electron beam to deflect horizontally.
    - Y plates can make the electron beam to deflect vertically.
3. Fluorescent screen
    - A bright spot is produced on the screen when the electron beam hits it.
    - The larger the number of electrons striking the screen, the brighter the spot.

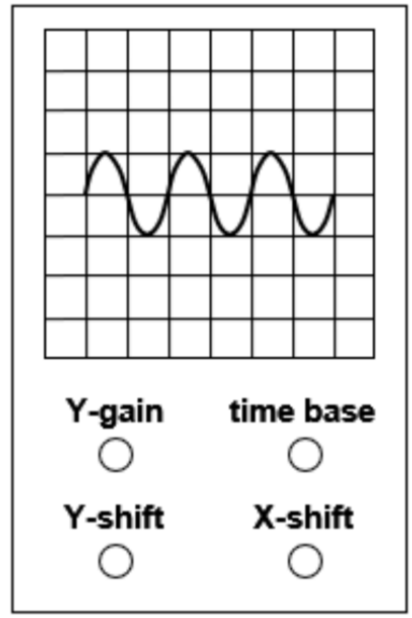
Using a C.R.O.
The Y-plates is connected to the Y-input terminals.
The external source of voltage to be measured is connected across the Y-input terminals.

X-shift and Y-shift

- The X-shift and the Y-shift knobs are used to **move the trace over the screen** in the X (horizontal) and Y (vertical) direction respectively.

Y-gain

- The Y-gain knob is used to control the **amplification (magnification) of the Y-deflection (vertical movement)**.
- The vertical axis is calibrated in **V/cm** or V/division.
- If the Y-gain control is set at 5.0 V/cm (or 5.0 V/division), it means that the spot is deflected 1 cm (or 1 division) vertically for every 5.0 V across the Y-input terminal.



Time base
The time base knob is used to control the speed at which the spot move across the screen in the horizontal (X) direction.

The horizontal axis is calibrated in ms/cm or ms/division

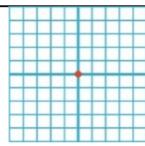
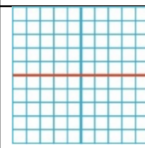
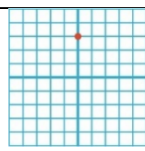
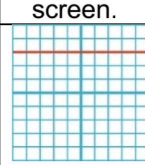
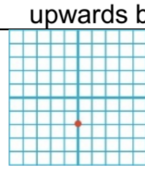
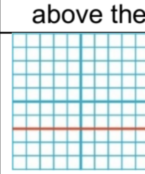
If the time base control is set at 10 ms/cm (or 10 ms/division), it means that the spot takes 10 ms to move 1 cm (or 1 division) horizontally.

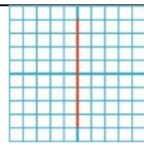
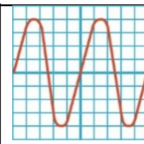
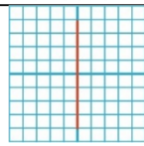
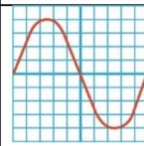
The time base is connected to an internal circuit in the c.r.o..

The time base controls the voltage of this internal circuit which applies voltage across the X-plates.

Uses of C.R.O.

1. Measuring voltages
    - The voltage to be measured is connected to the Y-input terminals and eventually to the Y-plates.
    - The time base is switched off.
    - The deflection of the electron beam (spot) is proportional to the voltage applied.
2. Displaying Voltage Waveform (Measuring Time and Frequency)
    - The time base is switched on.

		measuring voltage	**displaying voltage waveform**
voltage applied across the Y-plates	**Y-gain**	**time base switched OFF**	**time base switched ON (4.0 ms / div)**
0 V	0 V / div	 ▪ Beam is not deflected. ▪ No vertical deflection. ▪ V = 0 V	 ▪ Beam is swept horizontally across the screen.
d.c. input 1.5 V	0.5 V / div	 ▪ Beam is deflected upwards by 3 divisions.	 ▪ The line is 3 division above the horizontal axis.
d.c. input – 2.0 V	1.0 V / div	 ▪ Beam is deflected downwards by 2 divisions.	 ▪ The line is 2 division below the horizontal axis.

a.c. input peak voltage = 20 V	5.0 V / div	 ▪ Beam is deflected upwards and downwards by 4 divisions in each direction.	 ▪ Beam is swept horizontally and oscillates vertically. ▪ frequency = ...
a.c. input peak voltage = 20 V	5.0 V / div	 ▪ Beam is deflected upwards and downwards by 4 divisions in each direction.	 ▪ Beam is swept horizontally and oscillates vertically. frequency = ...

Transformer:
A transformer is a device that can change a high alternating voltage (at low current) to a low alternating voltage (at high current), and vice versa.

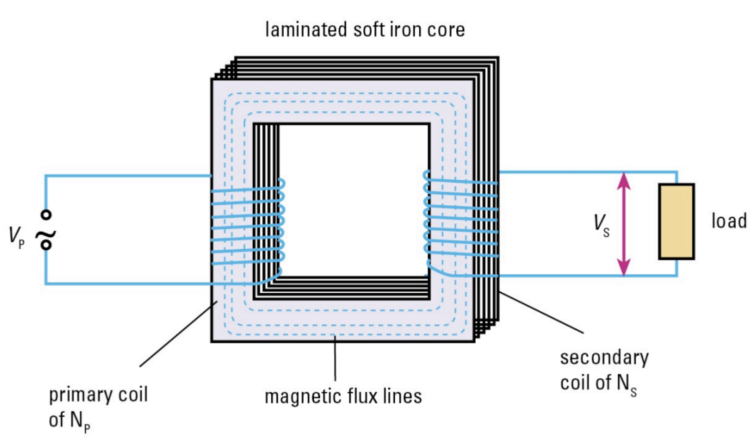
Closed Core Transformer
A closed core transformer consists of two coils of wire (primary and secondary coil) which are wound round a laminated soft iron core.

The soft iron core is an electrical conductor. Hence, the changing magnetic field will induce current (eddy current) in it.

Eddy currents flow in little circles in a solid iron core which cause heating in the core.

The laminated soft iron core is made up of thin sheets of soft iron insulated from each other.

The lamination reduces heat loss due to induced eddy current in the soft iron core.



At the primary coil, the applied alternating voltage (Vp) will drive an alternating current in the primary coil.

When an alternating current flows in the primary coil, it causes a changing (alternating) magnetic field in the soft iron core.

This changing magnetic field in the soft iron core cuts the secondary coil and induces an e.m.f. in the secondary coil.

Transformer will not work on direct current (d.c.).

Uses of transformers

1. Electrical power transmission from power station to households and factories
2. Regulating voltages in electrical appliances for proper operation

The transformer operates by having different number of turns in the primary and secondary coils.

Transformer	
$\frac{\text{secondary output voltage}}{\text{primary input voltage}} = \frac{\text{number of turns in secondary coil}}{\text{number of turns in primary coil}}$ $\frac{V_S}{V_P} = \frac{N_S}{N_P}$ **turns ratio** = $\frac{N_S}{N_P}$	
Step-up Transformer	**Step-down Transformer**
▪ The **secondary coil** has **more turns** than the primary coil. $N_S > N_P$ ▪ The **secondary output voltage** is **more** than primary input voltage. $V_S > V_P$ ▪ $I_S < I_P$	▪ The **primary coil** has **more turns** than the secondary coil. $N_S < N_P$ ▪ The **primary input voltage** is **more** than secondary output voltage. $V_S < V_P$ ▪ $I_S > I_P$

Power transmission in a transformer:
Ideal Transformer
For an ideal transformer, its efficiency is 100%.

The power supplied to the primary coil is fully transferred to the secondary coil.

Based on the **Principle of Conservation of Energy**, for an **ideal transformer**
power in primary coil = power is secondary coil
$V_P I_P = V_s I_s$

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

Non-ideal Transformer

In a non-ideal transformer, there will be power loss (efficiency is less than 100%).

$$\boxed{\text{Efficiency } \eta = \frac{\text{power output}}{\text{power input}} \times 100\%}$$

Efficiency = VS IS / (VP IP) x 100 %

Causes of power loss

1. Heat loss due to the resistance of the coil
2. Leakage of magnetic field lines between the primary and secondary coils
3. Heat loss due to eddy currents induced in the soft iron core.
4. Hysteresis loss caused by the flipping of the magnetic dipoles in the soft iron core due to the alternating current. Energy is dissipated in the form of heat.

High voltage transfer of electricity:

The electrical power generated at the power station is typically transmitted over long distances via metal cables.

As the cables are very long, they will have significant resistance. (resistance increases with length)

Hence, electrical energy will be wasted due to the heating effect of current. (heating effect increases with resistance)

This power losses is due to the process of joule heating in the transmission cables.

$$\boxed{\textbf{power loss} = I^2 R}$$

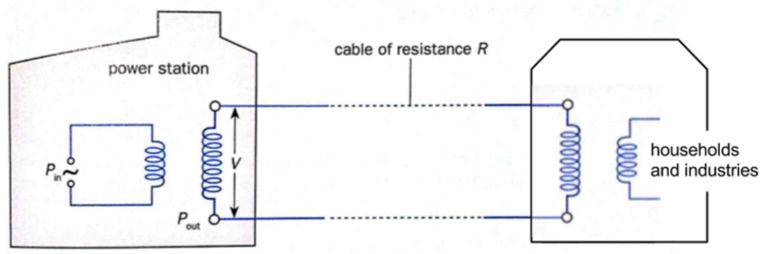
physical quantity	S.I. unit
power ***P***	watt W
current ***I***	ampere A
resistance ***R***	ohm Ω

Power loss can be reduced by reducing the current in the cable or reducing the resistance of the cable.

- The resistance of the cable can be reduced by using thick cable (increase cross sectional area). This is not economical as thicker cable increases the cable and construction cost.
- Current should be kept little to reduce power loss.

$$I = \frac{P_{\text{out}}}{V_{\text{out}}} \quad \therefore P_{\text{loss}} = I^2 R = \left(\frac{P_{out}}{V_{\text{out}}}\right)^2 R$$

The current in the cables can be reduced by using high voltage transmission.



step-up Transformer ***step-down Transformer***

High voltage transmission is achieved by having a step-up transformer at the power station to increase the voltage (about 230 000 V).

Where the electricity is to be used, there is a series of step-down transformers to reduce the voltage to values suitable for use in factories and homes.

22. Practical

Prefixes:

Prefix	Order of magnitude	Symbol
nano-	10^{-9}	n
micro-	10^{-6}	μ
milli-	10^{-3}	m
centi-	10^{-2}	c
deci-	10^{-1}	d
kilo-	10^{3}	k
mega-	10^{6}	M
giga-	10^{9}	G

Great Majestic kings drink cold milk µntil nine

Precision:

Instrument	Precision
Measuring Tape	1cm
Metre Rule	0.1cm
Vernier Calipers	0.01cm
Micrometer Screw Gauge	0.001cm
Stopwatch	0.01s
Ammeter	0.01A
Voltmeter	0.05V
Thermometer	0.5°C
Electronic Mass Balance	00.01g (Just copy off)
Measuring Cylinder	0.5cm^3

Planning:
Candidates are required to analyse a practical problem and produce an appropriate procedure for the investigation.

Candidates should be able to:
● identify key variables for a given question / problem
● outline an experimental procedure to investigate the question / problem
● describe how the data should be used in order to reach a conclusion
● identify the risks of the experiment and state precautions that should be taken to keep risks to a minimum

Key Variables

There are 3 types of key variables which need to be identified when planning an investigation.

1. **Independent Variables**
    - They are physical factors that would affect the outcome(s) of the investigation.
    - In a typical scientific investigation, there should only be ONE chosen independent variable.
    - The chosen independent variable must be:
        1. relevant to the objective of the investigation
        2. a physical quantity – it must be measurable
2. **Dependent Variables**
    - They are physical factors that will be affected by the chosen independent variable.
    - In a typical scientific investigation, there should only be ONE chosen dependent
    - variable.
    - The chosen independent variable must be:
        1. relevant to the objective of the investigation
        2. a physical quantity – it must be measurable
3. **Quantities to be kept constant**
    - They are physical factors that would affect the outcome(s) of the investigation.
    - They have to be monitored and kept constant throughout the entire investigation.

Relationship Between Independent Variables and Dependent
One of the key purposes of the investigation is to establish a relationship between the independent variable (x) and the dependent variable (y).

- Typically, a linear mathematical relationship connecting both variables is established (e.g. $y = mx + c$).
- When a relationship (i.e. equation) is given in the investigation, examine and identify the appropriate independent variable and dependent variable before proceeding with the experimental design and setup. In some cases, you may need to manipulate the equation to simplify it further.
    - e.g. $2y / m = 2x$ can be manipulated into the form $y = mx$.

Apparatus

- List down all the apparatus required for the investigation.
- Use only common laboratory apparatus are allowed.

Procedure

- Write down the procedure clearly in a series of step-by-step procedure.
- Make sure to include clear instructions on how to vary the independent variable, and how the dependent variable is being observed and measured (e.g. specify the measuring instrument) and recorded.
- [OPTIONAL] Include diagram(s) of the experiment set-up to help clarify the procedure.
- Describe how the recorded data should be processed (e.g. calculation, tabulation) to interpret the correlation between the chosen independent and dependent variables. It usually involves the plotting of a (linear) graph and determination of its gradient and vertical intercept.

EXAMPLE PLANNING TASK

Title: Bending of a straw by an applied force
Task: It is suggested that the following relationship applies to a horizontal straw supporting a load at its mid-point.

$$L = k(mg)^2$$

where
- L is the length of the straw (in m),
- m is the mass of the load (in kg) hanging on the straw that causes it to bend,
- g is the acceleration due to gravity (in m/s^2),
- k is an unknown constant.

Plan an experiment to investigate the relationship between L and m.

Your plan should include:
- the quantities that you should keep constant,
- a detailed description of how you will perform the experiment,
- a suitable table in which to display your measurements and calculated values (you do not need to enter any data into the table),
- a statement of the graph that you would plot to test the relationship,
- a sketch of the graph that you would obtain if the suggested relationship is correct,
- and explanation of how you would obtain a value of the constants k from your graph.

Independent Variable:	Length of straw L
Dependent Variable:	Total mass m hanging on straw that causes it to bend
Quantities to be kept Constant: (min. 2 to be stated)	1. material of straw 2. diameter of straw
List of Apparatus	1. straws 2. string 3. a mass hanger 4. slotted masses (10 g each) 5. a 30-cm rule 6. two retort stands

Diagram [Optional but reccomended]:

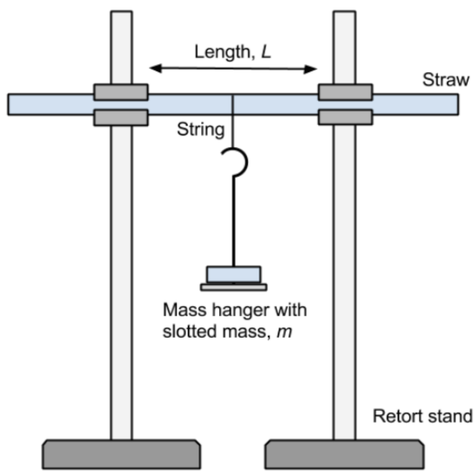


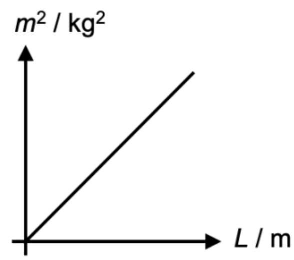
Fig. 1.1

Procedure:

1. Set up the experiment as shown in Fig. 1.1.
2. Using a 30-cm rule, measure that the length of straw (being suspended) L is 10.0 cm.
3. Ensure that the string supporting the mass hanger is placed at the midpoint of the straw (i.e. middle of L).
4. Place a slotted mass of 10 g onto the mass hanger and check if the straw is bent.
5. Repeat step 4 by adding another slotted mass of 10 g. Continue doing so until the straw becomes bent. Record the total mass m supported by the straw before it becomes bent.
6. Calculate and record m^2.
7. Repeat steps 2 to 6 for 4 further lengths of the straw L at 12.0 cm, 14.0 cm, 16.0 cm and 18.0 cm.
8. Record all the results for L, m and m^2 in a suitable table.

L/m	m/kg	m^2/kg^2

9. Plot a graph of m^2/kg^2 against L/m.
10. If the suggested relationship is correct, a linear graph will be obtained as shown.



The value of k can be determined from the gradient of the graph.

$L = k(mg)^2$

$m^2 = L/(kg^2)$

Gradient = $1/(k \times g^2)$

$k = 1/(\text{Gradient} \times g^2)$

Graph Plotting:

Axis

1. Highest value - Lowest value
2. Divide it by no. of big squares
3. Divide it by 10
4. Divide it by 2
5. Round of to nearest nice number (1,2,5,10,25,50)
6. That will be the precision of the axis
7. x10 of that to find range for 1 big square

Points

Can circle 1 outlier

Do not cross bigger than 1 small square

Line

Best fit line = same amount of points above and below