MECHANICS

Mass vs Weight

mass is a measure of the amount of substance in a body BUT **weight** is a measure of gravitational force on a mass

W = m g

electronic balance: mass (kilogram, kg)

spring balance: force/weight (newton, N)

Mass remains constant but weight can change because of acceleration due to gravity.

Density is mass per unit volume

D = m / V (SI Units: kg/m^3)

Density of water is 1 g/cm^3 or 1 000 kg/m^3)

Less dense (lower density): float

Denser (higher density): sink

Centre of gravity

It is the point where the whole weight seems to act.

For a body to be stable, base area of object must be large and its CG is low. The line of weight through the CG must lie within the base area of the object.

Forces

F = m a

Resultant force = 0 when

(i) object is **at rest** or

(ii) object is **at constant speed**

Zero resultant force means that the forces are opposite and equal. Eg. friction = forward force, weight = air resistance.

Vector drawing

Note: choose an appropriate scale, state both resultant force and direction.

Single arrow for forces but double arrow for resultant force.

For drawing of parallelogram, all forces point away from the same starting point.

Tracing of lines in dotted lines.

Length, volume and time

Prefixes: nano (10^{-9}), micro (10^{-6}), milli (10^{-3}), kilo(10^3), Mega(10^6), Giga (10^{9}).

Degree of accuracy of instruments:

Metre rule and measuring tape (0.1 cm),

Vernier calipers (0.01 cm),

Micrometer (0.01 mm).

Types of errors: **Zero error, parallax error**

Energy is the capacity to do work. (**Unit: Joule**)

Energy stores: chemical potential, kinetic, gravitational potential, elastic potential, internal, nuclear.

Methods of transfer: by heating, mechanically, electrically, by propagation of electromagnetic waves/ sound waves.

Energy cannot be created or destroyed, but can be transferred from one store to another.

The total amount of energy in an isolated system remains constant.

Work, energy and power

Work done is the product of the magnitude of a force and the distance moved in the direction of the force (**Unit: Joule**)

W = F x // d

Formulas of energy:

- Kinetic **= ½ mv^2**
- Gravitational Potential = **mgh**

Power is the rate of doing work.**(Unit: Watts**)

Power = Energy / time or Work / time

P = E / t or P = W / t

Speed and acceleration

Speed is the **rate** of **distance** travelled S = D/t

Acceleration is the **rate of change of velocity**

a = (v-u)/t (Unit: m/s^2)

Average speed = total distance / total time or
= (u + v) / 2

Speed-time graph: gradient = acceleration,
area under graph = distance

Distance-time graph: gradient = speed

Scalar & Vector

Scalar quantity is a quantity that has **magnitude only**. Eg. mass, speed, distnace.

Vector is a quantity that has both **magnitude and a direction**. Eg. force, velocity, acceleration, weight, displacement.

Turning effect of Forces

Moment is the product of a force and its perpendicular distance from the pivot to the line of action of the force. (Unit: Nm or Ncm)

Moment = F x ⊥ d

Principle of Moment states that for a body to be in equilibrium, the sum of anticlockwise moments is equal to the sum of clockwise moments about the same pivot.

Types of equilibrium: stable, unstable, neutral.

Pressure

Pressure is force per unit area.

(Unit: Pa or N/m^2, cmHg, N/cm^2)

P = F / A and

P = hρg (liquid pressure)

THERMAL PHYSICS

<u>Kinetic Model of Matter</u>

Solid: closely packed together by very strong attractive forces, vibrate about fixed positions.
Liquid: quite closely packed together by strong attractive forces, sliding past over each other.
Gas: far apart from one another with weak or negligible attractive forces, moving randomly at high speed.

Brownian motion: bombardment of smoke particles by air molecules gives rise to the random motion of smoke particles.

Pressure α temperature at constant volume
At constant volume, when temperature increases, the overall k.e. increases and the air molecules move faster. This results in more frequent collisions with the walls of container, thus increases the pressure of air.

Volume α temperature at constant pressure
At constant pressure, increasing the temperature of the air will result in the increase in k.e. of air molecules and causes the molecules to exert a greater force on the piston and the walls. Hence, this leads to an expansion of the air and results in an increase in the volume.

<u>Thermal Processes</u>

Conduction

Solids >Liquids>Gases

Works by molecular vibration.

Good conductors: Metals (electron diffusion and molecular vibration)

Convection (for fluids i.e. liquids/gases)

Due to density changes

When heated □ Expands □ Becomes less dense □ Rises

When cooled □ Contracts □ Denser □ Sinks

Convection current is set up.

E.g. air-conditioner, heating a liquid etc.

Conduction and convection cannot take place in vacuum.

Radiation can occur without medium i.e. in a vacuum or outer space.

Shiny and silver surface can reduce radiation.

Factors affecting a<u>bsorption</u>/<u>emission</u>:

<u>(i) nature of the surface (shiny/dull & light/dark)</u>

Black and dull surfaces are <u>better absorbers</u> (get hot more quickly)

and also <u>better emitters</u> (lose energy more quickly) than white and shiny surfaces.

<u>(ii) Temperature</u>

A hotter body gives out more thermal energy.

<u>(iii) surface area</u>

A body with a larger surface area loses energy more quickly.

E.g. oven, solar heating pipes, teapots, cooling fins of refrigerator etc.

THERMAL PHYSICS

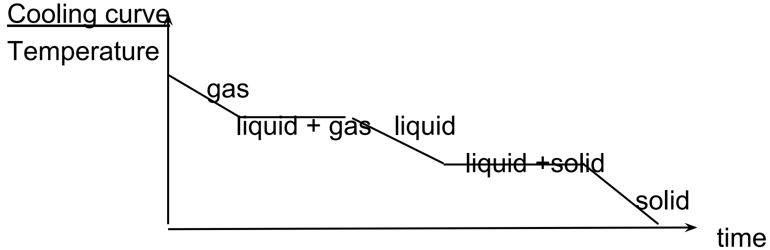
Thermal properties of Matter

Melting point (Boiling point) is a temperature in which a substance changes from solid to liquid **(liquid to gas)**.

During melting (boiling), energy is absorbed to break the forces of attraction changing from solid to liquid (liquid to gas), increasing potential energy as particles move further apart. Average kinetic energy of particles remains constant, hence temperature remains constant.

During **Freezing (Condensation)**, energy is released to strengthen the forces of attraction changing from liquid to solid (gas to liquid), decreasing the potential energy as particles move closer together. Average speed of particles remains constant, hence temperature remains constant.

Cooling curve



Gases expand more than liquids and liquids expand more than solids.

Boiling and evaporation involves in enerhy gain changing from liquid to gas.

Differences between boiling and evaporation.

Boiling	**Evaporation**
-Bubbles are formed.	- No bubbles present.
- Faster process.	- Slower process.
- Heat source is required.	- Heat from surrounding air.
- Occurs throughout the liquid.	- Occurs only the surface of liquid.
- Occurs at fixed temperature.	- Occurs at any.temperature.

Evaporation causes cooling as it takes energy away resulting in a drop of temperature.

Heat capacity is the amount of internal energy needed to raise the temperature of an object by 1 ℃.
SI unit: $J℃^{-1}$ or JK^{-1} .

$Q = c\Delta\theta$

Specific heat capacity is the amount of internal energy needed to raise a unit mass of a substance by 1℃..
SI unit: $Jkg^{-1}℃^{-1}$ or $Jkg^{-1}K^{-1}$

$Q = mc\Delta\theta$

Latent heat is the amount of internal energy required by a substance to change state without a change in temperature.

Latent heat of fusion is the amount of internal energy required to change a substance from solid to liquid states without a change in temperature.

Latent heat of vaporization is the amount of internal energy required to change a substance from liquid to gaseous states without a change in temperature.

Specific latent heat is the amount of internal energy required to change the state of a unit mass of substance without a change in temperature.
SI unit: Jkg^{-1}

$Q = ml$

Note: *when a heater is used,* ***$Q = Pt$***

WAVES

Waves

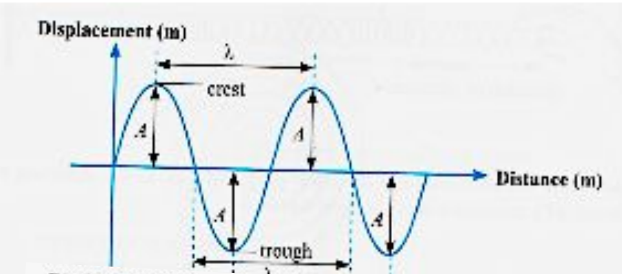
Transverse waves travel perpendicular to the direction of its vibration. Eg. water waves, electromagnetic waves.

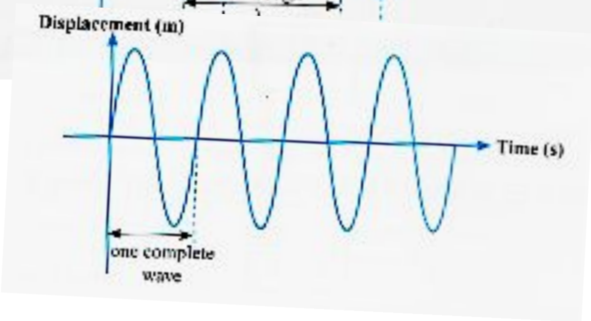
Longitudinal waves travel parallel to the direction of its vibration. Eg. sound waves. This wave forms a series of **compressions** and **rarefactions**.

A wavefront is an imaginary line joining all the adjacent points that are in phase together.

Wavelength is the shortest distance between two points that are in phase.
Amplitude is the max. displacement from the rest position.
Frequency is the number of waves made in one second.(SI unit: Hz)
Period is the time taken for one complete wave.
$f = 1 / T$

Wave speed: **$v = f \times \lambda$**





Sound

Is produced by vibration. Sound cannot travel through vacuum because there are no particles to vibrate.
Travels fastest in solid but **slowest in gas**.
Sound travels faster at a higher temperature as molecules move faster in higher temperature.
Speed of sound in air is about 300 m/s.

Normal human audible range:
20 Hz to 20 kHz.

Compression is a region where air pressure is high while **rarefaction** is a region where air pressure is low.

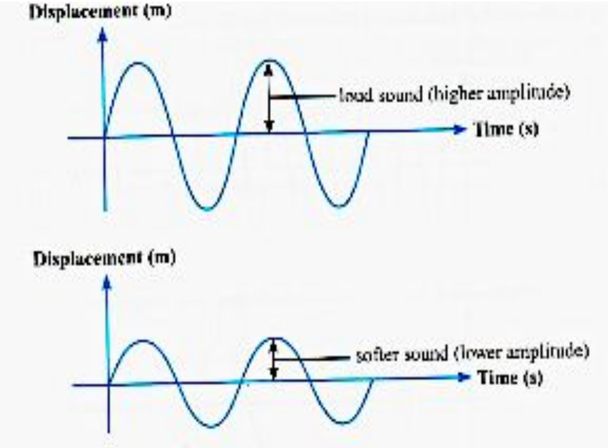
The wavelength is the distance between the centres of two sucessive compressions or rarefactions.

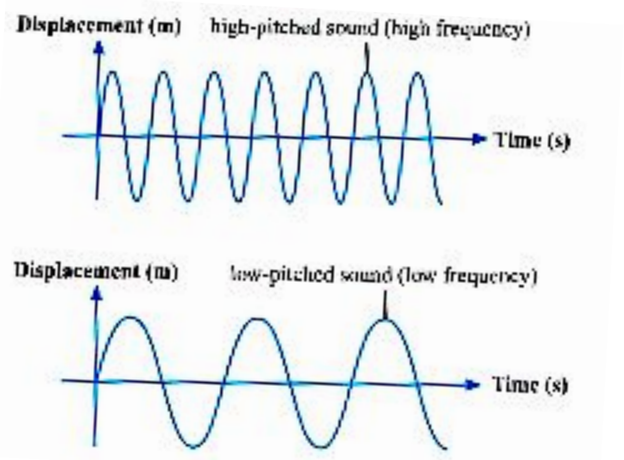
Pitch is related to **frequency**.
Loudness is related to **amplitude**.

Sonar is used in ocean exploration to find the depth of seabed or to detect other vessels under water.
Ultrasound is used to detect the fetal development in a mother's womb.

$S = 2D / t$ (echo method)

$S = D / t$ (direct method)





WAVES

Electromagnetic spectrum

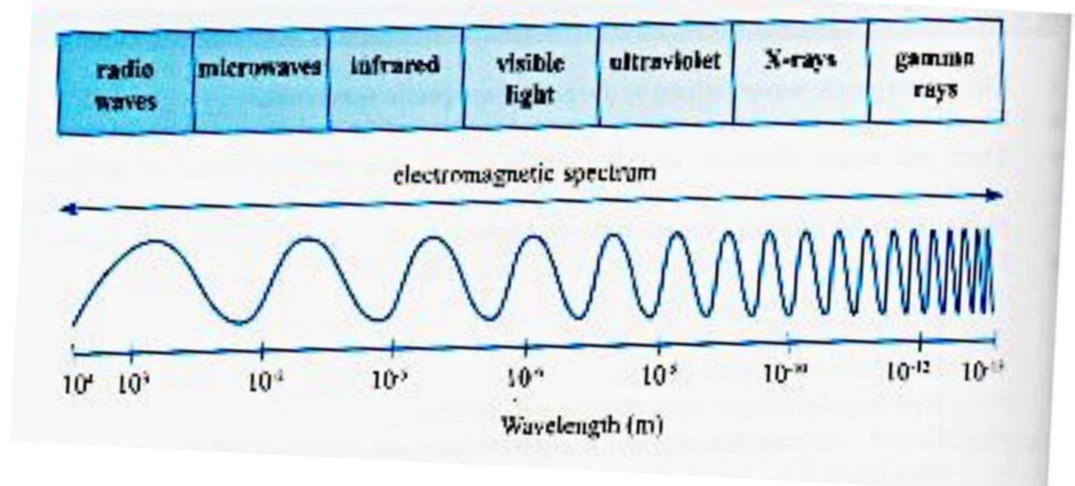
They are transverse waves, travelling at a speed of 3×10^8 m/s in vacuum. They obey the laws of reflection and refraction as well as the wave equation.

Gamma, X-rays, UV rays, visible light, infrared, microwaves, radiowaves

Uses: Gamma ray – kill cancer cells
- X ray – dental or bones inspection
- UV ray – sterilisation & detect forgery
- Infrared – remote control
- microwaves – communication via satellite
- radiowaves – radio and TV station signals

low frequency, long wavelength

high frequency, short wavelength



Light

Laws of reflection:

1. angle of incidence = angle of reflection
2. The incident ray, normal and reflected ray at the point of incidence all lie on the same plane.

Refraction is the bending of light when light travels from one medium to another. This is due to the change of speed of light in different medium.

Light bends **towards normal** in an optically **denser medium** but **bends away** in an optically **less dense medium**.

Light travels faster in air (optically less dense) than in solid (optically denser medium)

Ray diagrams for reflection and refraction.

Refractive index

η = sin i / sin r
= c / v
= 1 / sin c

Critical angle is the angle of incidence in the optically denser medium such that the angle of refraction in the less dense medium is 90^0.

Total Internal reflection occurs when

1. light travels from an optically denser medium to a less dense medium and
2. the angle of incidence is greater than critical angle.

Optics

Lenses

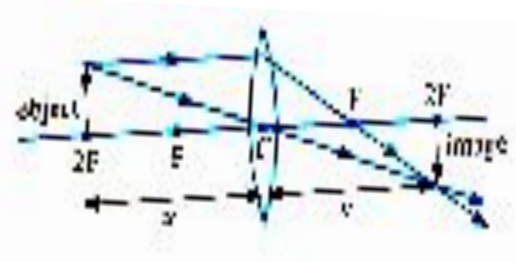
Parallel rays represent light coming from **a distant object.**
The image of the distant object is found at the focal point/ plane.
The focal length is the **distance between the optical centre and the image.**

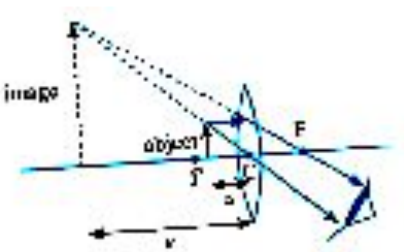
But for a <u>near object</u>, the **focal length** is the **distance between the optical centre and the focal point.**

Ray diagram

1. Object distance > 2F, image is real , inverted and diminished (used in camera or eye)
2. Object distance = 2F, image is real, inverted and same size (used in photocopier)
3. Object distance between F and 2F, image is real, inverted and enlarged (used in projector)
4. Object distance < F, image is virtual, upright and enlarged (used in magnifying glass)

Virtual image is image that cannot be projected on a screen.





ELECTRICITY

Current electricity

Potential difference
A potential difference is the work done to push a unit charge between two points in a circuit. (SI unit: volt)
Measured using a voltmeter connected in parallel across the component (bulb, resistor etc.)
V = W / Q

EMF is the work done to push a unit charge throughout the whole circuit.
(SI unit: volt)

E = W / Q

Current is the rate of flow of charges.
(SI unit: A)
Q = I x t
Measured using ammeter in series (with the component).

Resistance = potential difference /current.
(SI unit: Ω)
R = V / I

R = ρ *l* / A

Long and thin wire has a higher resistance.

Short and thick wire has a lower resistance.

Electric Field

Is a region where an electric charge experiences an electric force.
The field lines **flow out of a positive charge** but **flows into a negative charge.** Field strength is **stronger near a point charge** but weaker further away.

D.C Circuits

The current at every point in a series circuit is the same.

The current from the source is the sum of the currents in the separate branches of a parallel circuit.

The current from the source is larger than that in each of the branches

The sum of the potential differences in a series circuit is equal to the e.m.f across the whole circuit

Effective resistance of resistors in series $= r_1 + r_2 + \ldots$
Effective resistance of resistors in parallel $= (1/r_1 + 1/r_2 + \ldots)^{-1}$

LDR – resistance decreases when light intensity increases.

Thermistor – resistance decreases with rising temperature.

A **potential divider** is a circuit with 2 resistors connected in series.

A **potentiometer** makes use of variable resistor to obtain variable output voltage.

Static Electricity

An object can be charged either by induction or friction.
Like charges repel, unlike charges attract.
When a body loses/ gains electrons, it becomes positively/ negatively charged.

A neutral body carries equal no. of positive and negative charges.

Practical electricity

Power = I V = I^2 R = V^2 / R
E = I V t = I^2 R t = V^2 t / R or E = P t

Energy may be in **Joules** or **kWh.**
Cost of electricity = Energy (kWh) x unit charge

Hazards of:

-**damaged insulation** □ bare wires exposed □ short circuit and large current, overheating & fire. Person may get electrocuted (electric shock**)**

-**overheating of cables (overloading or wires of incorrect ratings)** □ thin wires have high R, produce more heat and gets hot faster. **Overloading** □ **large current, fire**

- damp conditions □ water is a good conductor of electricity □ electrocuted

- poor or loose connections □ short circuits, overheating and sparks □ fire

@ fuse (melts and breaks the circuit when current is very large, to prevent over-heating)

@ earthing metal case (large I flow to E, no E shock)

@ double insulation (electrical cables insulated from internal components & internal components are insulated from the external components)

@ circuit breakers (breaks when I is very large)

Live (brown): connected to mains at 240 V in SG, carries current from mains to appliance

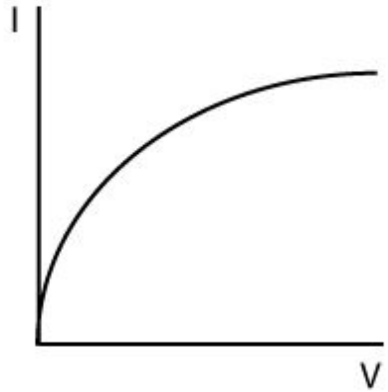
Neutral (blue): Connected to mains to ground (0 V), carries current from appliance to mains.

Earth(green & yellow): safety wire to **metal** body of appliance to ground (carry leakage current from metal casing to the ground, to prevent electric shock)

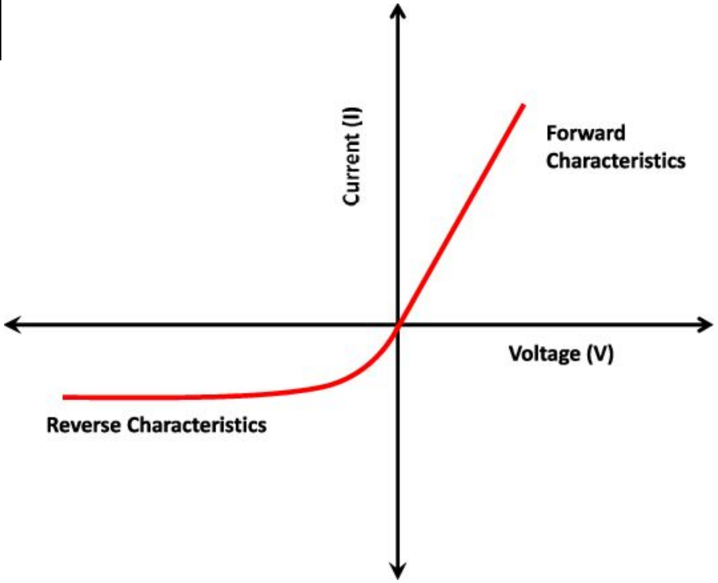
Switches and fuses are necessary in live leads so that when we switch off, the appliance will not be connected to the live wire.

When a fuse melts or blows, the appliance is also cut off from the live wire.

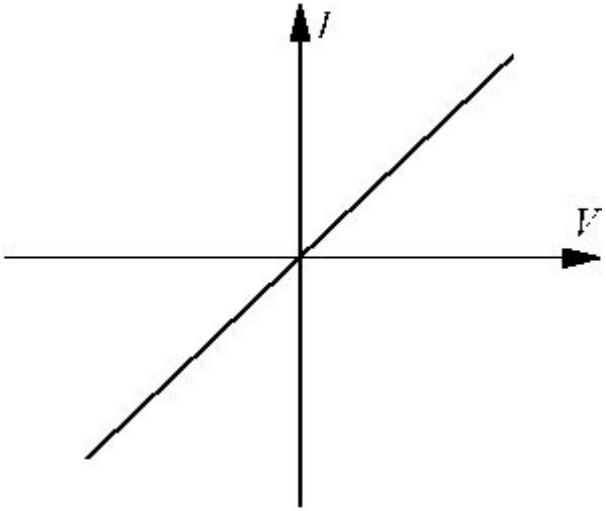
ELECTRICITY



I-V graph of a filament
(I increases, temp increases, R increases)



I-V graph of a semi-conductor diode
(I is very large, R decreases)



I-V graph of an ohmic conductor
(R is constant)

MAGNETISM

Magnets

Properties of magnets

1) Ends/Poles are where magnetic attraction is strongest
2) **Like poles repel, unlike poles attract.**
3) It can attract magnetic materials
4) A *freely suspended* magnet will always lie in a north-south direction

Magnetic materials:
Nickel, Iron, Steel, Cobalt

Non-magnetic materials: Copper, Aluminium, Bronze, Tin, Zinc, Plastic, Glass

A magnetic object is **an induced magnet** and the process is called **induced magnetism.**

Soft magnetic material: iron is easy to magnetise and demagnetise. Hence, eletromagnet is made of iron.

Hard magnetic material: Steel is difficult to magnetise and demagnetise. It is used as a permanent magnet. Permanent magnets are used in compass, loudspeakers, fridge door.

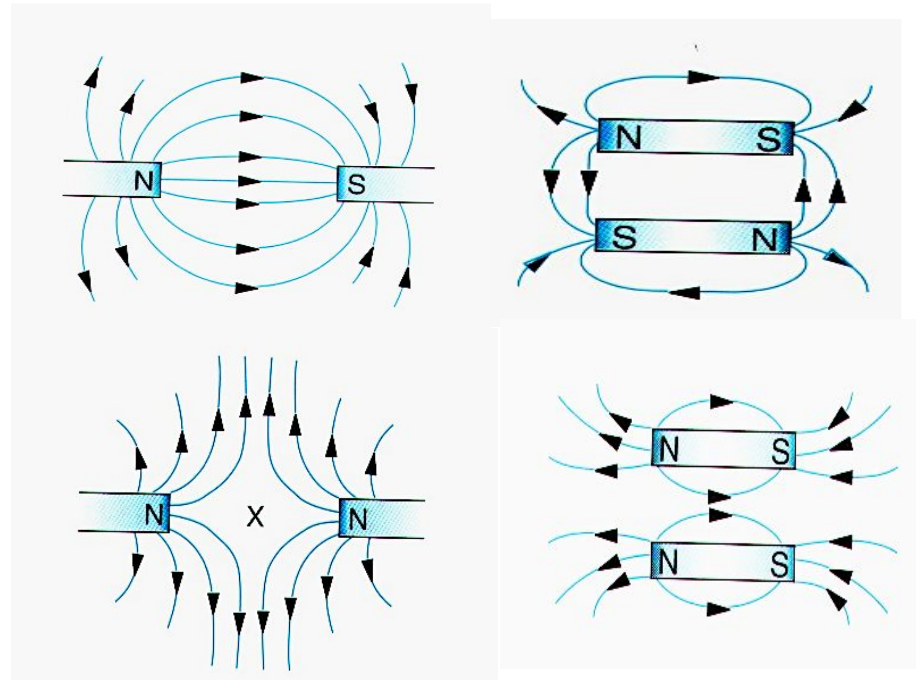
Magnetisation: stroking with a magnet and electrical method (d.c.)

Demagnetisation: heating strongly (with a Bunsen burner), hammering many times and electrical method (using a.c. supply and remove magnet from solenoid slowly in an east-west direction).

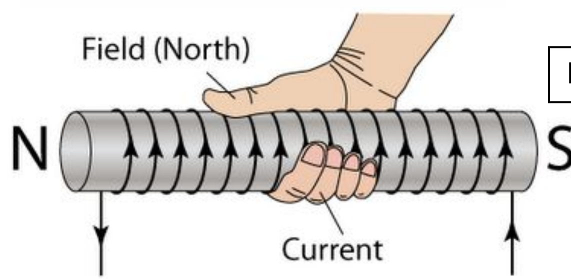
Use a **Right-hand grip rule** to determine the polarity of a magnet.
The thumb represents the North pole. The fingers represent the direction of current flow.

To make a magnet stronger:
1. increase the current
2. increase the number of turns in a coil

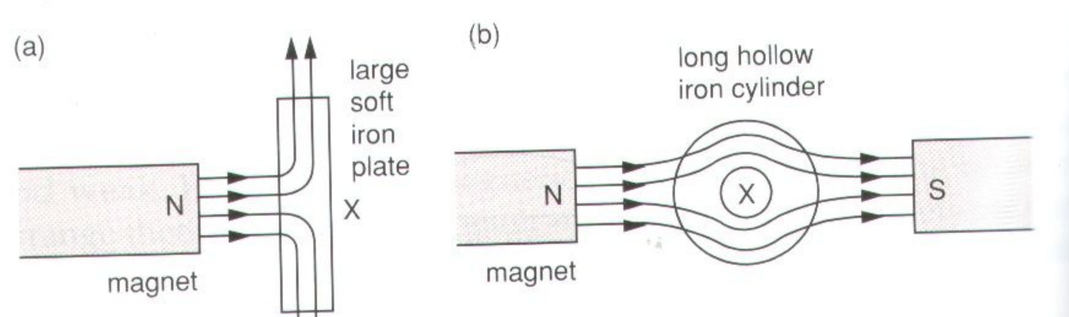
Magnetic field flows from **North pole to South pole**.



Right-hand grip rule



Magnetic shielding



ELECTROMAGNETISM

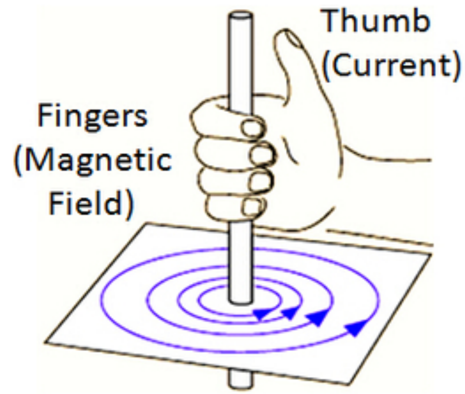
<u>Magnetic effect of a Current</u>
A current flowing through a straight wire creates a magnetic field.
The **Right-hand grip rule** is used to find the direction of the magnetic field. The thumb represents the current while the fingers represent the direction of the magnetic field (either in clockwise or anticlockwise direction). The circles get wider as the magnetic field moves further away from the wire.

The **magnetic field** in a long straight wire is **stronger** when iti is **closer** to the wire and a **large current** is flowing through the wire.

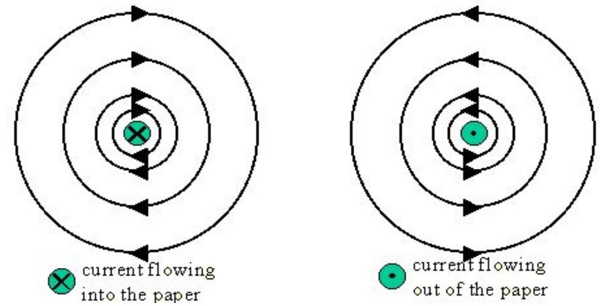
<u>Force on a current-carrying conductor</u>
A current-carrying conductor experiences a force when placed in a magnetic field.
The force acts perpendicular to both the current and the magnetic field.
If the **direction of the current or magnetic field is reversed**, **the direction of the force** on the conductor will **also reversed**.

Using **Fleming's Left-hand rule**, <u>thumb</u> <u>r</u>epresents the direction of FORCE, <u>fore-finger</u> represents the direction of MAGNETIC FIELD, <u>middle finger</u> represents the direction of CURRENT.

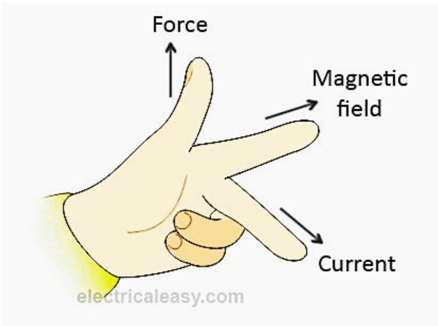
A magnetic field is set up by 2 magnets with a current flowing through a rectangular coil between them. The coil experiences a turning effect. The turning effect can be increased by **increasing the current** and **increasing the number of turns on the wire coil** and **inserting a soft iron core into the coil.**

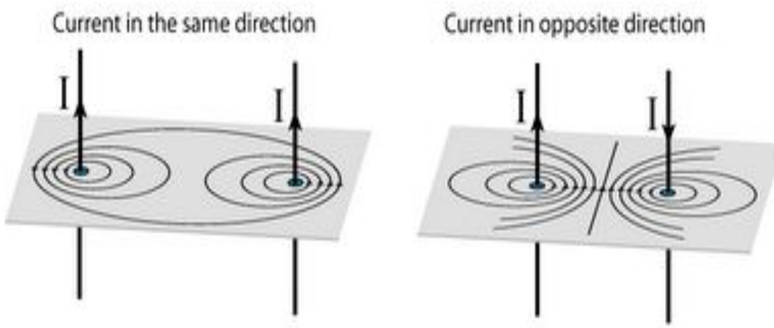


Magnetic field due to currents in straight wire

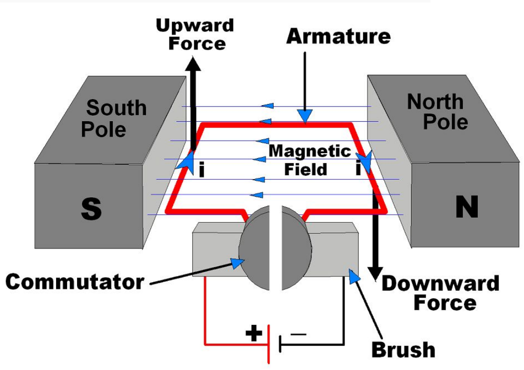


D.C. motor





Equal currents attract, unequal currents repel



DC Motor Conceptual Diagram

ELECTROMAGNETIC INDUCTION

Varying or changing a magnetic field can produce an e.m.f which will produce an induced current in a closed circuit. This process is known as **electromagnetic induction**.

Faraday's Solenoid Expt

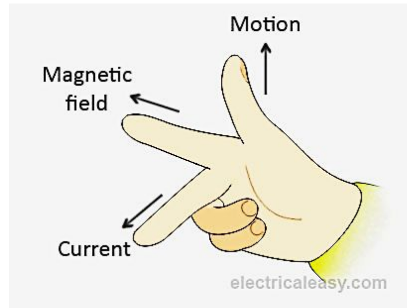
When a permanent magnet is **inserted into a solenoid** connected to a galvanometer, the needle is deflected to **one direction**.
When a permanent magnet is **withdrawn from the solenoid** connected to a galvanometer, the needle is deflected in the **opposite direction**.
When a permanent magnet is **stationary** in the solenoid, the galvanometer needle **does not deflect**.

The magnitude of the e.m.f depends on
- the no. of turns in the solenoid
- the strength of the magnet
- the speed at which the magnet is inserted or withdrawn from the solenoid

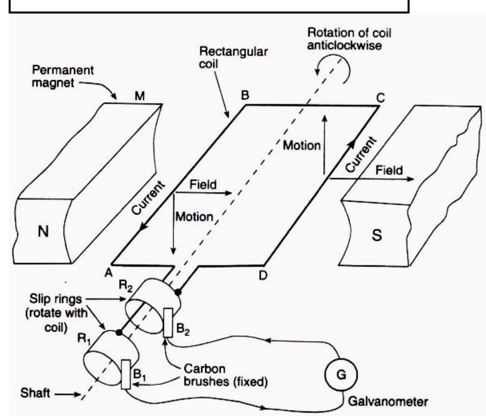
Laws of Electromagnetic induction

The motion of magnet generates an induced e.m.f in the circuit.
Faraday's Law states that the magnitude of the induced e.m.f is directly proportional to the rate of change of magnetic flux in the circuit.
Lenz's Law states that the direction of the induced e.m.f and hence the induced current in a closed circuit, is always such that its magnetic effect opposes the motion or change producing it.

A.C Generator



a.c. generator transforms mechanical energy into electrical energy, thus producing electricity.
When a force is applied to turn the coil between the magnets, magnetic field passing through a rectangular coil changes, thus causing an induced current. The direction of the induced current is determined by **Fleming's Right-hand rule.**



A **transformer** is a device that changes a high alternating voltage to a low alternating voltage and vice versa.

The relationship between the secondary output voltage to primary input voltage is related to the number of coils around the transformer.

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

In an ideal transformer, the power supplied to the primary coil is fully transferred to the secondary coil.

$$V_P I_P = V_S I_P$$

A **step-up transformer** increases the secondary voltage while a **step-down transformer** decreases the secondary voltage.

Power losses are incurred when voltages are transmitted over long distances.
In order to reduce power loss, high voltage is used.
When voltage is high, current in the cables is low.
The lower the current, the lesser the heat loss in the wire.
$P = I^2R$

RADIOACTIVITY

The atom
- positively charged nucleus and negatively charged electrons around the nucleus
- the nucleus is made up of positively charged protons and neutrons (no charge)
- The number of protons in a nucleus is known as the **proton/ atomic number, Z**.
- The number of protons and neutrons in a nucleus is known as the **nucleon/ mass number A.**
- Isotopes are atoms with the same proton number but different mass numbers.

Background radiation
- nuclear radiation in an environment where no radioactive source has been deliberately introduced
- should be subtracted from readings when measuring radioactivity of a source
- radioactivity can be measured using a Geiger-Muller (GM) counter

Half-life
- each nuclide has a fixed rate of decay
- half-life is the time taken for half of the nuclei in a sample to decay

Nuclide notation

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

- A: nucleon/ mass number
- Z: proton/ atomic number
- X: chemical symbol of element

Uses of Radioactivity

1)**Ionizing power**
- smoke detector (α)

2)**Penetrating ability**
- measuring thickness of materials (β/γ)

3)**Short half-life**
(used when the radioactive sample is needed to be put into the body for medical reasons)
- detection of tumours (γ)
- treatment of thyroid by destroying thyroid cells (β)

4)**Long half-life**
(radioactive samples don't need to be replaced frequently / only a small quantity is needed over a long time)
- gamma knife radiosurgery to destroy tumours (γ)
- sterilizing food/ medical equipment by killing microbes (γ)
- carbon dating (α)

Nuclear decay
- Nuclear decay is a **random** and **spontaneous** process whereby an unstable nucleus loses energy by emitting radiation
- Nuclear decay cannot be forced or predicted
- There are 3 types of nuclear decay: alpha decay, beta decay and gamma decay

Alpha (α) particles
- Emitted during alpha decay
- It is a **helium** nucleus
- Ionizing power: Highest
- Penetrating power: stopped by a sheet of paper (Low)

Beta (β) particles
- Emitted during beta decay
- It is a high energy **electron**
- Ionizing power: Mid
- Penetrating power: stopped by 3mm thick of aluminium (Mid)

Gamma (γ) rays
- Emitted during gamma decay
- It is an electromagnetic wave
- Ionizing power: Low
- Penetrating power: stopped by a few cm thick of lead (High)

Hazards of Radioactivity
- damage to healthy cells (kill cells, cause mutations and cancer)
- damage to the environment (plants and animals suffer from mutations, stunted growth or reproductive defects)

Precautions
- reducing exposure (reducing exposure time, increase distance from the source, shielding, proper storage of radioactive material)
- limit contamination (leave an affected area, remove outer layer and wash exposed body parts)