ZNOTES.ORG

UPDATED TO 2023-2025 SYLLABUS

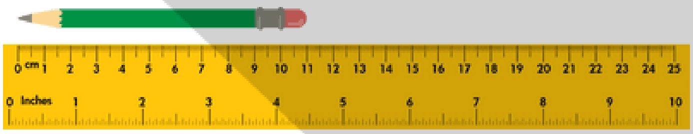
CAIE IGCSE
PHYSICS

SUMMARIZED NOTES ON THE THEORY SYLLABUS

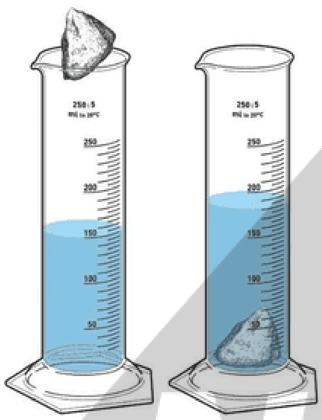
1. Motion, Forces and Energy

1.1. Physical Quantities and Measurement Techniques

- **Length:**
  - The **metre rule** can measure distances of a few centimetres (cm) and the nearest millimetre (mm).
  - A **tape measure** will be used for measuring longer distances.
  - Ensure the line of sight is at 90 degrees to avoid parallax error.



- **Volume**
  - A **measuring cylinder** can measure liquid volume and volume change when measuring irregular objects. (Ensure you measure from the bottom of the meniscus)



- **Time**
  - **Clock, Digital Timers** (reading to 0.1s or better) to measure time intervals

Finding the Thickness of 1 Paper

- Measure the thickness of 100 sheets of paper.
- Dividing your answer by 100 will then give an accurate figure for one sheet

Système International (SI) Units

SI Units	Units
Length	metre (m)
Mass	kilogram (kg)
Time	seconds (s)

~~Standard Notation is always in the **power of 10**~~

1. 4000 = 4 × 10 × 10 × 10 = 4×10^3
2. 400 = 4 × 10 × 10= 4×10^2

All answers in this IGCSE Physics syllabus can be written in 2 or 3 significant figures.

Common Length Conversions

Measurements	Units in meters
1 decimetre (dm)	10^{-1} meters (m)
1 centimetre (cm)	10^{-2} meters (m)
1 millimetre (mm)	10^{-3} meters (m)
1 micrometre (μm)	10^{-6} meters (m)
1 nanometre (nm)	10^{-9} meters (m)

Measurements	Units in meters
1 kilometre (km)	10^3 meters (m)
1 gigametre (Gm)	10^9 meters (m)

Scalar and Vector Quantities

Scalar	Vector
✔ magnitude, X direction	✔ magnitude, ✔ direction
Distance, Energy, Temperature, Speed, Time, Mass	Force, Weight, Velocity, Acceleration, Momentum, Electric Field Strength and Gravitational Field Strength

Calculating Vectors (Calculation or Graphically)

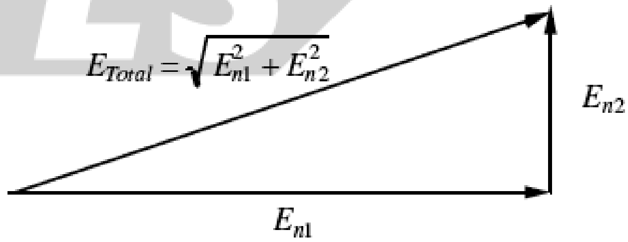
If forces W and Q are acting at right angles to each other from a point

Calculate the magnitude by using:

$F = \sqrt{W^2 + Q^2}$

Calculate the force by using:

$\tan(x) = \frac{W}{Q}$



1.2. Motion

Speed: the distance travelled per unit of time.

Use the equation

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

Where:

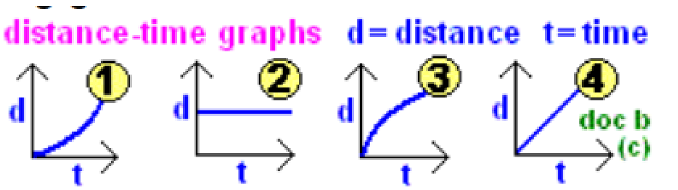
- v is speed (m/s)

- s is displacement (m)
- t is time (s)

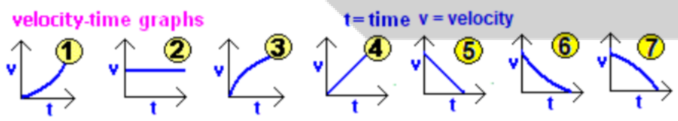
$$AverageSpeed = \frac{d}{t}$$

Velocity: the speed in a given direction.

Distance-Time Graphs



	Distance-Time Graphs
1	Acceleration
2	At rest
3	Deceleration
4	Constant Speed



Speed-Time Graphs

	Speed-Time Graphs
1	Increasing Acceleration
2	Constant Speed
3	Decreasing Acceleration
4	Uniform Acceleration
5	Uniform Deceleration
6	Decreasing Deceleration
7	Increasing Deceleration

Acceleration

Acceleration: the change in velocity per unit of time.

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

Where:

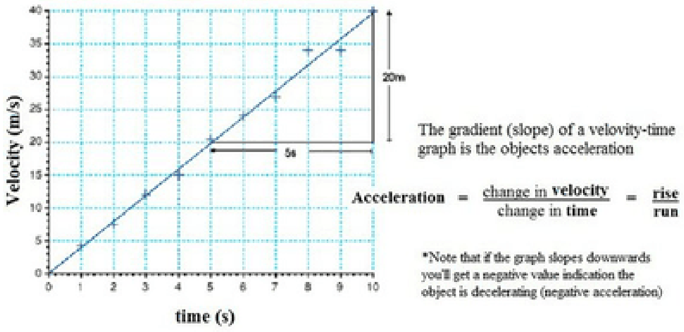
- a is acceleration
- v is the final velocity
- u is the initial velocity
- Δt is the change in time.

The difference between the initial and final velocity finds the **change in velocity.**

- Change in velocity = final velocity − initial velocity
- $\Delta v = v - u$

NOTE: Deceleration is the same as **Negative Acceleration**.

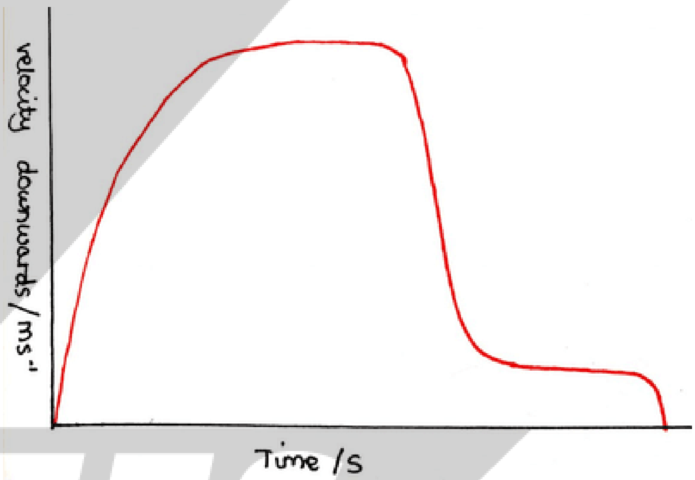
Calculating Acceleration on Speed-Time Graphs



Free Fall

- The acceleration of free fall "**g**" for an object near the surface of the Earth is constant and is approximately **9.8 m/s²**.
- Do note! In free fall, there is **No Air Resistance**.
- From 2023 onwards, the instructions will tell you to use **9.8 m/s²**. This detail is very important for numerous calculations in this chapter.

Terminal Velocity



1. As speed increases, air resistance increases.
2. The acceleration will decrease.
3. Eventually, **air resistance = weight**, leading to zero resultant force. This reaches terminal velocity.
4. When the parachute is deployed, the parachute surface area increases, leading to increased air resistance, decelerating the skydiver.
5. As the skydiver decelerates, air resistance will decrease until it equals the weight. A new terminal velocity is reached again.
6. At last, when it touches down, the velocity quickly drops to zero.

1.3. Mass and Weight

Mass: a measure of the quantity of matter in an object at rest relative to the observer. The mass of a body is a measure of the amount of matter in it.

Weight: a gravitational force on an object that has mass.

Gravitational field strength g: as force per unit mass.
The equation for gravitational field strength is :
$g = \frac{W}{m}$

- Gravitational field strength is equivalent to the **acceleration of free fall.**
- Weights (and masses) may be compared using a balance.
- The weight of an object is the effect of a gravitational field on its mass.

Weights (and masses) may be compared using a **balance.**

1.4. Density

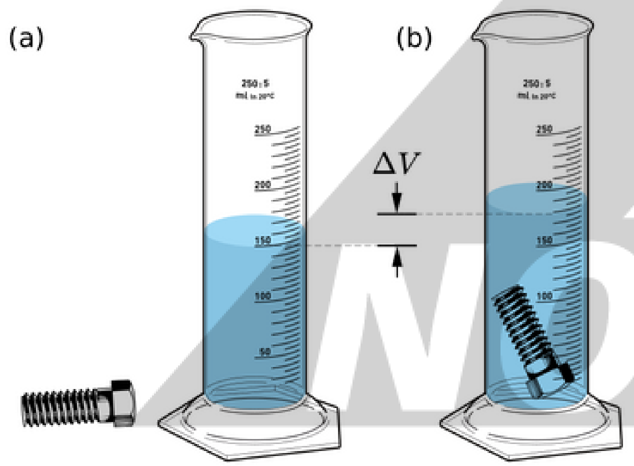
Density: mass per unit volume.
The equation for density is:
$p = \frac{m}{v}$

- p = density
- m = mass
- v = volume

With this equation, you can determine the density of a liquid, of a r**egularly shaped solid**

Finding the Density of an Irregularly Shaped Object

- Use a balance to measure the mass of the object
- Find the volume using the **water displacement method**



- Use the formulae $p = \frac{m}{v}$

Sinking Phenomenon

An object will sink in a liquid of lower density than its own

- e.g., Wood has a lower density than water, so it floats
- For, steel has a higher density than water, so it sinks

1.5. Forces

- A force is a push or a pull.
- Forces may produce changes in an object's **size, shape and motion.**
- Solid friction is the force between two surfaces that may impede motion and produce heating.
- Friction (drag) acts on an object moving through a liquid or a gas (air resistance).

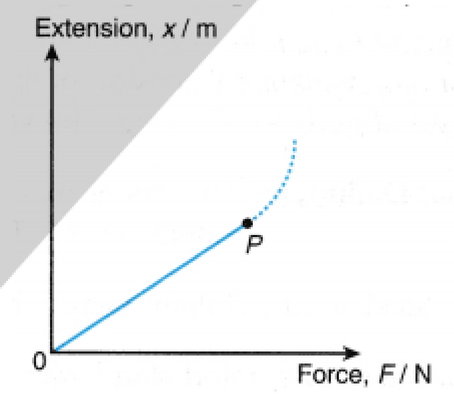
Springs

Hooke's Law
Extension is **directly proportional** to force
This is only true if the limit of proportionality is not exceeded

- **The limit of proportionality** is the point at which the load-extension graph becomes non-linear.

Properties of Hooke's Law

- The graph starts from the origin (0)
- The graph is regular and in a straight line



Spring Constant

The spring constant $k$is defined as force per unit extension. \n Recall and use the equation:
$k = \frac{F}{x}$
Where:

- F is the force or load (N)
- x is the extension (cm)
- k is the spring constant (N/m, N/cm, N/mm)

Forces And Resultants

- It has magnitude and direction (vector quantity)
- Usually, there is more than one force acting on the object

Newton's First Law

- An object stays at rest or continues to move in a straight line at a constant speed unless acted on by a resultant force.

For example, if these forces were absent, an object would move on forever

- The lesser the external forces opposing a moving body, the smaller the force needed to keep it moving with constant velocity

Newton's Second Law

$F = ma$

- F= force
- m= mass
- a = acceleration
- This is the force that acts on an object going from point A to point B

Friction

Friction is the force that opposes one surface moving or trying to move.

- ~~**Static Friction:** when the force is applied on the object at the start, and the friction is at its **highest** value~~
- ~~**Dynamic Friction:** when friction acts on the object when it moves, it is less than the maximum value.~~

Centripetal Force

- The force that acts towards the curve's centre and keeps a body moving in a circular path is called the **centripetal force.**
- Describe the motion in a circular path due to a force perpendicular to the motion.
- In a circular motion, if speed increases, the force needed increases (mass and radius are constants).
- In a circular motion, if the radius decreases, the force needed increases (mass and speed are constants). In a circular motion, an increased force is required to keep speed and radius constant if mass is increased.
- the direction of the force is always towards the centre of the circle

Moments of Forces

- Moment of a force as a measure of its **turning effect.**

The moment of a force is defined as
moment = force x perpendicular distance from pivot

Applying the Principle of Moments

> When a body is not moving the sum of the clockwise moments about any point equals the sum of the anticlockwise moments about the same point. There is no resultant moment on an object in equilibrium
> $clockwise = anticlockwise$

- Apply the principle of moments in situations with more than one force on each side of the pivot.

Conditions for No Resultant Force

- no resultant force
- clockwise = anticlockwise

Center of Gravity

Centre of Gravity: the position at which all the mass of the object is acted at

- If the centre of gravity passes through the base of the object, the object can **topple**

Conditions for Making an Object Stable

- Lower the centre of gravity
- increase the area of the bottom

1.6. Momentum

Momentum: as mass x velocity (kg m/s)

The equation for momentum is $p = mv$
Where:

- p is momentum
- m is mass
- v is velocity

The resultant force is defined as the change in momentum per unit of time:

$$F = \frac{\Delta p}{\Delta t}$$

$$\therefore F = \frac{m\Delta v}{\Delta t}$$

Impulse of a force: as force x time for which force acts:

$$Impulse = F\Delta t = \Delta(mv)$$

The Principle of the Conservation of Momentum

The general law of physics, according to which the quantity called momentum that characterises motion, never changes in an isolated collection of objects; that is, the total momentum of a closed system remains constant.

1.7. Energy, Work and Power

- Energy 'stores' are kinetic, gravitational potential, chemical, elastic (strain), nuclear electrostatic and internal (thermal).
- Energy is transferred between stores during events and processes.
- Energy is transferred by forces (mechanical work done), electrical currents (electrical work done), heating, electromagnetic, sound, and other waves.

The Principle of the Conservation of Energy

- The principle of energy conservation states that energy is neither created nor destroyed. It may transform from one type to another.

- Energy can only be used by converting it from one form to another. Unless energy is added from the outside, a system always possesses the same quantity of energy.
- The chemical energy of the batteries is transformed into electrical energy in a torch, which is then converted into light and heat. This energy is either absorbed or reflected by the environment.

Kinetic Energy Formula

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

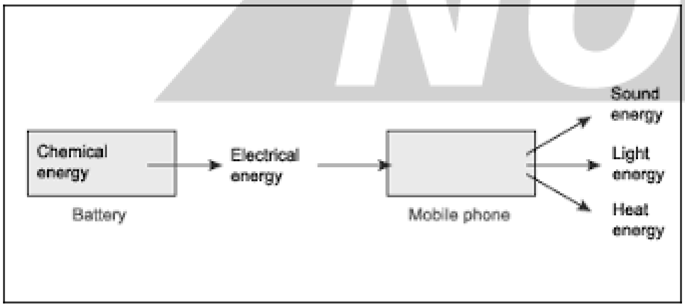
$$E_k = kinetic\ energy\ of\ object$$
$$m = mass\ of\ object$$
$$v = speed\ of\ object$$

Change in Gravitational Potential Energy

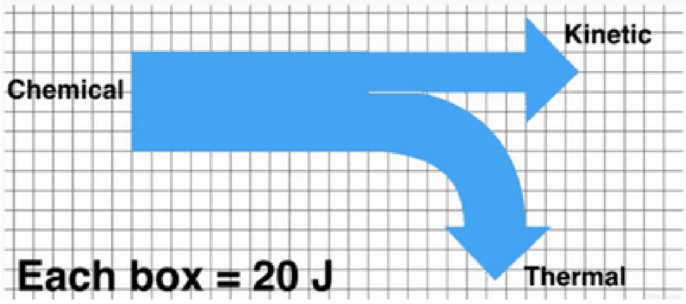
$$E_p = mgh$$

E_p = Potential Energy
m = Mass
g = Gravitational Field Strength
h = Vertical Height

Energy Transfer Diagrams



Sankey Diagrams



- Mechanical or electrical work done is equal to the energy transferred.

The Equation for (mechanical) Work Done is:
$$W = Fd = \Delta E$$
Units: Joules (J)
Where:

- W = Work Done
- F = magnitude of the force
- d = the distance in the direction of the force

Energy Resources

Useful energy may be obtained, or electrical power generated, from:

Non-Renewable Energy Sources	Renewable Energy Sources
Fossil Fuels	Wind
Oils	Tidal
Coal	Hydro-electric
Natural Gas	Geothermal
Nuclear	Solar (EM Waves from the sun)
-	Biofuels

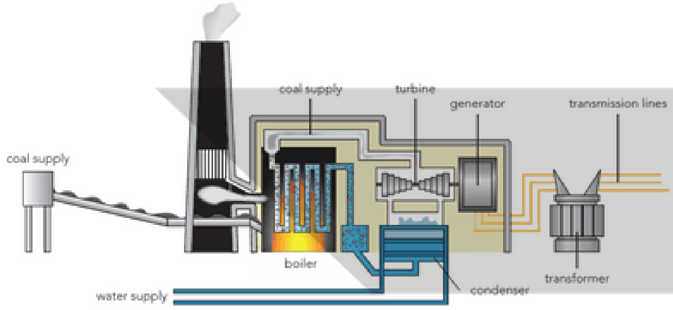
Some sources of energy derive their energy from the sun. These are:

- Coal: formed from dead trees that have used energy from the sun to produce hydrocarbons that have become coal under pressure
- Biofuels: organic matter that is burned to produce energy
- Hydroelectric: energy relies on the sun's energy to run the water cycle so energy can be harnessed
- Wind - gets heated and rises and cooler air flows to fill the space
- Solar - Electromagnetic waves from the sun are captured by photocells and turned into energy

	Renewability	Availability	Reliability	Scale	Environm Impac
Wind	✓	high	low	high	on birc
Solar	✓	high	low	high	low imp
Geothermal	✓	low	high	low	Almost impac
Biofuels	✓	high	high	high	low imp

	Renewability	Availability	Reliability	Scale	Environmental Impact
Hydro-electric	✓	high	high	high	impacts marine life
Tidal	✓	high	low	low	-
Coal	x	high	high	low	Greenhouse gases
Nuclear	x	low	high	high	Radioactive substances

Boilers, turbines, and generators generate electricity in a power plant.



Efficiency

$$\text{Efficiency} = \frac{\text{Useful energy output}}{\text{Total energy input}} \times 100$$

Power

Power: work done per unit of time and energy transferred per unit of time.

$$P = \frac{W}{t}$$

$$P = \frac{\Delta E}{t}$$

- P = power (watt)
- W = work done (J)
- ΔE = energy transferred (J)
- T = time (s)

1.8. Pressure

Pressure is defined as force per unit area and measured in N/m or Pa. 1 Pa = 1 N/m

The equation for pressure is: $p = \frac{F}{a}$

Where:
p is pressure
F is force
a is area

Pressure in Liquids

Pressure beneath a liquid's surface changes with the liquid's depth and density. The equation gives the change in pressure beneath the surface of a liquid:

change in pressure = density x gravitational field strength x change in depth

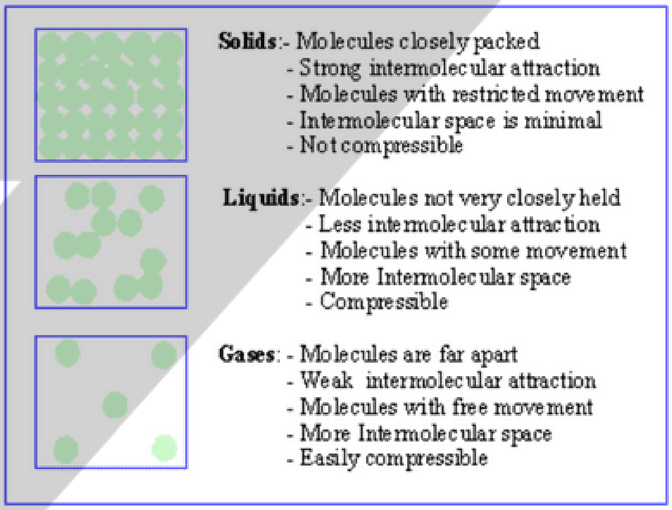
$$\Delta p = \rho g \Delta h$$

Where:
Δp = pressure difference in pascals (Pa)
ρ = density in kilograms per cubic metre (kg/m3)
g = gravitational field strength (N/kg)
Δh = change in height/height of vertical column (m)

2. Thermal Physics

2.1. Kinetic Model of Matter

- **Properties of the 3 States of Matter: The Molecular Model**



- Particles that make up matter can be made of one or more atoms
- **As particles of gas strike the walls of containers, their momentum changes and a force is created,** which can be calculated using the following:

$$F_{net} = \frac{\Delta P}{\Delta t}$$

- The temperature has an Absolute Zero: **-273 °C (Zero Kinetic Energy)**
- **Brownian Motion** is the random motion of particles suspended in a fluid resulting from their collision with fast-moving atoms or molecules in the fluid.

Pressure and Volume at Constant Temperature (Boyle's Law)

P, V, T (Constant)

$P \propto \frac{1}{V}$ P is inversely proportional to V

$P = \frac{k}{V}$

∴ k = PV

$$P_1V_1 = P_2V_2$$

Temperature Conversions

Celcius to Kelvin $^oC \to K : K = {^oC} + 273$
Kelvin to Celcius $K \to {^oC} : {^oC} = K - 273$

2.2. Thermal Properties of Matter and Temperature

Expansion

- All materials expand as they get warmer
- It is impossible to restrict the thermal expansion of solids and liquids
- In Solids, particles vibrate faster and expand slightly in volume when temperature increases.
- In Liquids, particles move faster around each other and expand when temperature increases.
- In Gases, the volume increases by a large amount as they spread out
- **The increasing internal energy of an object :**
  - **Heating**
  - **Rubbing**
  - **Shaking**
- Increased temperature → Increased Internal Energy → Increase in average kinetic energy of particles

e.g.- **Bimetallic Strip**

- When two equal lengths of metals are attached, one metal expands more, and the strip bends.

The Expansion of Ice
As water is cooled to 4°C, it contracts. However, between 4°C and 0°C it expands; water has its maximum density at 4°C

Liquid-in-Glass Thermometer

- It tells us how hot the body is
- the liquid in a glass bulb expands up a capillary tube when the bulb is heated
- this tells us the temperature of the object

Specific Heat Capacity

- The mass of the object
- The material of the object
- The temperature change required
- *The amount of energy required to change the temperature of a material depends on its Specific Heat Capacity.*

$$c = \frac{\Delta E}{m\Delta\theta}$$

Where :

- m = mass (kg)
- c = specific heat capacity (J/Kg^oC)
- ΔE = energy provided (J)
- $\Delta\theta$ = change in temperature (^oC)

Note: 1 Joule = 1 Watt for 1 sec \n J = W x t (s)

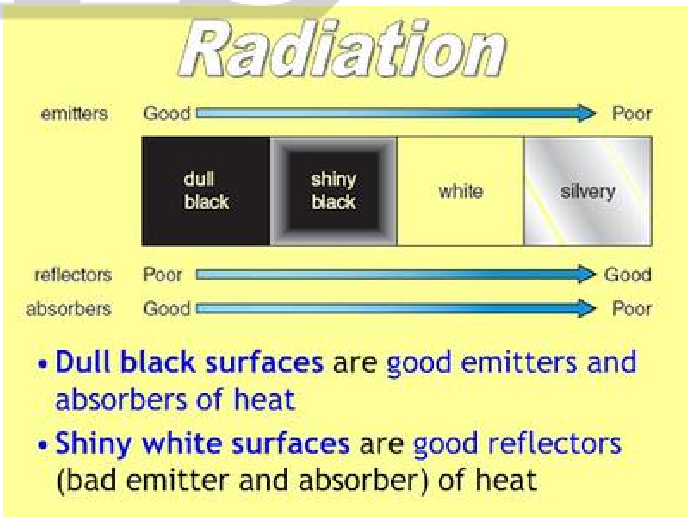
Melting, Boiling, and Evaporation

Melting	Boiling	Evaporation
Occurs at a fixed temperature	Occurs at a fixed temperature	Occurs at any temperature
Speed depends on the energy supply	Relatively fast process	Relatively slow process
It takes place at the surface of the solid only	It takes place throughout the liquid	It takes place at the surface only
No bubbles	Bubbles are formed	No bubbles
Temperature remains constant	Temperature remains constant	Temperature may change
The heat from surroundings or external source	External thermal energy source	Heat from surroundings is required enough

2.3. Thermal Energy Transfers

Conduction	Convection	Radiation
Thermal conductors Particle to Particle	Fluid Conductors are trapped in air pockets to prevent convection flow	Infrared Radiation and Electromagnetic waves. All objects emit and absorb radiation
Through movement and vibration of delocalized electrons \n Not for Vacuums	Fluid with more energy rises above less energy to create a convection current.	It depends on temperature, colour, surface area, and texture
Ex: Kitchen Pans	**Ex: Radiators or heaters**	**Ex: Vacuum of space**

Radiation vs Colour and Texture



Radiation vs Temperature and Surface Area

$$\text{Temperature} \propto \text{Surface area} \propto \text{Energy emitted}$$

3. Waves

3.1. Light

Light: an electromagnetic wave capable of passing through free space or a material medium in the form of varying electric and magnetic fields.

- Normal is a line drawn at right angles between the boundary of two materials.
- The angle of incidence is the angle made by the incident ray to the normal. The angle of reflection is the angle made by the reflected ray to the normal.
- The image formed by a plane mirror has the following characteristics: same size, same distance from the mirror, and virtual.
- **The Law of Reflection** states that the angle of incidence is equal to the angle of reflection.
- The angle of refraction is the angle made by the refracted ray to the normal.
- The critical angle is the angle made to the normal in the denser material when the angle of refraction is 90°.

The Equation for Critical Angle is:

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

$$\text{n} = \text{refractive Index}$$
$$\text{c} = \text{critical angle}$$

- **Refractive index, n**: as the ratio of the speeds of a wave in two different regions

The Equation for the Refractive Index is:

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

$$\text{n} = \text{refractive Index}$$
$$\text{i} = \text{angle of incident}$$
$$\text{r} = \text{angle of refraction}$$

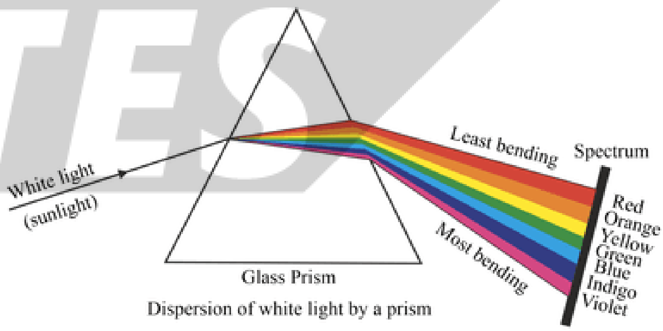
- **Optical fibers** are used mainly in telecommunications.
- A thin, converging lens converges a parallel beam of light.
- A thin diverging lens diverges a parallel beam of light.
- The principal focus (focal point) is the point on the principal axis where parallel waves passing through the lens meet.
- The principal axis is a line of symmetry passing through the centre of the lens.
- The focal length is the distance from the centre of the lens to the principal focus.
- A virtual image is formed when diverging rays are extrapolated backwards and do not form a visible projection on a screen.

Position of Object	Position of Image	The Relative Size of an Image	Nature of Image
At Infinity	At Focus	Point-sized, very small	Real and Inverted
Beyond 2F	Between F and 2F	Diminished	Real and Inverted
At 2F	At 2F	Same size	Real and Inverted
Between F and 2F	Beyond 2F	Enlarged	Real and Inverted
At Focus F	At Infinity	Huge, very large	Real and Inverted
Between F and O	On the same side of the lens as the object	Enlarged	Virtual and Erect

- A single lens is used as a magnifying glass.
- A converging lens is used to correct long-sightedness.
- A diverging lens is used to correct short-sightedness

Dispersion of Light

The **Dispersion of Light** is shown by the refraction of white light passing through a glass prism.



Dispersion of white light by a prism

- The seven colours (red, orange, yellow, green, blue, indigo, and violet) of white light increase from red to violet, and the wavelength decreases from red to blue.
- Visible light of a single frequency or wavelength is described as monochromatic.

Waves

3.2. Sound

Longitudinal waves produced by vibrating sources are known as **sound waves**.

- Sound waves require a medium to be transmitted (such as air).
- Compressions: high pressure
- Rarefactions - low pressure
- Solids transmit sound the fastest, liquids are slower, and gases are the slowest.

Pitch, Amplitude, Frequencies and Echoes

- The louder a sound wave is, the greater its amplitude.
- The higher the pitch of a sound wave, the higher its frequency.
- An echo is a reflection of sound waves.

Methods of Determining the Speed of Sound in Air

Make a noise at a known, significant distance from a solid wall and record the time it takes for the echo (reflected sound) to be heard, then use speed = distance/time, considering that the sound has to travel there and back.

Speed of Sound in Matters and the Human Audible Range

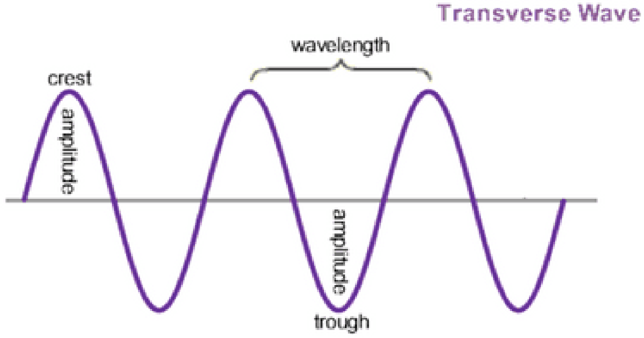
- Sound travels at 343 meters per second in air, 1493 meters per second in water, and 5130 meters per second in steel.
- The audible frequency range for a healthy human ear is 20 Hz to 20000 Hz.

Ultrasound

Ultrasound: sound having a frequency of more than 20000 Hz

- Ultrasound is partially reflected when it reaches a border between two media. The remaining waves pass through. A transceiver can produce ultrasound and collect the reflected waves to determine the distance of objects below the surface. Ultrasound is utilized for SONAR and medical imaging without ionizing radiation.

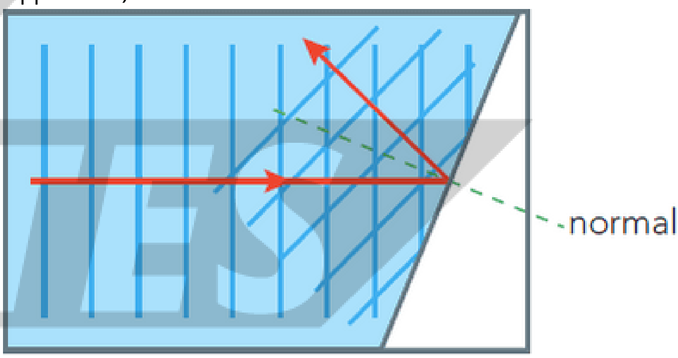
3.3. General Properties of Waves

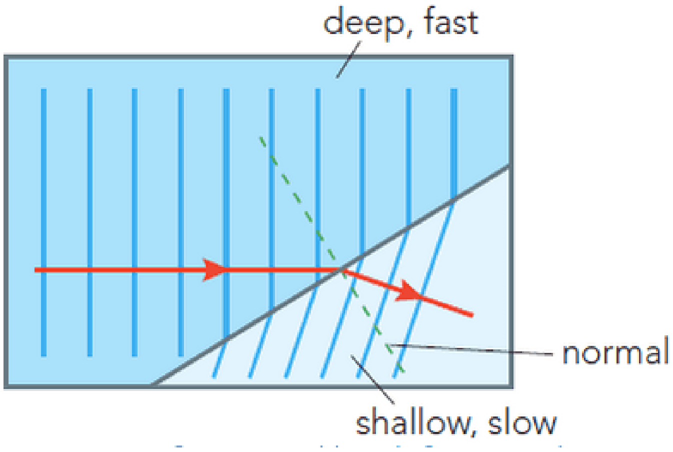


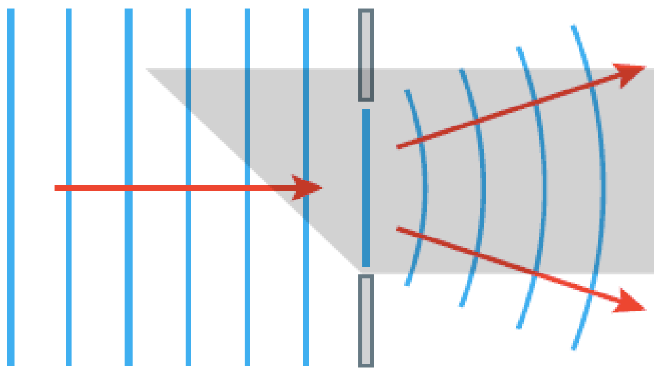
Wavelength (λ): distance between two crests or troughs, measured in mm cm or m
Frequency: Number of complete waves that go past a given point per unit of time.
Measured in hertz (Hz) 1Hz = 1 complete wave per unit second
Amplitude: The maximum particle displacement of the wave from the undisturbed position, measured in mm cm or m
Speed: Distance travelled by the wave per unit time, measured in m/s, cm/s or mm/s
Wavefront: A line drawn to represent the peaks of a wave in two dimensions. The distance between two adjacent wavefronts is the wavelength of the wave. Wavefronts can be used to show some properties of waves.

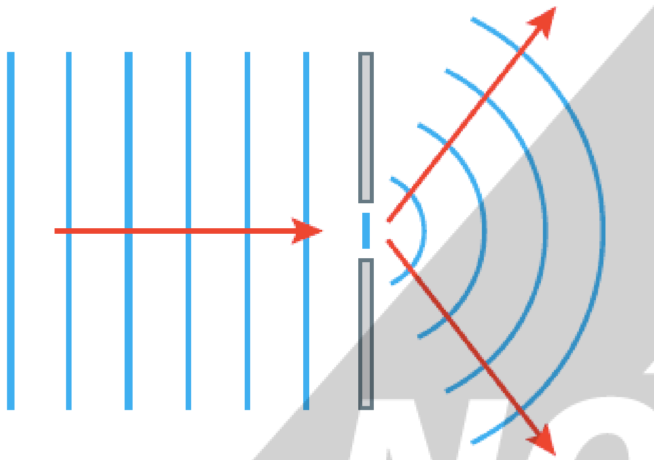
Relationship between speed, frequency and wavelength:

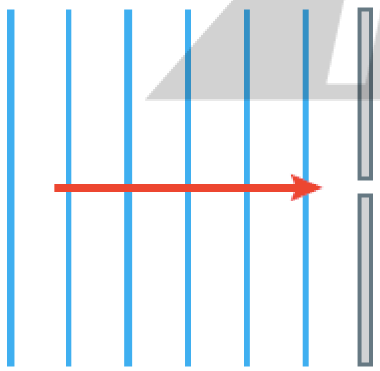
wave speed = frequency × wavelength ; $v = f \times \lambda$
Reflection, refraction and diffraction (using water waves in a ripple tank) :











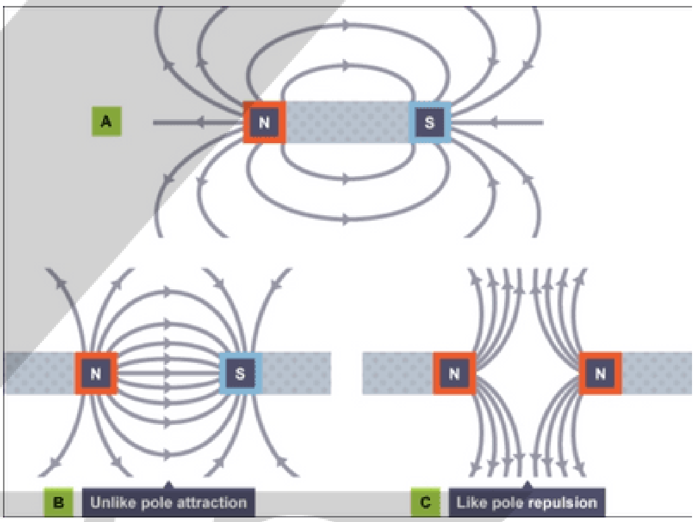
$$\text{Frequency} = \frac{1}{\text{period (s)}} \quad f = \frac{1}{T}$$

$$\text{Period (s)} = \frac{1}{\text{Frequency}} \quad T = \frac{1}{\text{Frequency}}$$

4. Electricity and Magnetism

4.1. Magnetism

- A magnet has a north pole and a south pole.
- The magnetism is strongest at the poles.
- **Unlike poles attract** and **like poles repel**.
- A magnetic material is defined as something that can be magnetised temporarily or permanently.
- When we refer to a 'magnet', we are referring to a permanent magnet, made of magnetically hard materials.
- Permanent magnets remain magnetic (hard) whereas temporary magnets lose their magnetism (soft).
- A soft magnetic material can be induced by attracting it to a strong magnet, however it loses its magnetism once it is removed.
- A magnetic field is a region in which a magnetic pole experiences a force.
- The direction of a magnetic field at a point is the direction of the force on the north pole of a magnet at that point.



- Magnetic field lines can be plotted using a compass or iron filings.
- The spacing between the magnetic field lines shows how strong the field is. As the field lines get further away, the force gets weaker.
- Electromagnetism is explained in the next few lessons.

4.2. Electrical Quantities

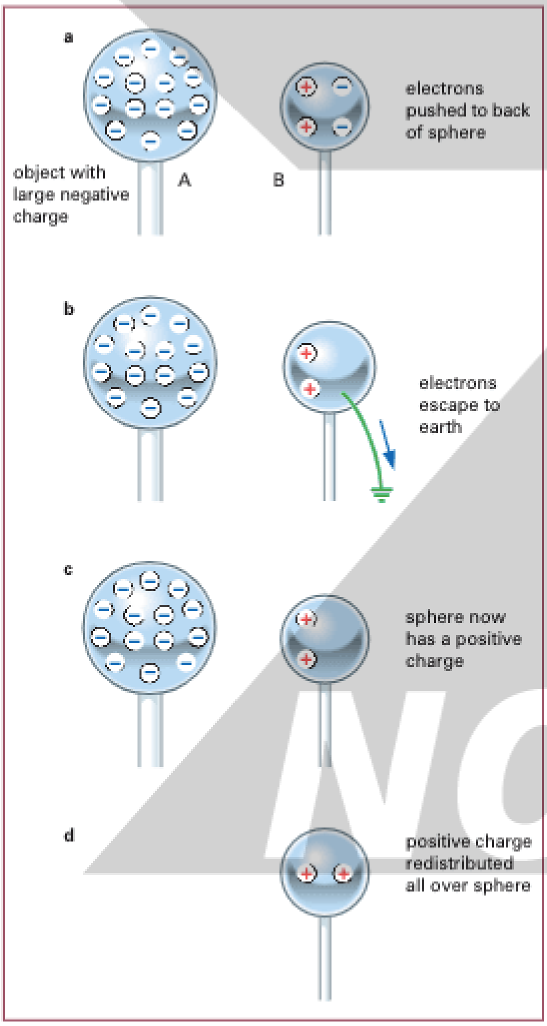
Electric Charge (measured in Coulombs)

- positive or negative
- similar charges repel, and opposite charges attract Electrical conductors and insulators Conductors: are materials that let electrons pass through them. Metals are the best electrical conductors as they have free electrons. E.g. copper

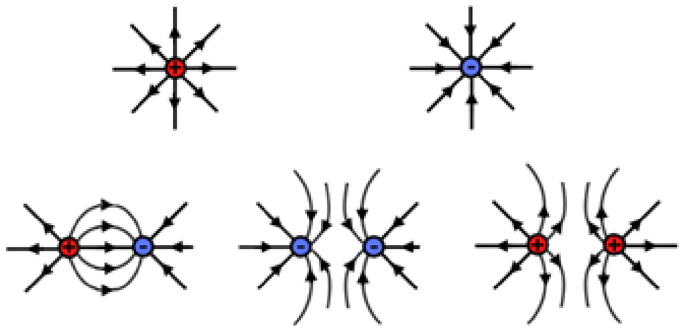
  Insulators: materials that hardly conduct at all. Their electrons are tightly held to atoms and hardly move, but they can be transferred by rubbing. E.g. Rubber Charging insulators by friction

Suspend one of the insulating materials using a cradle and a string length so that the material can rotate freely. Rub one end of the material using a cloth (to give it a charge). Now take a second piece of insulating material and charge that by rubbing with a cloth.
Hold the second piece's charged end close to the first piece's charged end: If the first piece rotates away (is repelled) from the second piece, then the materials have the same charge. If the first piece moved towards (is attracted to) the second piece, then they have opposite charges.

Simple Electrostatic Experiments



Attraction and Repulsion of Point Charges



Current

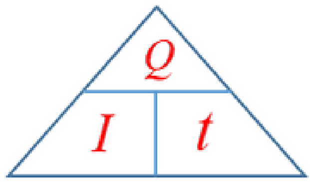
- Current: a flow of charge; the SI unit is the Ampere (A).
- An ammeter measures the current in a circuit and is connected in series
- Current is a rate of flow of charge
- In metals, the current is caused by a flow of electrons

Charge and Current

A current of 1 Ampere = 1 Coulomb of charge flowing in 1 second

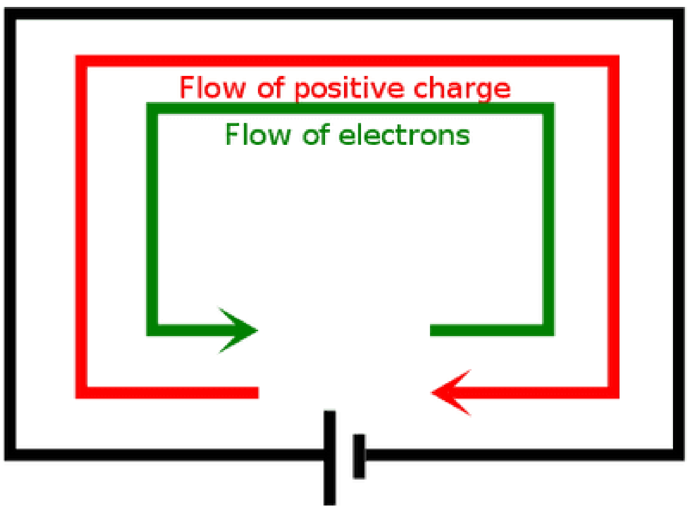
$$I = \frac{Q}{t}$$

$$Q = It$$



I = Current in amperes (A)
Q = Charge in coulombs (C)
t = time in seconds (s)

- Current follows the path of least resistance
- Conventional current flows in the direction opposite to that which electrons flow in.
- Red = Conventional Current
- Green = flow of electrons



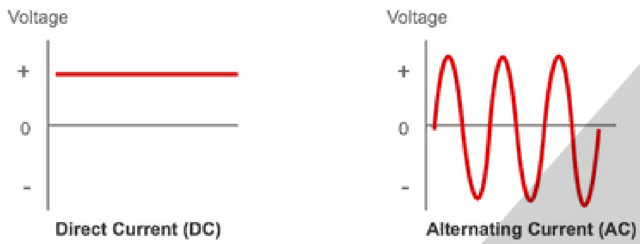
Alternating Current vs Direct Current

Direct Current (dc)

- Direct current is produced when using dry cells and batteries (and sometimes generators, although these are usually AC)
  - The electrons flow in only one direction, from the negative to the positive terminal.
  - Conventional current flows from the positive to the negative terminal

Alternating Current (ac)

- Alternating current typically comes from mains electricity and generators
- It is needed for use in transformers in the National Grid (covered later in this topic)
  - The direction of electron flow changes direction regularly
  - A typical frequency for the reversal of ac current in mains electricity is 50 Hz



Electromotive Force (EMF)

- The energy the source supplies in driving a unit charge around a complete circuit.
- A cell's maximum voltage is called the electromotive force (EMF), measured in volts.
- When a current is supplied, the voltage is lower because of the energy wastage inside the cell.
- A cell produces its maximum PD when not in a circuit and not supplying current.

Potential Difference (P.D)

- The potential difference, or PD for short, is also known as voltage.
- Voltage is the energy the cell gives the electrons it pushes out. Voltage is measured in volts (V) and is measured by a voltmeter (connected in parallel). A cell with 1 Volt delivers 1 Joule of energy to each coulomb of charge (J/C).

THE FORMULA OF P.D

- The formula used to calculate p.d is:

  V = p.d

  W = converted energy

  Q = positive charge
- Therefore, the SI unit of p.d is joule/coulomb, which is volt (V)

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

THE FORMULA OF E.M.F

- The formula used to calculate e.m.f is:

  E = e.m.f

  W = converted energy

  Q = positive charge
- Therefore, the SI unit of e.m.f is joule/coulomb, which is volt (V)

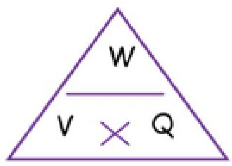
$$E = \frac{W}{Q}$$

Potential difference

- The work done or energy transferred by each coulomb of charge
- Sometimes called voltage
- Potential difference is measured in Volts (V).

Word equation (units): Potential difference (in V) = Work done (in J) / Charge (in C)

Symbol equation: $V = \frac{W}{Q}$



$$E = \frac{W}{Q}$$

E = Electromotive Force

W = Work done

E = Energy

Q = Charge

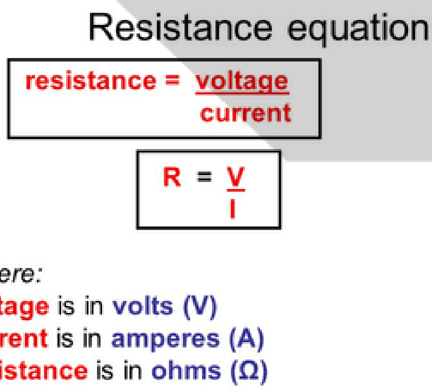
Measuring potential difference and voltage

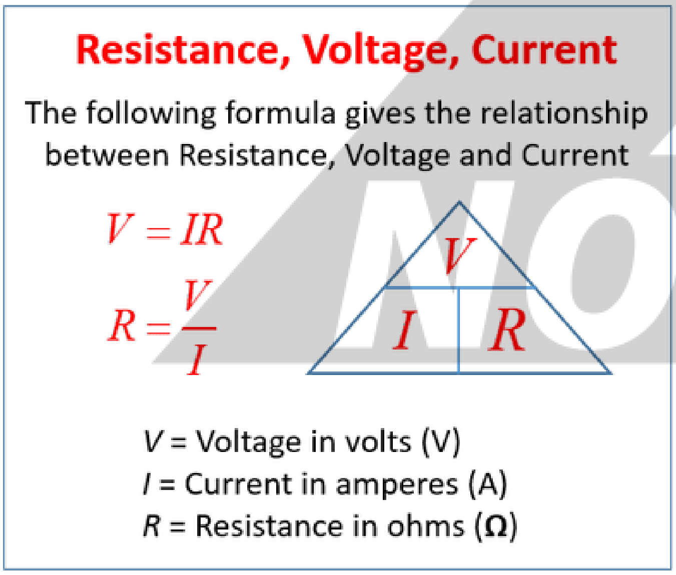
Potential difference is measured using a voltmeter. Voltmeters are connected in parallel with the component being tested. The potential difference is the difference in electrical potential between two points, therefore, the voltmeter has to be connected to two points in the circuit.

Resistance

Resistance is the opposition to the current. For a given potential difference, the higher the resistance, the lower the current. Therefore resistors are used in circuits to control the current. The unit of resistance is the ohm Ω.

$$\text{Resistance }(\Omega) = \frac{\text{Voltage}}{\text{Current}}$$





Factors affecting resistance:

- Length

  $$\Omega \propto L$$

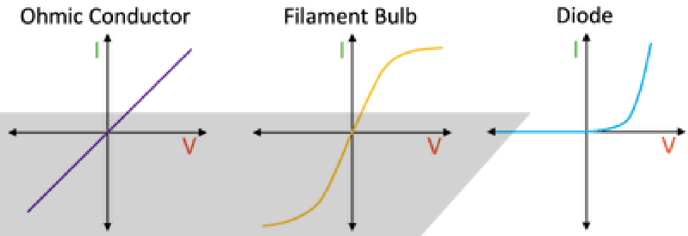
  The electrons have to travel a longer length and thus encounter more resistance.
- Cross-sectional area

$$\Omega \propto \frac{1}{A}$$

More electrons can flow per unit of time, increasing the current and decreasing the resistance.

Current Voltage (IV Graphs)

As the potential difference (voltage) across a component increases, the component's current also increases. The precise relationship between voltage and current can be different for different types of components and is shown by an IV graph:



(Ohmic Conductor = Resistor)

Electrical Energy and Electrical Power Electrical energy is transferred from the battery or power source to the circuit components and then into the surroundings.

1 Watt is 1 J/s $P = \frac{\Delta E}{t}$

P = IV ∴Electrical power = Voltage (V) × Current (A)

$IV = \frac{\Delta E}{t}$ ∴Electrical energy = Voltage (V) × Current (A) × Time (s)

$$E = VIt$$

The Kilowatt Hour

This energy is commonly measured in kilowatt-hour (kW h), which is then used to calculate the cost of energy used. 1 kWh is the electrical energy transferred by a 1 kW appliance in 1 hour

Energy in kWh = power in kW x time in hours.

To convert between Joules and kWh:

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

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

Explanation:

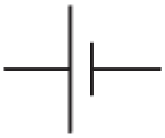
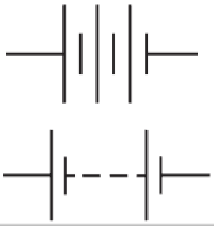
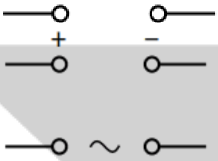
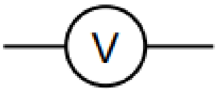
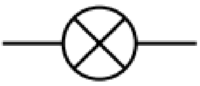
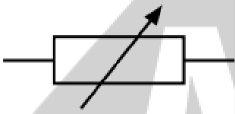
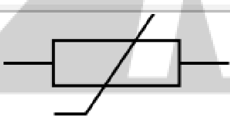
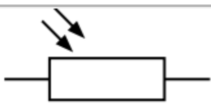
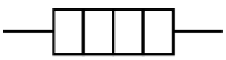
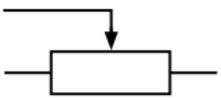
$$\Delta E = Pt \implies 1kWh = 1kW \times 1h$$

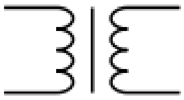
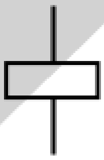
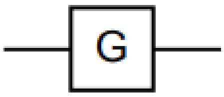
$$1\text{Watt} = \frac{1J}{s} \text{and } 1kW = 1000W \implies 1kW = \frac{1000J}{s}$$

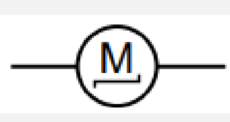
$$\implies 1kWh = 1000J \times 3600s = 3.6 \times 10^6 J$$

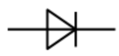
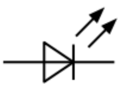
Circuit diagrams and components

Component	Symbol	Function
Switch		In open position the circuit is broken so no current flows

Component	Symbol	Function
Cell		Supplies the electrical energy to the circuit
Battery		A battery is more than one cell.
Power Supply d.c. and **a.c.**		A power supply is a device that converts one voltage to another more convenient voltage while delivering power.
Ammeter		Instrument used to measure electrical current.
Voltmeter		Instrument used to measure potential difference.
Lamp		Converts electrical energy to light.
Fixed Resistor		Restricts the flow of electrical current. Can be used to limit the flow of current to a particular component.
Variable Resistor		Used to control current and resistance in a circuit.
Thermistor		Converts heat to electrical resistance.
Light-Dependent Resistor		Converts light to electrical resistance.
Heater		Converts electrical energy to heat.
Potential Divider		To provide a variable potential difference. To split the potential difference of a power source between two or more components.

Component	Symbol	Function
Transformer		A transformer is a device that transfers electric energy from one alternating-current circuit to one or more other circuits, either increasing (stepping up) or reducing (stepping down) the voltage.
Magnetising Coils		Electromagnetic coils are used in electrical engineering, in applications where electric currents interact with magnetic fields, in devices such as electric motors, generators, inductors, electromagnets and transformers.
Fuse		A safety device which melts to break the circuit if the electrical current flowing through it exceeds a specified value.
Relay		The relay permits a small amount of electrical current to control high current loads. When voltage is supplied to the coil, small current passes through the coil, resulting in a larger amount of current passing through the contacts to control the electrical load.
Generator		An electric generator is a device that converts mechanical energy obtained from an external source into electrical energy as the output.

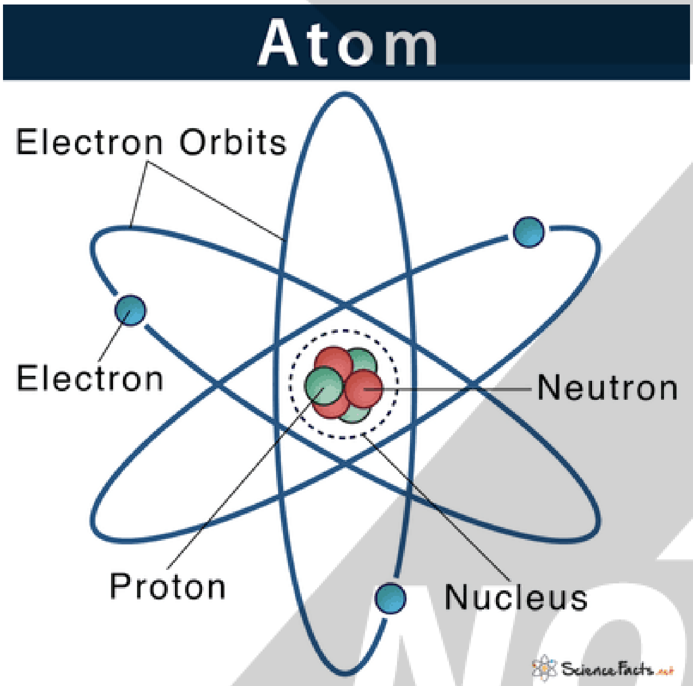
Component	Symbol	Function
Motor		A motor is a device that can convert electrical energy into mechanical energy.

Diode		A device which only allows current to flow in one direction
Light Emitting Diode (LED)		A diode that emits light

5. Atomic Physics

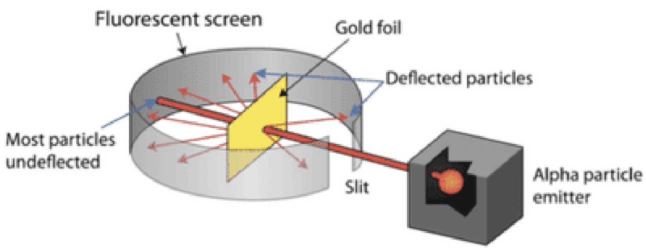
5.1. Nuclear Model of The Atom

- All matter is made up of atoms.



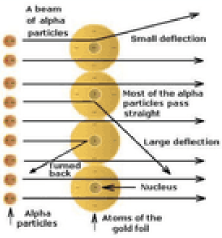
- The structure of an atom is simple.

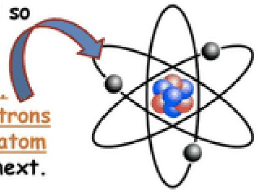
Alpha Scattering Gold Foil experiment (Rutherford's)



Conclusions from α scattering experiment

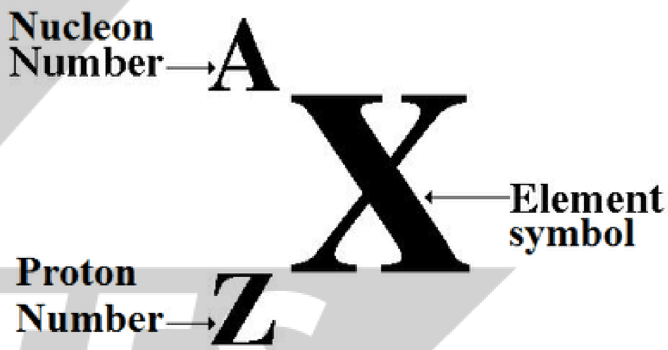
1. The vast majority of α particles were not deflected at all: the atom must be mostly empty space
2. Some α particles deflected through large angles: there must be a very small nucleus with a positive charge with a large electric field near to its surface.
3. Alpha particles repelled: alpha particles are positively charged so the nucleus must be positively charged in order to create an electrostatic force of repulsion.
4. Atoms are neutral overall: electrons must be on the outside of the atom separating one atom from the next.





The Atom

- Nucleus: central part of atom made of protons (positively charged) and neutrons. These two types of particles are called nucleons. They are bound together by the strong nuclear force.
- Electrons: almost massless particles which orbit nucleus in shells
- Proton number: number of protons in an atom
- Nucleon number: the number of nucleons (protons + neutrons) in an atom
- The following is the nuclide notation for atoms

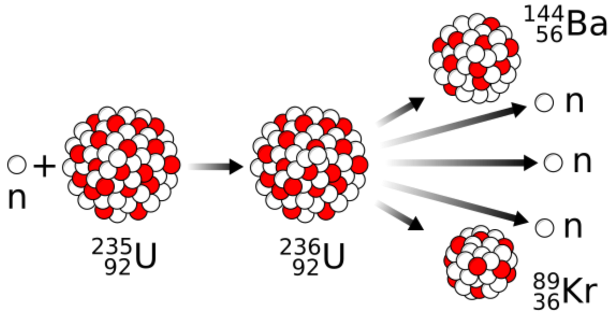


ISOTOPES

- Atoms of the same element that have different numbers of neutrons e.g. Carbon 12 and Carbon 14.
- They have identical chemical properties but can have different physical properties eg: radioactive

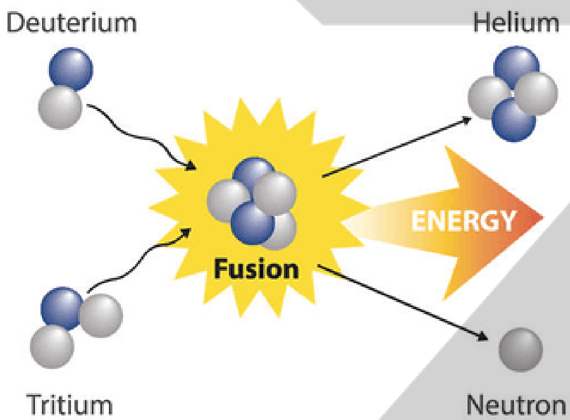
Nuclear Fission

Nuclear fission is a reaction in which the nucleus of an atom splits into two or more smaller nuclei, because of the addition of an electron. The fission process often produces gamma photons, and releases a very large amount of energy.



Nuclear Fusion

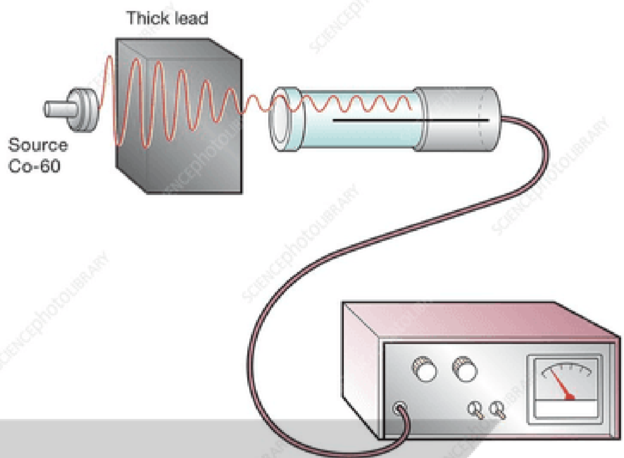
Nuclear Fusion reactions power the Sun and other stars. In a fusion reaction, two light nuclei merge to form a single heavier nucleus. The process releases energy because the total mass of the resulting single nucleus is less than the mass of the two original nuclei. The leftover mass becomes energy.



5.2. Radioactivity

Detecting radiation

- It is important to regulate the exposure of humans to radiation
- Ionising nuclear radiation is measured using a GM Tube detector connected to a radiation counter.
- Count rate is the number of decays per second recorded by a detector and recorded by the counter. It is measured in counts/s or counts/min
- The count rate decreases the further the detector is from the source. This is because the radiation becomes more spread out the further away it is from the source

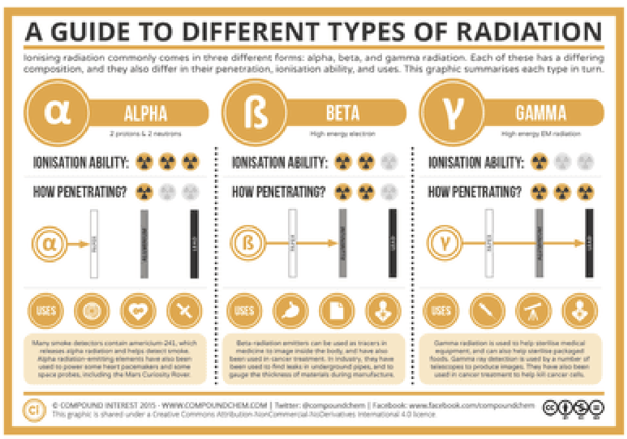


Background Radiation

- It is important to remember that radiation is a natural phenomenon
- Radioactive elements have always existed on Earth and in outer space
- However, human activity has added to the amount of radiation that humans are exposed to on Earth.
- Background radiation is defined as the radiation that exists around us all the time.
- The sources of it include : radioactivity in air, cosmic rays, rocks and buildings, food and drink, medical, nuclear power and testing.

The three types of nuclear emission

- Atomic nuclei of most isotopes are unstable.
- To become stable they give out radiation. As the radiation moves away it takes some energy with it. This makes the nucleus more stable. This is called radioactive decay.
- This cannot be controlled by external factors so it is known as a spontaneous and random event.
- The 3 types of radioactive emissions are:



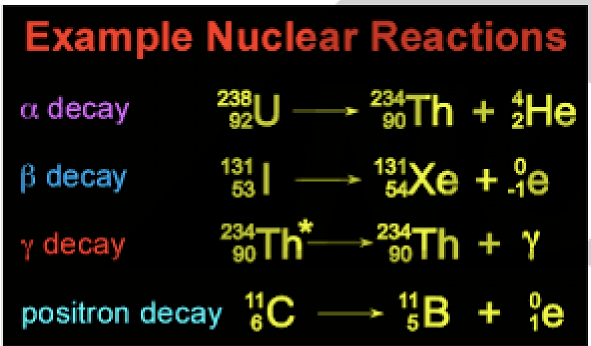
-Helium Nucleus \n -Relative charge of +2 \n -2p and 2n	- Electrons/Positrons \n -$1e^-/1e^+$	-Short wavelength EM waves \n -Uncharged

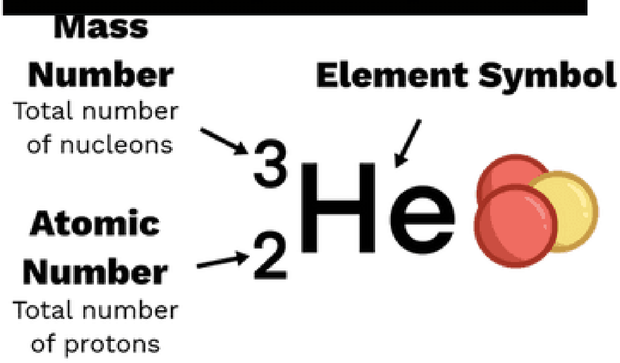
Effects of electricity & magnetism on radioactive emissions, and ionisation caused by them.

	Alpha	Beta	Gamma
Electric fields	Move away from + particles	Move towards + particles	No change
Magnetic fields	Use the left hand rule	Use the left hand rule	No change
Ionisation	Ionises most particles due to great mass	Ionises lesser particles	Ionises least particles because no charge

Radioactive Decay

- During α-decay or β-decay, the nucleus changes to a different element
- The initial nucleus is often called the parent nucleus
- The nucleus of the new element is often called the daughter nucleus
- During α-decay, 2p and 2n is lost and hence the nucleon number and proton number changes and a new element is formed.
- During β-decay, one neutron from the nucleus changes into a proton and electron. The electron is removed from the atom and given out as radiation.
- During gamma ray decay, the nucleus releases an EM wave and rearranges itself internally. No change is made in the number of subatomic particles.



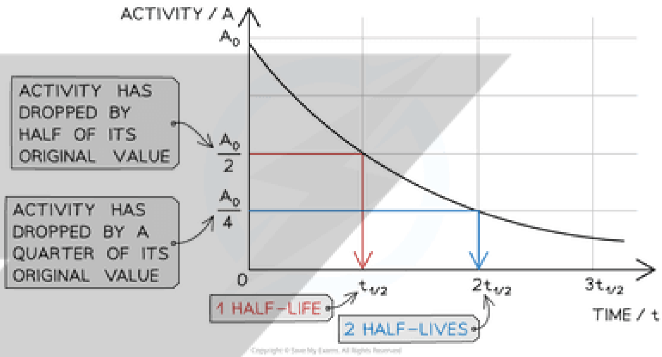


Half Life

- It is impossible to know when a particular unstable nucleus will decay
- But the rate at which the activity of a sample decreases can be known. This is known as the half-life. Half-life is defined as:

The time taken for half the nuclei of that isotope in any sample to decay

- The activity of a source is measured in **becquerels**. (Bq)
- Different isotopes have different half-lives and half-lives can vary from a fraction of a second to billions of years in length
- Half-life can be determined from an activity–time graph



- The time it takes for the activity of the sample to decrease from 100 % to 50 % is the half-life
  - It is the same length of time as it would take to decrease from 50 % activity to 25 % activity
  - The half-life is constant for a particular isotope

Uses of isotopes

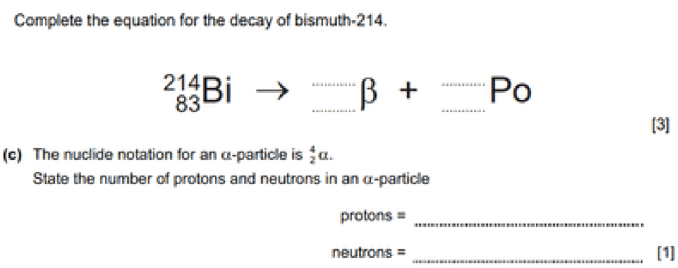
- Medical procedures including diagnosis and treatment of cancer
- Sterilising food (irradiating food to kill bacteria)
- Sterilising medical equipment (using gamma rays)
- Checking the thickness of materials
- Smoke detectors (alarms)
- Medical and industrial tracers

Safety Precautions

- Minimise the amount of time you handle sources for and return them to their boxes as soon as you have finished using them
- During use, keep yourself (and other people) as far from the sources as feasible. When handling the sources do not point at human tissue, using a pair of tweezers
- Store the sources in lead-lined boxes.
- Sometimes you can wear lead lined aprons

Nuclide Notation and Nuclear reactions.

There are 2 basic types of questions:



Complete the equation for the decay of bismuth-214.

$$^{214}_{83}\text{Bi} \rightarrow \,\ldots\ldots\,\beta + \,\ldots\ldots\,\text{Po}$$

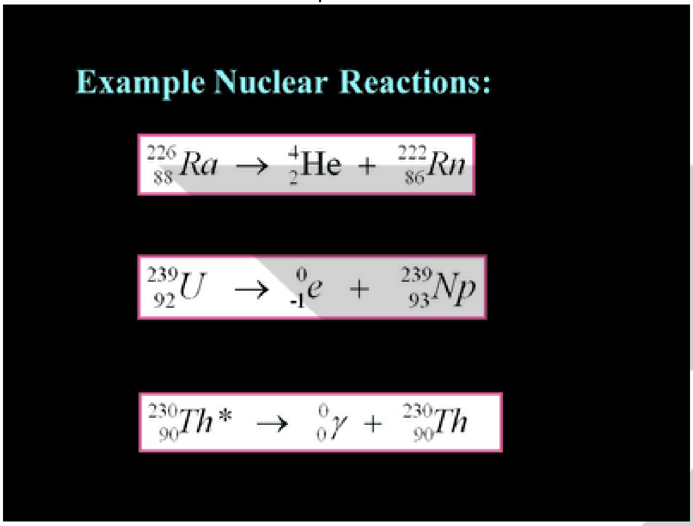
[3]

(c) The nuclide notation for an α-particle is $^{4}_{2}\alpha$.
State the number of protons and neutrons in an α-particle

protons = ...

neutrons = ... [1]

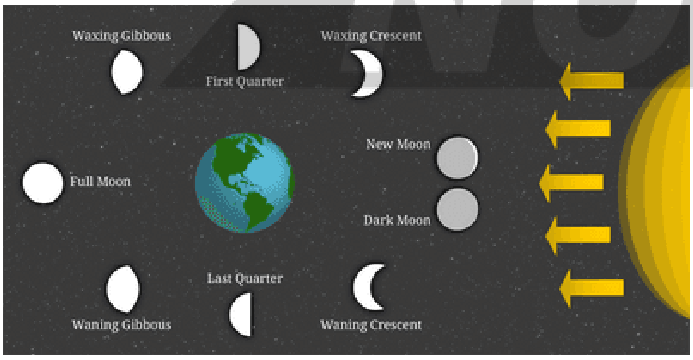
Nuclide notation is the notation of an element when it is written with its proton number and nucleon number. \n A nuclear reaction would take place like this.



6. Space Physics

6.1. Earth and Other Bodies

- The Earth rotates around its axis, which is tilted 23.5 degrees from West to East and revolves around the sun in 365.25 days.
- The Earth has a Southern Hemisphere and a Northern Hemisphere divided by the Equator.
  - Hemisphere: half of a sphere; Earth is divided into 2 hemispheres.

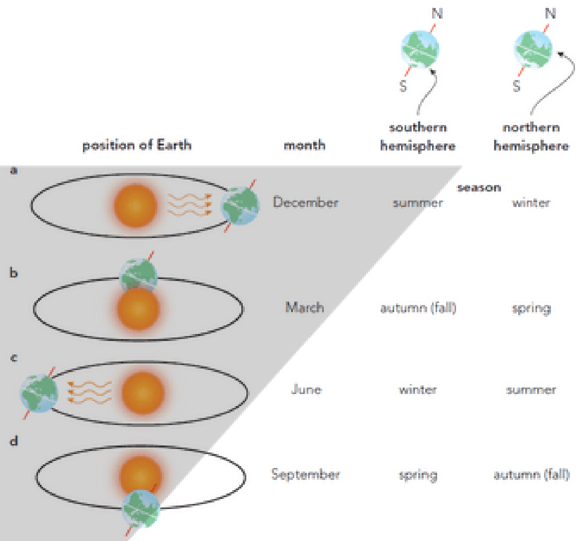


https://qph.cf2.quoracdn.net/main-qimg-c99eb0c0beb3e19bef78e8bfed6bc564

- Countries at the equator do not experience season changes as the sun hits them at the same angle at all times.

- The solar system consists of eight planets: Mercury, Venus, Earth, and Mars are the inner, rocky planets. Jupiter, Saturn, Uranus and Neptune are the outer gas giants.
- Millions of asteroids and meteoroids are orbiting the sun, mainly found between Mars and Jupiter.

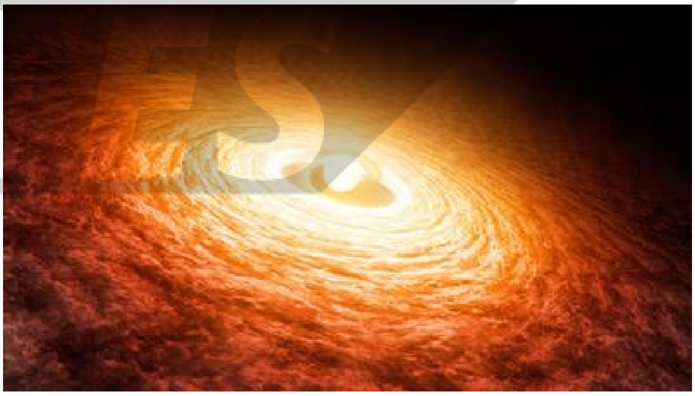
Comets are balls of ice, dust and gas. They orbit the sun in a very elliptical orbit, leaving behind a trail of gas and dust. However, this is not the comet's tail because the tail always faces away from the Sun.



Source: IGCSE textbook 0625

The Formation of A Solar System

Our solar system was formed when a molecular cloud collapsed into itself because of its gravity. Gasses and dust particles start to come together, getting closer and faster. They gain speed in a spinning motion. This process is called accretion. The disk formed by accretion is called the accretion disk.



https://encrypted-tbn1.gstatic.com/images?q=tbn:ANd9GcRhn2q4cvaoJd08MCr6EiNBafbyhktMBpjbfz_DIn7I

- Gravity pulls heavier particles close together toward the centre.
- The gasses get hot and pressurised enough to start nuclear fusion.
- The dust particles clump together and form the inner rocky planets while gasses orbit the centre farther away

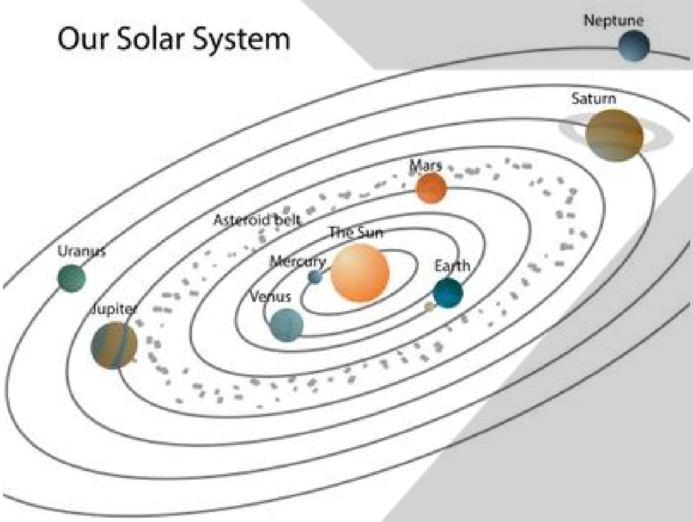
and form gas giants.
- The centre of the accretion disk starts to form a new star called a protostar. At this point, gravity is still pulling mass together.

Our Solar System

- The Sun makes up about 99.8% of the solar system's mass. It has a strong gravitational pull, keeping all the planets in orbit.

We know from the chapter on circular motion that for an object to move in a circular path, a force needs to act on the object towards the centre of its orbit.

- All the planet's orbits are elliptical, and the measure of how elliptical it is is called **eccentricity**.
- The centre of the orbit is not directly on the sun but close enough to the centre that we say that we orbit the sun.



https://static8.depositphotos.com/1163607/1070/i/950/depositphotos-stock-photo-our-solar-system.jpg
All orbits are not perfectly circular because of the energy changes during its orbital period.
The star pulls the body of mass towards itself. This pull generates speed which, we know, will cause the body to move away from the star. (Increasing speed increases the size of the orbit.)
We need to consider only two main energy types in space.

1. Kinetic Energy
2. Gravitational Potential Energy

A planet near the sun has a low GPE but a high KE. A planet far from the sun has a high GPE and a low KE.
How to calculate orbital speed:

- The formula for speed is distance/time. We consider the orbits to be perfectly circular in this situation. The formula is:

$$\text{Orbital speed} = \frac{2\pi r}{t}$$

Universe and Stars

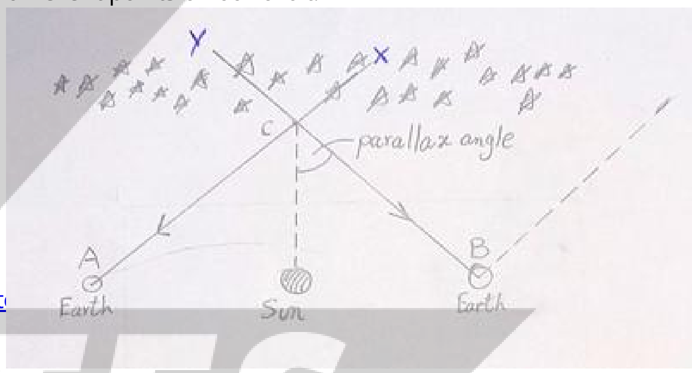
6.2. Sun

The Sun produces energy through nuclear fusion of hydrogen into helium.

- It is made of 75% hydrogen, 24% helium and the rest is made of other elements like oxygen and carbon.
- **40% of its energy is visible light, 50% of it is infrared radiation and 10% is ultraviolet.**
- Matter exists as plasma in the sun's core which has a temperature of 15 000 000K, and a surface temperature of 5800K.
- It has a mass of 2×10^{30} Kg which is often referred to as solar mass.

Light Year and Distances

A light-year is the distance travelled by light in one year. So:
$\text{one light-year} = 3 \times 10^8\ m/s \times 365.25\ days \times 24\ hours \times 3600\ seconds = 9.5 \times 10^{15}\ m$
Astronomers can also use other ways to measure distances. They can be done using parallax. This is when the stars appear to move across the sky when we view them from different points on our orbit.



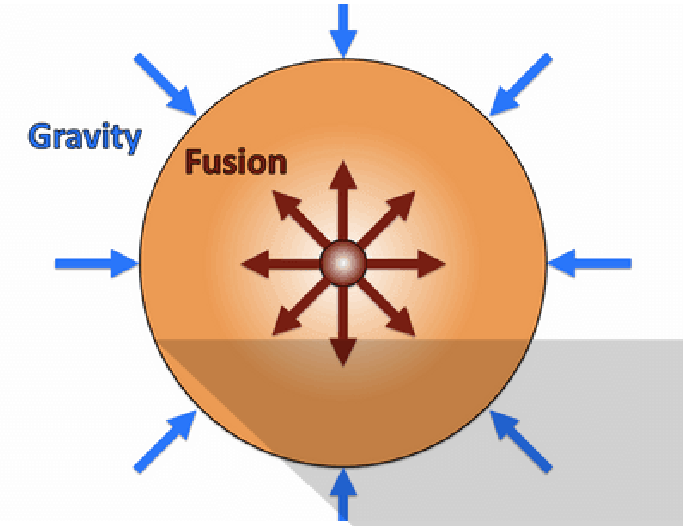
Point A is Earth in the summer and point B is Earth in the winter. The telescope is pointed towards X at point A and the stars are seen. The telescope is pointed in the direction of X at point B - denoted by the dotted line - and shows that the same stars cannot be seen. The telescope is moved twice the parallax angle to see the point Y.
We can use trigonometry to calculate the distance between the stars and the Earth.

Stars and Star Life Cycles

There might be 200 billion stars in the Milky Way. A star starts out as a protostar. Interstellar clouds are dust clouds that exist between stars. Molecular clouds are clouds mostly of hydrogen that is cold and dense enough to collapse and form stars.

- Accretion begins to pull matter in.
- A protostar is formed (refer to previous card for revision)

- A stable star is born when gravity is equal to the radiation pressure exerted by the high temperature and nuclear fusion.
  - Radiation pressure - the outward force due to the high temperature of the star.



http://www.cosmos.esa.int/documents/519784/1188283/Hydrostatic_equ_standfordUni/7ad412ee-be12-4a56-9da8-592533719992?t=1476554115279

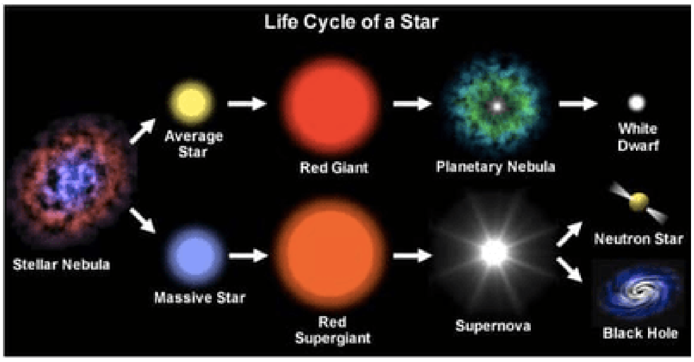
Life Cycle of a Star Less Than Eight Solar Masses

Like the sun, a stable star fuses hydrogen into helium. This is a stable main sequence star. Our sun is 4.5 billion years old and about half-way though its time as a stable star.

- Main sequence - stable star that is burning up hydrogen in its core; once it has used up 12% of its hydrogen it goes onto another stage of its life cycle.

Once it burns through the hydrogen, it starts to fuse helium. This requires a higher temperature at the core. It becomes a red giant which are larger stars with cooler surfaces.
Eventually the core will collapse into a white dwarf star not exceeding 1.4 solar masses.
It is not hot enough to fuse the elements inside it and cools to become a black dwarf.
The outer shell is blown off by radiation pressure and becomes a planetary nebula.

- Red Giant - a star that began with fewer than eight solar masses and is burning helium at its core; the shell of hydrogen has expanded and cooled.
- White dwarf - the final stage of a star that started with fewer than eight solar masses after all its fuel has been used up

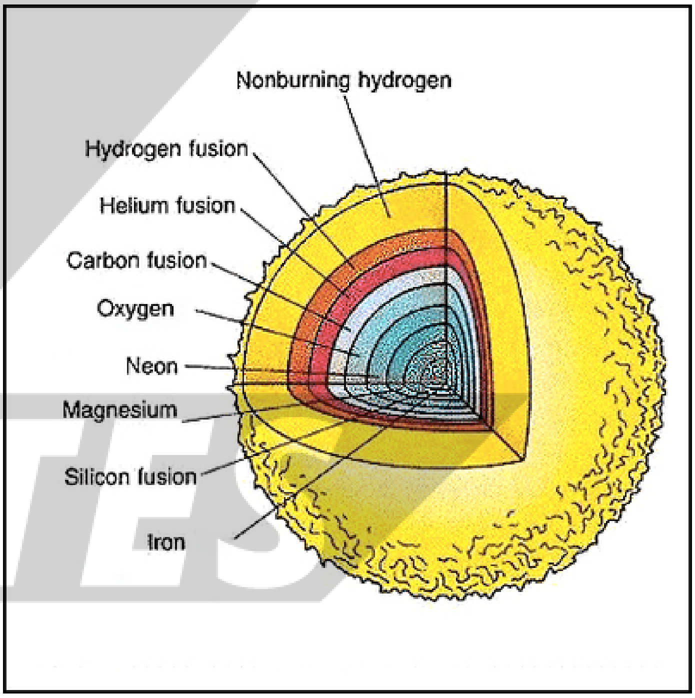


https://schoolworkhelper.net/wp-content/uploads/2010/05/life-cycle-of-star.jpg

The Life Cycle of A Star Exceeding Eight Solar Masses

It begin as a protostar but the core is more massive and hot enough to fuse heavier elements further from the core. The outer shell expands into a red supergiant.

- Red Supergiants - similar to red giants, they form when stars with at least 8 times the mass of the sun run out of hydrogen fuel in their core but fusion of hydrogen continues in their outer shell



https://lh5.googleusercontent.com/H58eVHSXEQH37qkPX2qdUU0kITDK1YQqFDsIe1kN2SRXc5cd66h-Kyh4n5JZweLHyFi8lSqL0HSpIER3PubnM-RwIRzk3yVsK88RyJuwaDholouMZFGrQuzShftvpurUk

The layers go in order of outer-most to inner-most: HYDROGEN, HELIUM, CARBON, OXYGEN, NEON, MAGNESIUM, SILICON and then IRON.

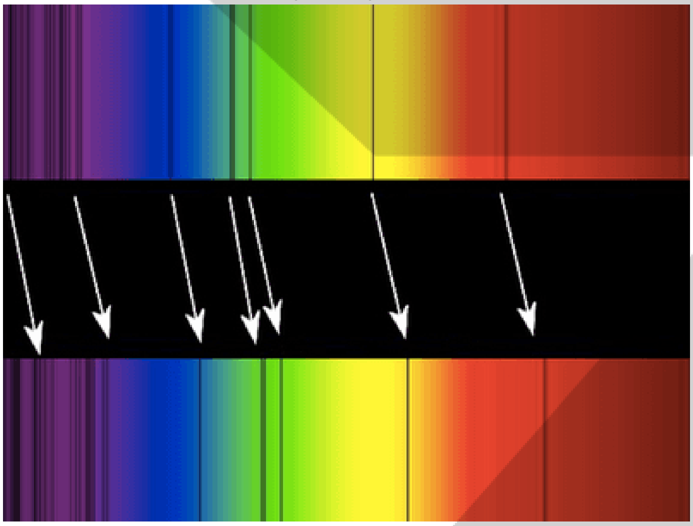
- It is not possible to make elements heavier than iron by nuclear fusion.
- Once all the fuel runs out, the star collapses in a supernova, providing the energy to fuse the iron into

heavier elements and pushing matter out into space as a nebula.

- After the supernova, the core becomes one of two things: a neutron star or a black hole.
  - A neutron star is formed if the mass of the core is less than about 3 solar masses. It forces protons and electrons together to form neutrons.
  - A heavier core will keep collapsing till it becomes so dense that not even light can escape it. It becomes a black hole.

Spectroscopy

There are many dark lines in the wavelengths of visible light coming from the Sun. This is because the cool gas in the Sun's atmosphere absorbs them. A spectrum with these absorption lines is known as an absorption spectrum.



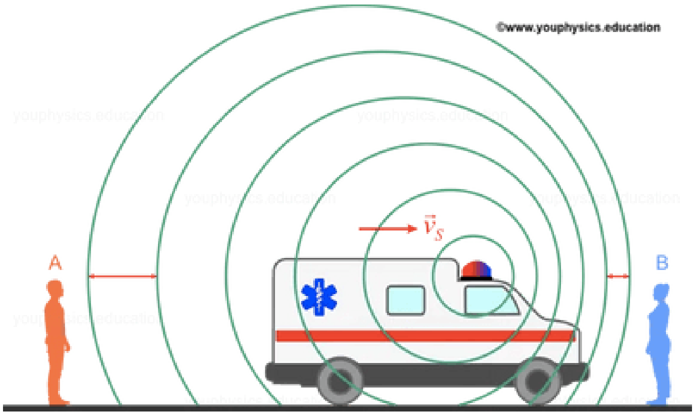
https://www.redshift-live.com/binaries/asset/image/18408/image/Redshift_of_spectral_lines_in_the_optical_spectrum.jpg

The top line represents the absorption spectrum observed in an experiment in earth and the bottom line is a redshifted one from a distant galaxy.

- Redshift is the shifting of light to the red end of the spectrum which has longer wavelengths.
- Redshift is caused by the Doppler effect

The Doppler Effect

The doppler effect is the rise or fall in pitch as the source of the wave moves closer or away from us. Here is an example.



https://www.youphysics.education/wp-content/uploads/Doppler2.webp

- The ambulance is moving at a certain speed towards the right.
- As the siren rings once, the sound wave is produced and starts to move away from that point.
- By the time the siren rings again, the ambulance has moved.
- The ambulance closes that gap between itself and the wave in front of it.
- This causes the second wave to be released closer to the first wave. The waves ahead of the vehicle compress as it approaches and observer B hears a rising pitch.
- The wave emitted behind the car is moving in the opposite direction. The car is moved away before emitting a second wave.
- The waves behind the ambulance are further apart giving it a receding pitch as the waves are stretched behind the vehicle. Observer A hears a receding pitch.

The Doppler effect is a property of all waves including light. It is proof that the Universe is expanding and suggests that the galaxies must have been close together in the past.

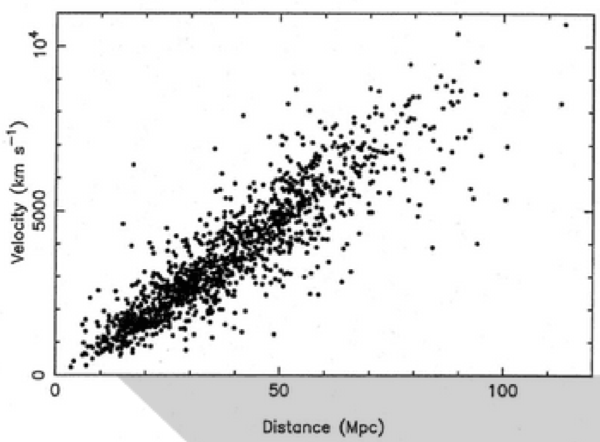
The Big Bang Theory and Cosmic Microwave Background Radiation

- The theory that the Universe had a beginning is the Big Bang Theory which states that the Universe (space, time, matter, energy) was created at a single point 13.8 billion years ago and has been expanding and cooling ever since.
- The Big Bang was not an explosion. The singularity was unimaginably hot and dense which has been expanding and cooling. Neutral atoms could not form due to the heat of the early Universe; they would ionise.
- Light continuously scattered around until the universe cooled.
- The expansion of the Universe has caused the wavelength of the light to redshift.

(For a detailed understanding, refer the new text book, Chapter 25, Page 477 - 478)

Hubble's Law

The Doppler effect can be used to work out how **fast** galaxies are moving away from us. The speed at which galaxies are moving away from us is proportional to the distance away from us.



https://physicsanduniverse.com/wp-content/uploads/2014/02/Hubble-Law-2010.jpeg

The line of best fit is Hubble's Law:

$V = H_o d$ where v is the recession speed of the galaxies, d is their distance from us and H_o is the Hubble Constant

The Hubble constant is the gradient of this graph:

$$H_o = \frac{v}{d}$$

Estimate for the age of the Universe:

$$\frac{d}{v} = \frac{1}{H_o}$$

The reciprocal (inverse) of the Hubble constant is known as Hubble time because it can be used to work out the age of the universe. The current estimate for Ho is 2.2 x 10^-18 per second.

We know that:

$time = \frac{distance}{speed}$ So:

$$t_{universe} = \frac{d}{v} = \frac{1}{H_o}$$

Therefore the age of the Universe is:

$$t_{universe} = \frac{1}{H_o} = \frac{1}{2.2 \times 10^{-18}} = 4.5 \times 10^{17} s = 14.4 \times 10^9 \ years$$

The Universe began at a single point (called a singularity) about 14.5 billion years ago.

CAIE IGCSE
Physics