PRINCIPLES OF PHYSICS

Principles of Physics for NLSC has been uniquely designed to assist students to quickly revise physics topics taught at these levels right from paper one 5351 without any handles.

It's essential for both teachers and students preparing for NLSC UNEB physics

Sample papers have been put to aid quick revision for both paper one and paper two, and a sample marking guide has been provided for both students and the teachers.

For any inquiries you can contact me on the addresses provided above for further assistance and guidance aid quick revision for both papers to act as guide has been provided for both students and the teachers.

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Passionate quotes

1. *If you can't explain it, simply you didn't understand it.*
2. *Experience is the teacher of all things.*
3. *Always keep an open mind and a compassionate heart.*
4. *Be happy. It's one way of being wise.*

INTRODUCTION

Definition of Physics

Physics is the branch of science which deals with the study of matter in relation to energy.

Matter

Matter is anything that occupies space and has weight

Fundamental quantities of physics

These are some of the fundamental quantities measured in physics, namely:

1. Length
2. Mass
3. Time
4. Current
5. Amount of substance

MEASUREMENT

INTERNATIONAL SYSTEM OF UNITS (S.I UNIT)

This is a metric system of measurements recommended in physics. S.I units were derived from the M.K.S system. The first 3 basic (fundamental) units are the metre (m), kilogram (kg) and second (s)

LENGTH

Length is the distance between two fixed points

S.I unit of length is metres (m)

Other units

kilometres (km), centimetres (cm), millimetres (mm), Inches, yards, miles etc.

Km = 1000m

1m = 1000cm = 1000000mm

1cm = 10mm.

Very small lengths are measured in micrometer and nanometers (nm).

1m = 1,000,000nm = 10^6 µm

1m = 1,000,000,000nm = 10^9 nm

Example,

Convert the following measurements.

(a) 20mm to metres.

1m = 1000mm

1mm = m

20mm = 0.02m

(b) 0.8m to centimeters

1m = 100cm

0.8m = 0.8×100cm = 80cm

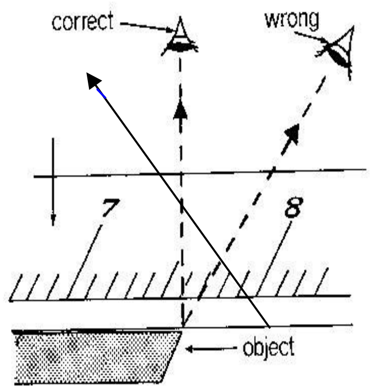
Length is measured using;

- Metre rule
- Tape measure
- Calipers
- Micrometer screw gauge
- Thread.

PARALLAX

METRE RULE

Length measurement made with a metre rule should be **correctly** ***read as shown below:***



The eye must be right over the mark on the scale, and the reading should be to one decimal place i.e. 7.6cm.

CALIPERS:

These are used to measure distance in solid objects where an ordinary metre rule cannot be applied. They are made out of pair of hinged steel jaws which are closed until they touch the object in the desired position.

Calipers are of two types namely:

1. Engineer's calipers, 2. Vernier calipers

MICROMETER SCREW GAUGE

This is used to measure small distance such as diameter of pieces of wire, bicycle spoke pins, needles etc.

The instrument measures up to 2 decimal places in mm. It consists of a spindle which can be screwed and it is fitted with a scaled thimble.

MEASUREMENT OF AREA OF AN OBJECT

Area is a measure of the extent of a two-dimensional surface or shape. It quantifies the amount of space enclosed within the boundaries of a flat object, such as a rectangle, circle, or triangle. Area is an important concept in various fields, including mathematics, physics, engineering, and everyday life.

Units of Area:

Area is measured in square units, reflecting the number of unit squares that fit into the shape. Common units of area include:

Square meters (m^2) in the metric system.

Square centimeters (cm^2) and square millimeters (mm^2) for smaller areas.

Square kilometers (km^2) for large areas.

Square feet (ft^2) and square inches (in^2) in the imperial system.

Acres and hectares for measuring land areas.

Calculating Area

The method to calculate the area depends on the shape:

Importance and Applications

Architecture and Construction: Calculating the area is crucial for designing floor plans, determining the amount of materials needed (e.g., paint, flooring), and estimating costs.

Agriculture: Farmers need to know the area of their fields to manage planting, fertilization, and irrigation effectively.

Real Estate: The area of land and buildings is a fundamental factor in property valuation and transactions.

Clothing and Textiles: Manufacturers calculate the area of fabric needed to produce garments and other textile products.

Science and Engineering: In physics, area calculations are used in various contexts, such as determining the pressure exerted on surfaces (pressure = force/area) and in fluid dynamics.

Everyday Life: Understanding area helps in tasks like planning gardens, arranging furniture, and organizing spaces efficiently.

Visualization and Understanding:

Visualizing area often involves tiling a shape with unit squares. For instance, a rectangle with dimensions 3 meters by 4 meters can be covered by 12 unit squares of 1 square meter each, thus having an area of 12 square meters.

Practical Examples:

A rectangular garden: If the garden is 5 meters long and 3 meters wide, the area is $5 \times 3 = 15$ square meters.

Understanding area is fundamental to both theoretical and practical applications, helping to quantify and manage spaces efficiently in various contexts.

VOLUME:

Volume is a measure of the amount of space an object or substance occupies. It is a three-dimensional quantity, representing the extent of an object in the three dimensions of space: length, width, and height. The concept of volume applies to both solid objects and fluids (liquids and gases).

Units of Volume:

Volume can be expressed in various units, depending on the system of measurement:

Metric System:

Cubic meters (m^3)

Liters (L), where 1 liter = 1 cubic decimeter (dm^3) = 1,000 cubic centimeters (cm^3)

Milliliters (mL), where 1 milliliter = 1 cubic centimeter (cm^3)

Imperial System:

Cubic inches (in^3)

Cubic feet (ft^3)

Gallons, quarts, pints, and fluid ounces

Importance and Applications:

Everyday Life: Understanding volume is crucial in everyday activities like cooking (measuring ingredients), filling fuel tanks, and packing.

Science and Engineering: Volume calculations are essential in various scientific fields, including chemistry (stoichiometry and reactions involving gases), physics (density calculations), and engineering (designing containers, buildings, and other structures).

Medicine: Dosage of liquid medications, blood transfusions, and intravenous fluids are often calculated based on volume.

Commerce: Industries dealing with liquids (e.g., oil, beverages) and gases need to measure and control volumes accurately for production, storage, and distribution.

Understanding and calculating volume is fundamental to many aspects of both practical and theoretical applications, making it a critical concept in numerous disciplines.

VOLUME OF IRREGULAR SHAPED OBJECTS

The volume of irregularly shaped objects is found by using the displacement method.

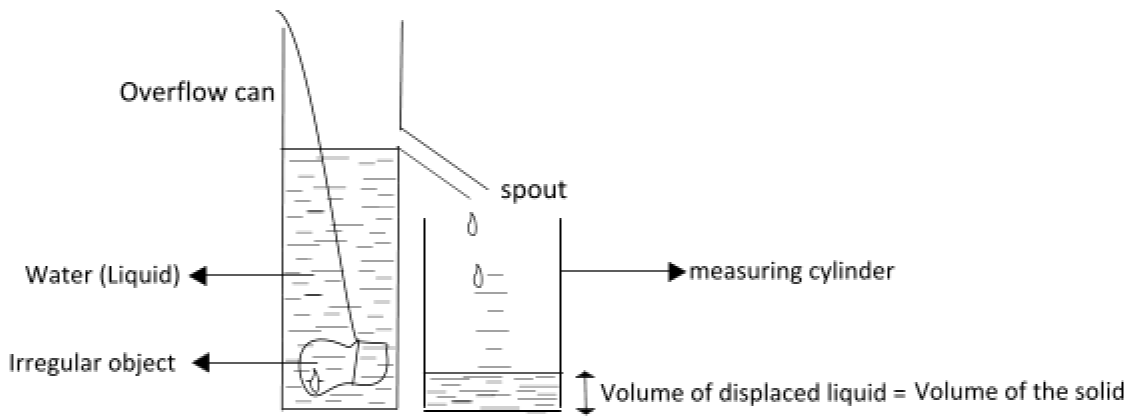
Procedure;

An over flow can is filled with water

The irregular shaped object is tied onto a string and carefully lowered into the water in the overflow can. The water level is displaced.

The water flowing out of the can through the spout is collected using a measuring cylinder

The volume of the water collected is determined

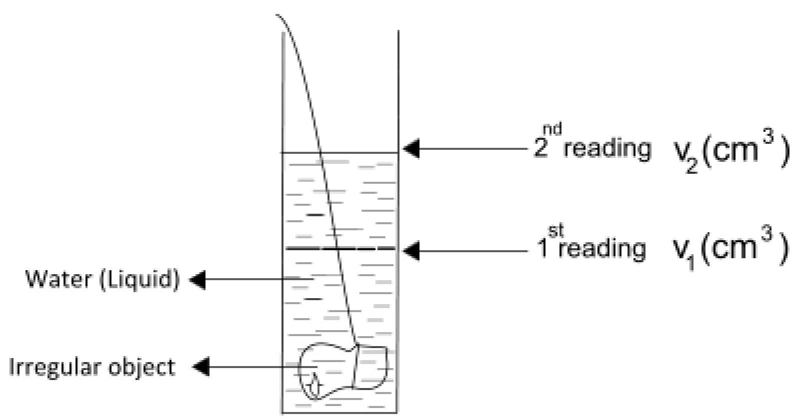


The volume of the liquid displaced is equal to the volume of the irregular object (stone).

METHOD II;

Procedure;

Water is poured into a measuring cylinder and the volume noted on its scale



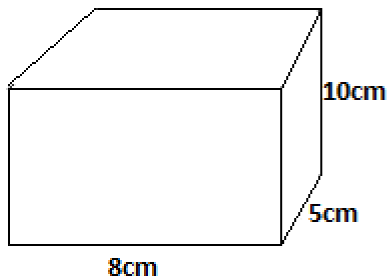
- A thread is tied around the irregular object
- The solid (object) is lowered into the water in the cylinder and the 2nd reading noted.
- Volume of the solid is obtained from:
- volume 2nd reading - Volume 1st reading
- Therefore, $V = V_2 – V_1$

Volume of liquids

- To measure fixed volumes, the following vessels are used:
  Volumetric flask, measuring cylinder, beaker, pipettes etc
- To measure varying volumes use a burette.

Exercise:

1. Use the cuboid below to answer questions that follow.



Find the volume; (i) in cm^3

Volume = L x W x H

= 8cm x 5cm x 10cm

= **$400cm^3$**

(ii) In m^3

Volume in m^3

$1m^3 = 1000,000\ cm^3$

$400cm^3$ = m3 = **$0.0004m^3$**

2. A cuboid has dimensions 2cm by 10cm. Find its width in metre if it occupies a volume of $80cm^3$.

<u>**Solution**</u>

L x W x H = V

2cm x W x 10cm = $80cm^3$

W = 4cm

Width in metres

4cm = m = **0.04m**

3(a) Find the volume of water in a cylinder of water radius 7cm if its height is 10cm.

$$\text{Volume} = \pi r^2 h$$
$$= \text{ x } 7\text{cm x } 7\text{cm x}10\text{cm}$$
$$= \mathbf{1540cm^3}$$

(c) The volume of the cylinder was $120m^3$.When a stone was lowered in the cylinder filled with water the volume increased to $15cm^3$.

Find the

(i) Height of the cylinder of radius 7cm.

Volume V = $\pi r^2 h$, 12 = $x7^2xh$

∴ h = 0.078 cm

MASS

Mass is the property of a body that is a measure of its inertia and that is commonly taken as a measure of the amount of material it contains and causes it to have weight in a gravitational field.

Mass is a fundamental property of physical objects that quantifies the amount of matter they contain. It is a measure of an object's resistance to acceleration when a force is applied, and it is a key component in understanding and describing the dynamics of objects and systems in physics.

Key Characteristics of Mass:

Inertia: Mass is a measure of inertia, which is the resistance of an object to changes in its state of motion. The more massive an object, the more force is required to accelerate it.

Gravitational Interaction: Mass determines the strength of the gravitational force an object experiences in a gravitational field. The gravitational force between two objects is proportional to the product of their masses and inversely proportional to the square of the distance between them.

Conservation: Mass is conserved in isolated systems, meaning it cannot be created or destroyed. This principle is fundamental in classical mechanics and is extended in the form of mass-energy equivalence in relativity.

Units of Mass:

Mass is measured in units such as:

Kilograms (kg): The base unit of mass in the International System of Units (SI).

Grams (g): Commonly used for smaller masses, where 1 kilogram = 1,000 grams.

Metric tons (t): Used for large masses, where 1 metric ton = 1,000 kilograms.

Pounds (lb): Used primarily in the United States, where 1 pound is approximately 0.453592 kilograms.

Types of Mass:

Inertial Mass: A measure of an object's resistance to acceleration when a force is applied. It is defined by Newton's second law of motion, F=ma, where F is the force applied, m is the inertial mass, and a is the acceleration.

Gravitational Mass: A measure of the strength of an object's interaction with a gravitational field.

Importance and Applications:

Physics and Mechanics: Understanding mass is essential for analyzing forces, motion, and energy in physical systems. It plays a critical role in Newton's laws of motion, momentum, and kinetic energy.

Astronomy and Cosmology: Mass is a key parameter in studying celestial bodies, including their formation, dynamics, and interactions. It influences the structure and evolution of stars, galaxies, and the universe.

Engineering and Technology: Accurate measurement and control of mass are crucial in designing and manufacturing products, from small electronic components to large structures like buildings and bridges.

Everyday Life: Mass is commonly encountered in everyday activities, such as cooking (measuring ingredients), transportation (vehicle weight and fuel efficiency), and health (body weight).

Mass of the body is measured using the following instruments:

- Beam balance
- Lever – arm-balance
- Top-arm-balance

TIME

Time is a fundamental concept that quantifies the progression of events from the past through the present to the future. It is a continuous, measurable quantity used to sequence events, compare the durations of events or the intervals between them, and quantify the motions of objects.

Characteristics of Time:

Linear Progression: Time is often perceived as moving in a linear fashion from the past to the present and into the future.

Measurement: Time can be measured using various units and instruments, with seconds being the base unit in the International System of Units (SI).

Irreversibility: In most everyday contexts and classical physics, time is perceived as unidirectional and irreversible, meaning events move forward and cannot be reversed.

Units of Time:

Time is measured in units such as:

Seconds (s): The base unit of time in the SI system.

Minutes (min) : 1 minute = 60 seconds.

Hours (h): 1 hour = 60 minutes = 3,600 seconds.

Days, weeks, months, and years: Larger units of time based on the Earth's rotation and orbit around the Sun.

Measurement of Time:

Clocks and Watches: Devices designed to measure and display time accurately. They range from mechanical clocks to electronic digital watches.

Atomic Clocks: Extremely precise timekeeping devices that use the vibrations of atoms (often cesium or rubidium) to measure time. These are used for scientific research and to maintain the accuracy of time standards.

Calendars: Systems for organizing days and larger units of time into a coherent structure. The Gregorian calendar is the most widely used today.

Importance and Applications:

Daily Life: Time is essential for organizing daily activities, schedules, and routines. It helps in planning, coordinating, and managing tasks and events.

Science and Technology: Accurate time measurement is crucial for experiments, observations, and the functioning of various technologies, including GPS, communication networks, and computer systems.

Physics: Time is a key variable in the laws of motion, thermodynamics, and quantum mechanics. It plays a crucial role in understanding the universe's structure and dynamics.

Economics and Business: Time is a critical factor in financial markets, production schedules, project management, and service delivery.

Theories and Concepts:

Newtonian Time: In classical mechanics, time is considered absolute and universal, flowing at a constant rate regardless of the observer's state of motion.

Relativistic Time: According to Einstein's theory of relativity, time is relative and can vary depending on the observer's velocity and the presence of gravitational fields. Time dilates, or stretches, for objects moving at high speeds or in strong gravitational fields.

Arrow of Time: This concept describes the one-way direction or asymmetry of time, primarily observed through the increase of entropy as stated in the second law of thermodynamics, where systems evolve from order to disorder.

Practical Examples:

Daily Activities: Waking up at 7:00 AM, attending a meeting at 2:00 PM, or catching a flight scheduled for 6:00 PM.

Scientific Experiments: Measuring the reaction time in a chemical experiment or the half-life of a radioactive substance.

Technological Systems: Synchronizing data across global networks using Coordinated Universal Time (UTC).

Understanding time is essential for organizing and navigating our daily lives, advancing scientific knowledge, and developing and maintaining technological systems. It is a fundamental dimension that intersects with virtually all aspects of human experience and inquiry.

Scientific notation and significant figures

- A number is in scientific form, when it is written as a number between 1 and 9 which is multiplied by a power of 10.
- Scientific notation is used for writing down very large and very small measurements.

Example:

(i)	598,000,000m	=	5.98×10^8m
(ii)	0.00000087m	=	8.7×10^{-7}m
(iii)	60220m	=	6.022×10^4m

SIGNIFICANT FIGURES

All figures from 1-9 are significant figures. (i.e. all non-zero)

<u>**Examples**</u>

a) 3 0 0 8

4th sf

3rd sf

2nd sf

1st sf

b) 0 2 3

3rd sf

2nd sf

1st sf

c) 2.30 cm

3rd sf

2nd sf

1st sf

Questions

Write the following to the stated significant figures

a) 28.8 to 3 s.f *b) to 2 s.f* *c) 4.027 x10^{-2} to 3 s.f*

DENSITY

Density is a measure of how much mass is contained in a given volume.

It is a key physical property of materials and substances and is defined as *the mass per unit volume*.

The concept of density helps to understand how compact or spread out the mass in a material is.

Formula for Density:

$$density = \frac{mass}{volume} = \frac{m}{v}$$

Units of Density:

The units of density depend on the units used for mass and volume:

In the metric system, density is commonly expressed in kilograms per cubic meter (kg/m^3) or grams per cubic centimeter (g/cm^3). For example, water has a density of about 1 g/cm^3 or 1000 kg/m^3.
In the imperial system, density can be expressed in pounds per cubic foot (lb/ft^3) or pounds per cubic inch (lb/in^3).

Characteristics of Density:

Intrinsic Property: Density is an intrinsic property of a substance, meaning it does not depend on the amount of substance present. It is a characteristic property that can be used to identify materials.

Temperature and Pressure Dependence: The density of substances, especially gases, can change with temperature and pressure. For example, heating a substance typically decreases its density because the volume increases while the mass remains constant.

Comparison of Substances: Density allows for comparison of different materials. For example, lead is denser than aluminum, meaning a given volume of lead has more mass than the same volume of aluminum.

Applications of Density:

Material Identification: Density is used to identify substances and verify their purity. For instance, gold's high density can help distinguish it from less dense metals.

Buoyancy: Objects with lower density than the fluid they are in will float, while those with higher density will sink. This principle is crucial in designing ships, submarines, and hot air balloons.

Engineering and Construction: Knowing the density of materials helps in calculating loads, stresses, and stability in construction projects.

Resource Management: Density is used to estimate quantities and manage resources, such as determining the fuel efficiency of vehicles or the storage capacity for liquids.

Practical Examples:

Water: Water has a standard density of 1 g/cm^3 at 4°C. This property is often used as a reference point.

Air: The density of air at sea level is approximately 1.225 kg/m^3. This value is important in fields like meteorology and aviation.

Gold: Gold has a high density of about 19.32 g/cm^3, which is why gold objects feel heavy for their size.

Wood: Different types of wood have varying densities. For example, balsa wood is less dense and therefore lighter than oak wood.

Calculating Density - Example:

Imagine you have a metal block with a mass of 200 grams and a volume of 50 cubic centimeters.

Solution: This means the metal block has a density of 4 grams per cubic centimeter.

Understanding density is essential in many scientific, engineering, and everyday contexts, allowing for the assessment and comparison of different materials and their properties.

Other units for density: g/cm^3

E.g. density of iron metal is $0.8g/cm^3$.This means that 8g of iron have a volume of $1cm^3$.

Example:

Find the density of a substance of;

(i) Mass 9kg and volume $3m^3$

(ii) Mass 100g and volume $10cm^3$

Converting density from g/cm^3 to kg/m^3

The density of the substance in g/cm^3 is multiplied by 1000 in order to convert to kg/m^3.And to convert from kgm^{-3} to $gcm^{-3,}$ divide by 1000.

Example:

The density to water is $1.0g/cm^3$. Find its density in kgm^{-3}.

Density $= 1.0gm^{-3}$

$= 1.0 \times 1000kgm^{-3}$

$= 1000kgm^{-3}$.

1. A piece of steel has a volume of $12cm^3$ and a mass 96g.Find its density.

   (a) In g/cm^3

   Density = = = $8g/cm^3$

   (b) $8g/cm^3$ to kg/m^3

   $= 8 \times 1000$

   $= 8000kg/m^3$

2. The oil level in a burette is $25cm^3$. 50 drops of oil fall from a burette. If the volume of one drop is $0.1cm^3$.What is the final oil level in the burette.

   Volume of one water drop = $0.1cm^3$

   Volume of 50 water drops = $\times\ 50cm^3 = 5cm^3$

   Final level = $25cm^3 + 5cm^3 = 30cm^3$

Question

1. A measuring cylinder has water level of 13cm.What will be the new water level if 1.6g of a metallic block of density $0.8g/cm^3$ is added.

EXPERIMENT TO DETERMINE DENSITY OF REGULAR OBJECT

The mass of the solid is found using a beam balance. The volume of the object is obtained by measuring the dimensions length, width and height using a ruler or Vernier calipers or both

HOW TO DETERMINE DENSITY OF AN IRREGULAR OBJECT (e.g. a stone)

- The mass of a solid is measured using a beam balance.
- Its volume is found using displacement method
- The density is then obtained from

  Density =

Density of liquids

- The volume V of the liquid is measured using a measuring cylinder

- The liquid is poured into the beaker of known mass M
- The mass M_2 of the beaker containing the liquid is found using a beam balance
- The density of the liquid will be

Density =

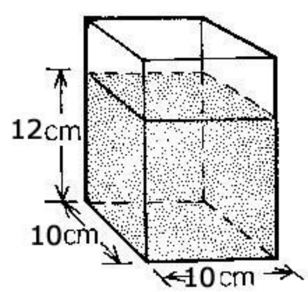
Density =

<u>Density of Air</u>

- A round bottomed flask is weighed when full of air and its weighed again after removing air with a vacuum pump.
- The difference gives the mass of air.
- The volume of air is obtained by putting water in the same flask and measures its volume using a measuring cylinder.
- The volume of water will be the volume of air
- The density then calculated from; $density = \frac{mass\ of\ a\ substance}{volume\ of\ a\ substance}$

Examples

1. A Perspex box has a 10cm square base containing water to a height of10 cm. a piece of rock of mass 600g is lowered into the water and the level rises to 12 cm.



a) What is the volume of water displaced by the rock?

V = L x w x h

$= \quad 10 \times 10 \times (12-10) \quad = \quad 200\ cm^3$

b) What is the volume of the rock?

Volume of rock = volume of water displaced

= $200cm^3$

Alternatively,

Volume of water before adding the rock, V_1 = L x W x H

= (10 x 10 x 10) cm

= $1000cm^3$

Volume of water after adding the rock V_2 = L x W x H

= $(10 \times 10 \times 12)\ cm^3$

= $1200cm^3$

Volume of water displaced $= V_2 - V_1$

$= (1200 - 1000)\ cm^3 = 200cm^3$

c) Calculate the density of the rock

Density = $3g/cm^3$

1. A Perspex box having 6cm square base contains water to a height of 10cm.
   a. Find the volume of water in the box.

   Volume of water in the box = L x w x h

   = 6cm x 6cm x 10cm

   = $360cm^3$

   b. A stone of mass 120g is lowered into the box and the level of water rises to 13cm.

   (i) Find the new volume of water

   = L x w x h

   = 6cm x 6cm x 13cm

   = $468cm^3$

(i) Find the volume of the stone

Volume of the stone = Volume of displaced water

= $V_2 - V_1$

= $468 - 360 cm^3$

= $108\ cm^3$

(ii) Calculate the density of the stone.

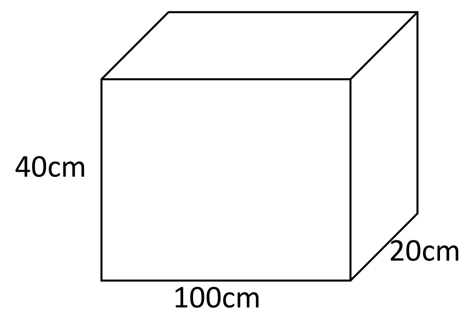
Density = $1.11\ g/cm^3$

2. A steel C.P.U below, has a mass of 560g

Find its density

(i) In g/cm^3

(ii) In kg/m^3



Volume = L x W x H

= (100 x 40 x 20) cm^3

= $80,000cm^3$

Density = $0.007g/cm^3$

(i) In kg/m^3

Density = 0.007 x 1000 = $7kg/m^3$

DENSITY OF MIXTURES

Suppose two substances are mixed as follows:

Substance	Mass	Volume	Density
X	M_1	V_1	$d = \frac{m}{v}$

Y	M_2	V_2	$d = \frac{m}{v}$

Then Density of the mixture: $density = \frac{m_1+m_2}{v_{1+}v_2}$

Example;

Two liquids x and y mixed to form a solution. If the density of x = 0.8gcm^{-3} and volume = 100cm^3, y = 1.5cm^{-3} and volume = 300m^3.Find;

(i) The mass of liquid x

Density x Volume = 0.8 x 100gcm^3

= 80g

(ii) The mass of liquid

Density x Volume = 1.5 x 300 = 450g

(iii) Density of a mixture = =

= 1.325gcm^{-3}

RELATIVE DENSITY

Relative density, also known as ***specific gravity***, is a dimensionless quantity that compares the density of a substance to the density of a reference substance, typically water for liquids and solids, and air for gases. It indicates whether a substance is more or less dense than the reference substance without requiring units.

The relative density (RD) is calculated using the formula:

$$RD = \frac{density\ of\ reference\ substance}{density\ of\ the\ substance}$$

For liquids and solids, the reference substance is usually water, which has a density of approximately 1 g/cm³ (or 1000 kg/m³) at 4°C.

Key Characteristics:

Dimensionless: Since relative density is a ratio of two densities, it has no units.

Comparison: It allows for easy comparison of the density of a substance to the reference substance.

If R.D > 1, the substance is denser than the reference.

If R.D < 1, the substance is less dense.

Temperature and Pressure: When measuring relative density, it is important to specify the temperatures and pressures of both the substance and the reference substance, as density can change with these conditions.

Applications of Relative Density:

Material Identification: Helps in identifying materials and verifying their purity. For example, the relative density of pure gold is about 19.3.

Industrial Processes: Used in industries like mining, oil, and chemicals to assess material properties.

Buoyancy and Flotation: Determines whether an object will float or sink in a fluid. An object with an RD less than 1 will float in water.

Quality Control: Used in quality control processes to ensure consistency and standards in manufacturing.

Practical Examples:

Water: The relative density of water is 1, as it is the reference substance.

Ethanol: Ethanol has a relative density of about 0.79, meaning it is less dense than water and will float on it.

Mercury: Mercury has a relative density of about 13.6, making it much denser than water. This high density allows mercury to be used in barometers and other instruments.

Calculating Relative Density - Example:

Suppose you have a liquid with a density of 850 kg/m³. To find its relative density compared to water:

This means the liquid has a relative density of 0.85 and is less dense than water.

Importance in Different Fields:

Chemistry and Biology: Used to determine the concentration of solutions and the purity of substances.

Environmental Science: Helps in studying the stratification of lakes and oceans where water density varies with temperature and salinity.

Engineering: Essential in designing systems involving fluid flow, such as pipelines and hydraulics.

Understanding relative density is crucial for comparing materials, designing systems involving buoyancy and fluid flow, and ensuring quality and consistency in various industrial processes.

FORCE, MASS AND ACCELERATION

Definition of Force

Force is a physical quantity that is an interaction that, when unopposed, changes the motion/state of an object. This can include starting to move, stopping, changing direction, or changing speed. Force can be described simply as a push or a pull.

Newton's Laws of Motion

The behavior of forces is governed by Newton's Three Laws of Motion:

First Law (Law of Inertia): An object will remain at rest or in uniform motion in a straight line unless acted upon by a net external force.

Second Law (Law of Acceleration): The acceleration of an object is directly proportional to the net force acting on it and inversely proportional to its mass. This relationship is described by the equation:

F=ma, where F is the force, m is the mass, and a is the acceleration.

Third Law (Action and Reaction): For every action, there is an equal and opposite reaction. This means that forces always come in pairs; if object A exerts a force on object B, then object B exerts an equal and opposite force on object A.

Vector Nature of Force

Force is a vector quantity, meaning it has both magnitude (how strong the force is) and direction (where the force is applied). This can be represented graphically with arrows in physics diagrams, where the length of the arrow indicates the magnitude and the direction of the arrow indicates the direction of the force.

Units of Force

In the International System of Units (SI), force is measured in newtons (N). One newton is defined as the amount of force required to accelerate a one-kilogram mass by one meter per second squared (1 N = 1 kgm/s^2).

Types of Forces

Forces can be categorized based on their origin and effect:

Gravitational Force: The attraction between two masses. It is what gives weight to physical objects and causes them to fall to the ground when dropped.

Electromagnetic Force: Forces between charged particles. This includes both electric forces (between charges) and magnetic forces (between magnetic poles).

Normal Force: The perpendicular contact force exerted by a surface against an object resting on it.

Frictional Force: The force that opposes the relative motion or tendency of such motion of two surfaces in contact.

Tension Force: The pulling force transmitted along a string, rope, cable, or similar object.

Applied Force : Any force that is applied to an object by a person or another object.

Resultant Force: When multiple forces act on an object, the resultant force (or net force) is the vector sum of all these forces. The resultant force determines the object's acceleration according to Newton's Second Law.

Importance in Daily Life and Technology

Understanding forces is essential in many areas, from engineering and construction to sports and biomechanics. For example, engineers must calculate forces to ensure structures are safe, while athletes use knowledge of forces to improve performance and reduce injury risk.

In essence, the concept of force is fundamental to explaining and predicting the behavior of objects under various conditions and interactions, making it a cornerstone of physics and engineering.

Effects of force:
When a force is applied on the body it may cause the following on the body;

1. The body accelerates
2. Change in shape.

TYPES OF FORCES

GRAVITATIONAL FORCE

- Is the force that pulls an object toward the centre of the earth

- When bodies fall under gravity, they have a constant acceleration due to gravity
- On the earth, acceleration due to gravity g = 10m/s^2
- The gravitational force on an object of mass m is given by F = mg

Example:

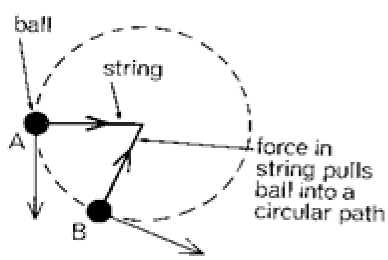
1. Find the gravitational force of a body of 2kg on earth.

   Gravitational force F = mg

   = 2 x 10 = 20N

Centripetal force:

- Is a force which keeps bodies moving in circular path e.g. vehicles in roundabout, planets around the sun etc.
- Centripetal forces always act towards the centre of the path.



Weight:

Weight is a force exerted by a body on its free support. It is a pull of gravity on an object. The weight of a body of mass M is given by W = mg and its direction is always vertically downwards. SI unit is Newton (N)

Newton

A newton is force required to give a mass of 1kg an acceleration of 1m/s^2.

Example:

A piece of wood has mass of 2kg. Find its weight on earth (g=10m/s^2).

Solution

W = mg = 2 x 10 = 20N.

Acceleration (g) varies slightly on the surface of the earth. Its value at the equator is slightly less than that at the poles. This implies that the weight of the body is slightly less at the poles.

Relationship between weight and mass;

Weight or force on a body is got by multiplying mass and acceleration(g) W = mg.

Differences

Mass	Weight
Measured using beam balance	Measured using spring balance
SI unit is kilogram (kg)	SI unit Newton (N)
It is constant	Varies from place to place
It is a scalar quantity	It is a vector quantity
Quantity of matter	Force

1. An object weighs 50N on earth. What is the weight of the same object on the moon? Gravitation acceleration on the moon is 8 m/s² while on earth g = 10m/s²

W = Mg

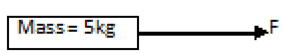
50 = m x 10

M = 5N

Weight on the moon W = Mg

= 0.5 x 8= 4N.

3. A body of mass 5kg is acted on by a force in horizontal direction as shown below



If the force causes an acceleration of 4m/s². Find the force F.

Force F = ma

= 5 x 4

= 20N.

4. Find acceleration of the body of mass 8kg when acted upon by a force of 16N.

Force = ma

16N = m x a

Acceleration =$2m/s^2$.

Exercise;

1. An object has a mass of 6kg. Find its weight?

(i) On earth where g = $10m/s^2$

Weight = $10m/s^2$ x 6kg

= 60N

(ii) On Jupiter where = g = $12m/s^2$

Weight = Mg = $12m/s^2$ x 6kg

= 72N

(iii) On mars where g = $3m/s^2$

Weight = $3m/s^2$ x 6kg

= 18N.

2. The weight of a body on earth 1.5 times than that on the moon. Given the mass of the body is 0.4kg and acceleration g = $10m/s^2$ on earth. Calculate;

(i) Weight on earth

W = mg = 0.4 x 10 = 4N.

(ii) Weight on the moon = = 2.67N

(iii) Acceleration due to gravity on the moon;

W = mg

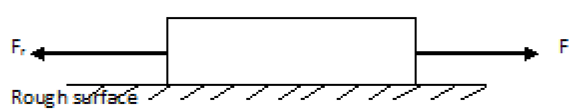
2.67 = 0.4 x a

a = $6.67m/s^2$

Friction:

Friction is a force that opposes relative motion of two bodies' in contact

Friction acts in the direction opposite to that in which motion is taking place



Where F_r – Friction force

F – Force acting on the body

In the diagram above is force F moves the block to the right then friction acts with the block to the left.

<u>Example:</u>

A body of mass 3kg is acted on by a horizontal force of 9N as shown below.

If the opposing friction is 6N. Find the acceleration of body.

Resultant force $F = (9 - 6) = 3N$

But force $F = ma$

$3 = 3a$

$a = 1m/s^2$

Question

A block of wood of mass 4kg acted upon by a horizontal force of 10N, if the block moves with an acceleration of $2m/s^2$. Find the friction force that opposes its motion.

Advantages of friction:

Friction, although sometimes seen as a hindrance, has many advantageous applications in everyday life and various technological and industrial processes.

1. Enables Movement

Friction is essential for walking, driving, and other forms of locomotion. The friction between our shoes and the ground allows us to walk without slipping. Similarly, the friction between car tires and the road surface provides the necessary grip for vehicles to move and stop safely.

2. Provides Grip and Traction

Friction provides the grip needed for holding objects. Without friction, it would be nearly impossible to pick up and hold items, as they would slip out of our hands. The traction provided by friction is also crucial for climbing, gripping tools, and operating machinery.

3. Facilitates Braking

The frictional force between brake pads and wheels or discs is what allows vehicles to slow down and stop. This is critical for the safety of all forms of transportation, from bicycles to cars to trains.

4. Enables Writing and Drawing

The friction between a pen or pencil and paper allows us to write and draw. Without friction, writing instruments would not leave marks on surfaces, making communication through writing impossible.

5. Generates Heat

Friction can generate heat, which can be advantageous in certain applications. For example, friction is used in processes such as striking a match or generating warmth through rubbing hands together.

6. Mechanical Functionality

Friction is essential for the functioning of many mechanical systems. For example:

Clutches in vehicles rely on friction to engage and disengage the engine from the transmission.

Belts and pulleys depend on friction to transmit motion and force.

7. Prevents Slipping and Skidding

Friction helps prevent slipping and skidding, making surfaces safer to walk or drive on. Anti-slip mats, treads on tires, and textured surfaces all rely on friction to improve safety.

8. Energy Dissipation

In systems where excess kinetic energy needs to be dissipated, such as in car shock absorbers or certain types of machinery, frictional forces convert kinetic energy into thermal energy, thereby reducing vibrations and improving stability.

9. Manufacturing Processes

Friction is used in various manufacturing processes, such as sanding, grinding, and polishing. These processes rely on friction to smooth surfaces, shape materials, and remove excess material.

10. Holding Objects in Place

Friction helps keep objects in place, preventing them from sliding or moving unintentionally. This is crucial for stability in construction, furniture, and everyday items like rugs and floor mats.

In summary, frictional force plays a vital role in many aspects of daily life and technology. It facilitates movement, provides grip, enables braking, and contributes to numerous mechanical and manufacturing processes, making it an indispensable force despite its sometimes perceived drawbacks.

Disadvantages of friction

While friction has many advantages, it also has several disadvantages that can be problematic in various contexts.

1. Wear and Tear

Friction causes wear and tear on materials and surfaces in contact. This can lead to the gradual degradation of components such as machine parts, tools, and even everyday items like shoes and tires. Over time, this wear can lead to failure or the need for replacement.

2. Energy Loss

Friction converts kinetic energy into thermal energy, resulting in energy loss. In mechanical systems, this means that more energy is required to maintain motion, reducing overall efficiency. For example, engines and machines lose efficiency due to the heat generated by friction.

3. Heat Generation

The heat produced by friction can be undesirable and damaging. In mechanical systems, excessive heat can cause overheating, leading to thermal expansion, warping, or even failure of components. In electronics, heat generated by friction can affect performance and longevity.

4. Reduced Efficiency

In various processes and systems, friction reduces efficiency by increasing the amount of energy required to achieve desired outcomes. For example, in transportation, friction between moving parts and the air or road surface means more fuel is needed to maintain speed.

5. Noise and Vibration

Friction often results in noise and vibration, which can be bothersome and lead to mechanical issues. For instance, squeaking brakes or the hum of machinery are both caused by frictional forces.

6. Slows Down Motion

While friction is necessary to initiate and control motion, it also acts as a resisting force that slows down motion. This can be a disadvantage in scenarios where minimal resistance is desired, such as in ball bearings or high-speed transportation.

7. Material Deformation

Prolonged friction can cause deformation of materials. For instance, sliding friction can cause grooves or scratches on surfaces, affecting the integrity and functionality of the material.

8. Lubrication and Maintenance Costs

To mitigate the negative effects of friction, lubrication and regular maintenance are often required. This adds to the operational costs and complexity of maintaining machinery and equipment.

9. Energy Consumption in Overcoming Friction

In industrial processes and daily activities, additional energy is needed to overcome friction. This can lead to higher energy consumption and increased operational costs.

10. Environmental Impact

The wear and tear caused by friction can lead to the release of particles and pollutants into the environment. For example, tire wear releases micro plastics into the environment, contributing to pollution.

In summary, while friction is essential in many contexts, it also presents several challenges, including wear and tear, energy loss, heat generation, reduced efficiency, noise, and the need for additional maintenance. Managing friction effectively is crucial in many industries to minimize its negative impacts while maximizing its benefits.

Types of friction:

Friction is a force that resists the relative motion or tendency of such motion of two surfaces in contact. There are several types of friction, each with distinct characteristics and applications. The primary types of friction include:

1. Static Friction

Definition: Static friction is the force that resists the initiation of sliding motion between two surfaces that are in contact and at rest relative to each other.

Characteristics: Static friction keeps objects stationary and must be overcome to start moving an object.

Equation: $f_s \leq \mu_s R$ where f_s is the static friction force, μ_s is the coefficient of static friction, and R is the normal force.

Example: Pushing a heavy box on the floor; the box does not move until the applied force exceeds the static friction force.

2. Kinetic (Sliding) Friction

Definition: Kinetic friction, also known as sliding friction, occurs when two surfaces are in relative motion.

Characteristics: It is usually less than static friction for the same materials.

Equation: $f_k = \mu_k R$, where f_k is the kinetic friction force, μ_k is the coefficient of kinetic friction, and R is the normal force.

Example: Sliding a book across a table; the force resisting the motion of the book is kinetic friction.

3. Rolling Friction

Definition: Rolling friction occurs when an object rolls over a surface.

Characteristics: Rolling friction is generally much smaller than static or kinetic friction.

Factors Influencing : It depends on the nature of the surfaces in contact, the radius of the rolling object, and the deformation of the surfaces.

Example: Wheels of a car rolling on the road experience rolling friction.

4. Fluid Friction

Definition: Fluid friction occurs when an object moves through a fluid (liquid or gas), also known as drag.

Characteristics: It depends on the object's speed, the fluid's viscosity, and the object's shape.

Example: A boat moving through water or an airplane flying through the air.

5. Internal Friction

Definition: Internal friction refers to the resistance to motion within a material due to its internal structure.

Characteristics: It occurs when layers within a material slide past each other.

Example: Deformation of materials such as rubber or the damping of vibrations in materials.

Comparison and Applications

Static vs. Kinetic Friction: Static friction is generally higher than kinetic friction for the same surfaces, which is why more force is needed to start moving an object than to keep it moving.

Rolling Friction : Used in applications where low resistance is desired, such as wheels, ball bearings, and rollers.

Fluid Friction: Important in the design of vehicles, aircraft, and ships to minimize drag and improve efficiency.

Internal Friction: Relevant in materials science and engineering for understanding material properties and behaviors.

In summary, friction comes in various forms depending on the nature of the contact between surfaces and the state of motion. Understanding these types is crucial for solving practical problems in engineering, physics, and everyday life.

Static friction presents motion whereas dynamic friction slows down motion.

Ways of reducing friction:

- By lubricating, oil or grease is introduced between surfaces sliding over one another. The oil therefore keeps rough surface apart and friction is reduced.
- By using ball bearings, these are used e.g. in axle and shaft of the bicycle, they do not slide but roll over one another. Rolling friction is less than sliding friction; therefore friction is reduced by the ball bearings by using rollers between two rough surfaces.

VECTOR AND SCALAR QUANTITIES

In physics and mathematics, quantities can be classified into two broad categories: vectors and scalars. Each has distinct properties and plays different roles in describing physical phenomena.

Scalars

Definition: Scalars are quantities that are fully described by a magnitude (or numerical value) alone. They do not have a direction.

Characteristics:

Magnitude: Scalars have only a size or magnitude.

No Direction: Scalars are directionless.

Operations: Scalars can be added, subtracted, multiplied, and divided like ordinary numbers.

Examples:

Temperature: 25°C

Mass: 10 kg

Time: 30 seconds

Speed: 60 km/h (Note: Speed is scalar, while velocity is vector)

Energy: 500 Joules

Vectors

Definition: Vectors are quantities that have both magnitude and direction. They are often represented graphically by arrows.

Characteristics:

Magnitude and Direction: Vectors have a specific size and direction.

Representation: Represented graphically by arrows, where the length represents the magnitude, and the arrow points in the direction.

Components: Vectors can be broken down into components along coordinate axes, typically using x, y, and sometimes z components in a Cartesian coordinate system.

Operations: Vector addition, subtraction, and multiplication (dot product and cross product) follow specific rules.

Examples:

Displacement: 5 meters east

Velocity: 30 km/h north

Force: 10 newtons downward

Acceleration: 9.8 m/s^2 downward

Momentum: A mass moving in a specific direction

Importance in Physics

Scalars are used to describe quantities that are only concerned with magnitude, like temperature or mass.

Vectors are crucial for describing quantities that involve direction, like force, velocity, and acceleration, making them essential in mechanics, electromagnetism, and many other fields.

Understanding the distinction between vectors and scalars is fundamental in physics and engineering, as it helps in the proper formulation and solution of physical problems.

Vector quantity e*xamples include:*

Weight, acceleration, force, displacement, momentum, velocity, friction etc.

Scalar quantity examples include:

Mass, speed, distance, time, density, volume, pressure, area, energy etc.

Adding vectors and resultant forces

When vector such a force are added their direction must be specified.

Resultant force

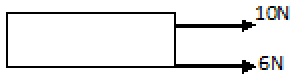
It is a single force which has the same effect as the two or more forces acting together at a point. When two or more forces act on a body, the total force on the body is called the resultant force.

Adding force in the same direction

When two or more forces act on the body in the same direction the resultant force is got by addition

Example:

(i)



Resultant force, F = 10 + 6 = 16N

(ii)

Resultant force, F = (3 - 2) = 1N

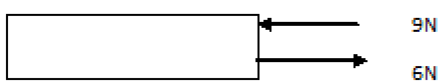
(a) When two or more forces act in opposite direction, the resultant force is got by subtraction.

(i)

Resultant force

F = (6 -2) = 4N to the left

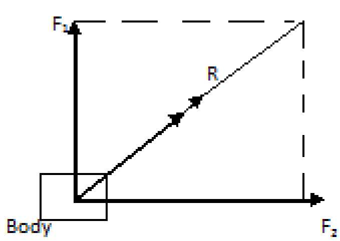
(ii)



Resultant force F = (9-6) N = 3N to the left

a. Forces at right angles

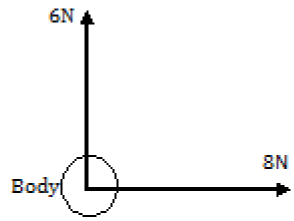
When two or more forces act on a body at right angles, the resultant force is obtained by use of Pythagoras theorem

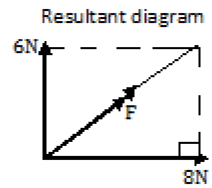


Resultant force,

Example;

1. Find the resultant force acting on the body shown.





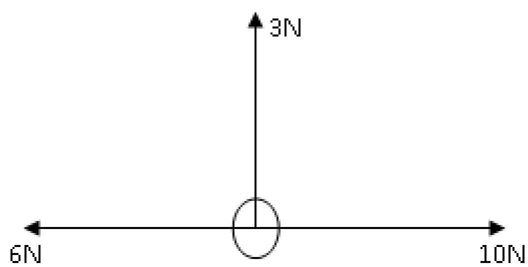
Resultant force F

$F^2 = 6^2 + 8^2$

$F^2 = 36 + 64$

$F = 10N$

2. A body of mass 2kg is acted on by 3 forces of 10N, 6N and 3N as shown below.



Find the resultant force and acceleration of the body

Resultant Horizontal force = (10 - 6) N

= 4N to the right

Resultant Vertical force = 3N

R = 5N

$F = Ma$

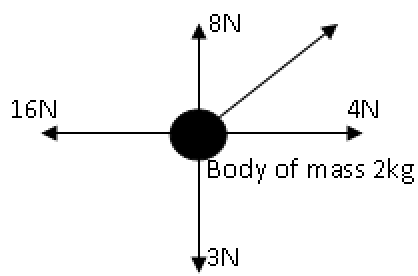
$5N = 2a$

=

$a = 2.5\ m/s^2$

Exercise:

1. Four forces act on a body as shown below;



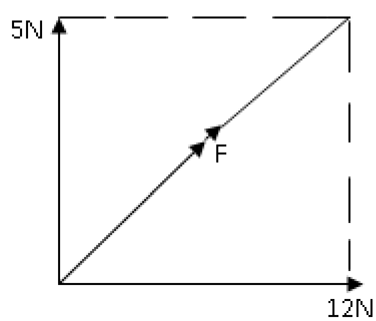
Find the resultant force and acceleration of the body.

Resultant force horizontally = (16N – 4N)

= 12N to the left

Resultant force vertically = (8N – 3N)

= 5N to the North



$= 12^2 + 5^2$

$= 144 + 25$

F =

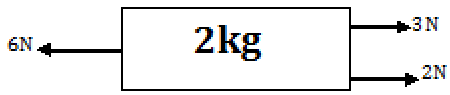
= 13N

F = Ma

a = = 6.5m/s^2

Exercise

A Force acts on a body on a smooth ground as shown;



Find the resultant force and acceleration of the body

WORK, ENERGY AND POWER

Work, energy, and power are fundamental concepts in physics that describe how forces interact with objects, how energy is transferred and transformed, and how quickly work is done.

Definition: Work is done when a force acts on an object and causes it to move. The work done by a force is equal to the product of the force and the displacement of the object in the direction of the force.

Equation:

$W = Fd\cos\theta$, where: W is the work done, F is the magnitude of the force, d is the displacement of the object, θ is the angle between the force and the displacement direction.

Units: The SI unit of work is the joule (J), where 1 J=1 Nm

A joule is the work done when force of one Newton moves its point of application through a distance of one metre in the direction of the force.

Other units include: kilo Joules (KJ), Mega joules (MJ) etc.

1 kilo Joule= 1,000joules

1megajoule =1,000,000 joules

Example: Pushing a box with a force of 10 newtons over a distance of 5 meters in the direction of the force does 50 joules of work.

Energy

Definition: *Energy is the capacity to do work.*

It exists in various forms and can be converted from one form to another.

Types of Energy:

Kinetic Energy: The energy an object possesses due to its motion.

$K.E = \frac{1}{2}mv^2$, Where m is the mass and v is the velocity.

Potential Energy: The energy an object possesses due to its position or configuration. For example, gravitational potential energy is given by: PE=mgh, where m is the mass, g is the acceleration due to gravity, and h is the height above the reference point.

Thermal Energy: The internal energy of an object due to the kinetic energy of its molecules.

Chemical Energy: The energy stored in chemical bonds.

Electrical Energy: The energy associated with electric charges and their movement.

Units: The SI unit of energy is the joule (J).

Example: A 2 kg object moving at 3 m/s has a kinetic energy of 9J.

Power

Definition: *Power is the rate at which work is done or the rate at which energy is transferred or converted.*

It measures how quickly work can be performed or energy can be used.

Equation:$Power = \frac{work\ done}{time}$, where: P is the power, W is the work done, t is the time taken.

Alternative Equation: Power can also be expressed in terms of force and velocity:

P=FV, where F is the force and V is the velocity.

Units: The SI unit of power is the watt (W), where 1 W=1 J/s

Example: If 100 joules of work is done in 10 seconds, the power is 100 J10 s=10 W

Other units: Kilo watt (kW), Megawatt (Mw)

Note; 1 kW = 1000w

1Mw = 1000, 000w

1kw = Mw

Definition of a watt

A watt –is the power developed when one joule of work is done in one second I.e. 1W = 1J/s.

Relationship between Work, Energy, and Power

Work and Energy: Work is a means of transferring energy. When work is done on an object, energy is transferred to or from that object. The work-energy theorem states that the work done on an object is equal to the change in its kinetic energy.

Energy and Power: Power quantifies how quickly energy is used or transferred. Higher power means more energy is used or transferred in a given amount of time.

Practical Examples

Work: Lifting a weight off the ground involves doing work against the force of gravity.

Energy: A roller coaster at the top of a hill has high potential energy, which converts to kinetic energy as it descends.

Power: A high-powered engine can do more work in a shorter time, enabling a car to accelerate rapidly.

Understanding these concepts is crucial in fields such as mechanics, thermodynamics, and electrical engineering, as they provide a framework for analyzing and solving problems related to forces, motion, and energy transfer.

Energy is essential for various applications in our daily lives, powering everything from homes to industries. There are several sources of energy, each with distinct characteristics, advantages, and disadvantages.

The primary sources of energy:

1. Fossil Fuels

Types:

Coal: A solid fossil fuel used primarily for electricity generation and steel production.

Oil: A liquid fossil fuel used for transportation, heating, and generating electricity.

Natural Gas: A gaseous fossil fuel used for heating, electricity generation, and as a raw material in chemical industries.

Advantages:

High energy density

Established infrastructure and technology

Reliable and consistent power generation

Disadvantages:

Significant greenhouse gas emissions

Air pollution and health impacts

Finite resource, leading to depletion concerns

2. Nuclear Energy

Source: Generated through nuclear fission, where atomic nuclei (typically uranium-235 or plutonium-239) are split to release energy.

Advantages:

Low greenhouse gas emissions during operation

High energy density and reliable power generation

Long-term energy supply with abundant fuel resources

Disadvantages:

Radioactive waste disposal issues

High initial capital costs

Risk of nuclear accidents (e.g., Chernobyl, Fukushima)

3. Renewable Energy

Solar Energy

Source: Energy from the sun captured using solar panels or photovoltaic cells.

Advantages:

Abundant and inexhaustible source

Low operating costs after installation

No greenhouse gas emissions during operation

Disadvantages:

Intermittent energy supply (dependent on weather and time of day)

High initial installation costs

Requires significant space for large-scale installations

Wind Energy

Source: Energy from wind captured using wind turbines.

Advantages:

Renewable and abundant

Low operating costs after installation

No greenhouse gas emissions during operation

Disadvantages:

Intermittent energy supply (dependent on wind availability)

Noise and visual impact concerns

Requires suitable locations with consistent wind

Hydropower

Source: Energy from moving water, typically harnessed using dams on rivers.

Advantages:

Reliable and consistent power generation

Can provide large-scale power

No greenhouse gas emissions during operation

Disadvantages:

Ecological impact on aquatic ecosystems

Displacement of communities and wildlife

High initial construction costs

Biomass Energy

Source: Energy from organic materials (plant and animal matter), including wood, agricultural residues, and biofuels.

Advantages:

Can use waste materials, reducing landfill use

Renewable if managed sustainably

Can reduce greenhouse gas emissions if replacing fossil fuels

Disadvantages:

Air pollution from burning biomass

Land and water resource competition with food production

Can contribute to deforestation if not managed sustainably

Geothermal Energy

Source: Energy from heat stored within the Earth, harnessed using geothermal power plants or heat pumps.

Advantages:

Reliable and consistent power generation

Low greenhouse gas emissions

Small land footprint compared to other renewables

Disadvantages:

Limited to regions with accessible geothermal resources

High initial capital costs

Potential for induced seismic activity

Emerging and Alternative Energy Sources

Hydrogen Energy

Source: Energy from hydrogen, used in fuel cells to generate electricity or as a direct fuel.

Advantages:

High energy density

Can be produced from various resources (including water and renewable energy)

No greenhouse gas emissions when used in fuel cells

Disadvantages:

High production and storage costs

Infrastructure for widespread use is still developing

Energy-intensive production process if not using renewable sources

Tidal and Wave Energy

Source: Energy from ocean tides and waves captured using specialized turbines and generators.

Advantages:

Predictable and reliable energy source

High energy potential in coastal areas

No greenhouse gas emissions during operation

Disadvantages:

High initial capital costs

Environmental impact on marine ecosystems

Limited to suitable coastal locations

Comparison and Integration

Each energy source has unique characteristics, making them suitable for different applications and regions. In practice, a mix of energy sources is often used to balance the advantages and disadvantages, enhance energy security, and reduce environmental impact. The transition to a more sustainable energy system involves integrating renewable sources, improving energy efficiency, and developing new technologies to minimize the drawbacks of current energy sources.

Mechanical forms of energy

KINETIC ENERGY

This is the energy possessed by a body in motion e.g. running water, moving bullet etc.

SI unit; joules

Kinetic energy is given by, KE = mv^2 where M is the mass of the body, V is the speed or velocity.

Example;

1. Find the kinetic energy of a body mass 2kg moving with a speed of 4m/s

   $K.E = \frac{1}{2}mv^2$

   KE = $0.5 \times 2 \times 4^2$

   KE = 4^2

   KE = 16 J

2. A boy of mass 60 kg is running at a speed of 10m/s. Find his kinetic energy

   KE = mv^2

   = $\times 60 \times 10^2$

   = 30×10^2

   = 30×100

   = 3000J

3. A ball has a mass of 50kg moving with kinetic energy of 3125J. Calculate the speed with which he runs.

   KE = mv^2

   3125 = $\times 50 v^2$

   = 11.2m/s

PONTENTIAL ENERGY:

This is the energy possessed by a body due to its position above the ground. It lifts a body to some height above the ground. Work is done against gravitational force and it is stored in the body as potential energy.

When the body is allowed to fall, its potential energy reduces as it approaches the ground

Potential energy = Work done

= F x d but F = mg and d = h

P.E = mgh

Where $g = 10m/s^2$ and h is the height above the ground.

Example

1. A stone of mass 8kg is lifted through a height of 2 metres. Find the potential energy the stone develops (Take $g = 10m/s^2$)

   P.E = mgh

   = 8 x 10 x 2

   = 160J

2. A girl of mass 40kg is 15 metres above the ground. Find the potential energy she possesses.

   P.E = mgh

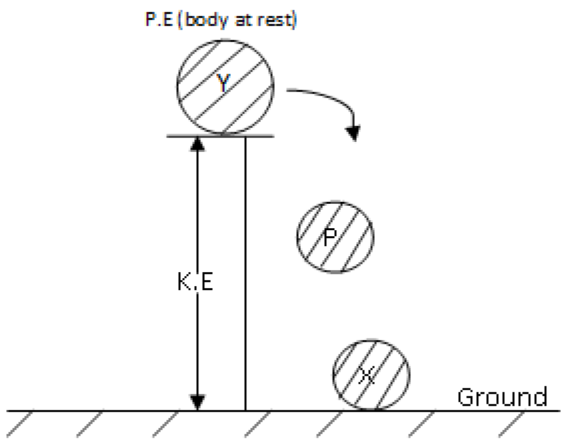
   = 40 x 10 x 15

   = 400 x 15

   = 6000J

ENERGY INTERCHANGE

In the gravitational field energy changes from one form to another



The stone has maximum potential energy at position y where it is at rest above the ground

At P, the stone has both potential and kinetic energy and when it hits the ground at X it losses all the potential energy.

This potential energy is converted to kinetic energy which is maximum as it hits the ground

P.E at Y = K.E at X

$Mgh = mv^2$

$2mgh = mv^2$, $2gh = v^2, v = \sqrt{2gh}$, where V is the speed with which the stone lands on the ground

Example;

A stone of mass 1kg falls from rest at height of 120m above the ground

a. Find its potential energy before it begins to fall.

   P.E = mgh

   = 1 x 10 x120

   = 1200J

b. If the stone falls with a velocity of 2m/s, find its Kinetic energy.

   $KE = mv^2$

$= \times 1 \text{ x } 2^2$

$= 2J$

C. Find the velocity with which it hits the ground.

Gain in K.E = Loss in P.E

$mv^2 = mgh$

$\text{x } 1 \text{ x } v^2 = 1 \text{ x } 10 \text{ x } 120$

$V^2 = 10 \text{ x } 120 \text{ x } 2$

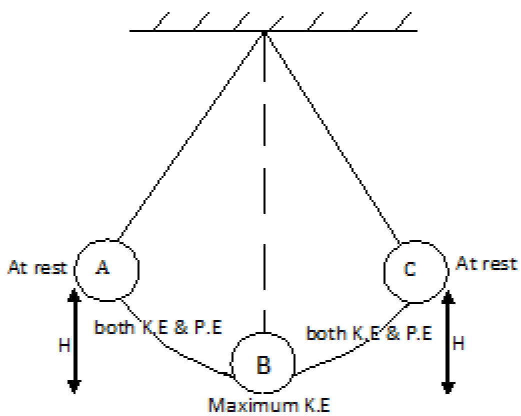
$V = 48.99m/s$

Or Simply $V =$

$V =$

$V =$

$V = 48.99m/s$



The swinging pendulum demonstrates inter conversion of energy.

At A and C the body has maximum potential energy.

At B the body has the highest speed and therefore maximum kinetic energy and zero potential energy because the height h = 0.

Along AB and BC the body possesses both potential and kinetic energy.

PRINCIPLES OF CONSERVATION OF ENERGY

It states that energy can neither be created nor destroyed but can be transformed from one form to another

Activity

a. Explain why a swinging pendulum eventually stops after sometime?

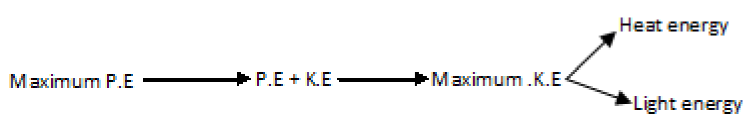
b. (i) Describe the energy changes that occur at an instant the stone is released from a height h to the ground.

(ii)Given that the height in b(i) was 20m. Calculate the speed with which the stone hits the ground.

Answer;

b.(i) At the height, the stone maximum P.E, as it falls, it gains K.E and loses P.E.

On reaching the ground it attains maximum K.E and zero P.E. Sound and heat energy are given out



b. (ii) Gain K.E = Loss in P.E, $mv^2 = mgh$

$V^2 = 2gh = 2 \times 10 \times 20$

$V = 20m/s$

ACTIVITY

Boy climbs some stairs. Each step raises 20cm and there are 10 steps, if the boy has a mass of 50kg

a) How much work does he do in climbing the stairs

b) Calculate the power developed if he took 10 seconds in climbing.

A machine lifts a load of 2500N through a vertical height of 3m in 1.5s. Find i) The power developed by a machine, (ii) Using the same power how long would it take to lift 6000N through a vertical height of 5m

1. A force of 500N displaced a mass of 20kg through a distance of 4m in 5 seconds; find (i) the work done (ii) power developed

2. A pump is rated 400w. How many kilograms of water can it raise in one hour through a height of 72m?

MECHANICAL PROPERTIES OF MATTER

Mechanical properties of matter refer to the behaviors and characteristics of materials when they are subjected to mechanical forces.

These properties are crucial in determining how materials will react under different conditions of stress, strain, and temperature, and they are fundamental in fields such as materials science, engineering, and physics. Here are some of the key mechanical properties of matter:

1. Elasticity

Definition: Elasticity is the ability of a material to return to its original shape and size after the removal of a deforming force.

Key Concepts:

Hooke's Law: Within the elastic limit, the deformation (strain) of a material is directly proportional to the applied force (stress).

Example: A rubber band stretches when pulled and returns to its original shape when the force is released.

2. Plasticity

Definition: Plasticity is the ability of a material to undergo permanent deformation without breaking when a force is applied beyond its elastic limit.

Ductility: The ability of a material to be stretched into a wire.

Malleability: The ability of a material to be hammered or rolled into thin sheets.

Example: Metal being shaped into a car body panel.

3. Strength

Definition: Strength is the ability of a material to withstand an applied force without failure or plastic deformation.

Types:

Tensile Strength: Resistance to breaking under tension.

Compressive Strength: Resistance to breaking under compression.

Shear Strength: Resistance to breaking under shear stress.

Example: Steel beams in construction must have high tensile and compressive strength to support loads.

4. Hardness

Definition: Hardness is the resistance of a material to deformation, particularly permanent deformation, scratching, cutting, or abrasion.

Measurement: Often measured using tests such as the Mohs scale, Brinell hardness test, or Vickers hardness test.

Example: Diamond is the hardest known material and can scratch almost any other material.

5. Toughness

Definition: Toughness is the ability of a material to absorb energy and plastically deform without fracturing. It is a measure of how much energy a material can absorb before failure.

Example: Rubber has high toughness because it can absorb significant energy before breaking.

6. Brittleness

Definition: Brittleness is the tendency of a material to break or shatter without significant plastic deformation when subjected to stress.

Example: Glass and ceramics are brittle materials; they break easily under stress without significant deformation.

7. Ductility

Definition: Ductility is the ability of a material to undergo significant plastic deformation before rupture or fracture.

Elongation and Reduction in Area: Measures of ductility.

Example: Copper is highly ductile and can be drawn into thin wires.

8. Malleability

Definition: Malleability is the ability of a material to withstand deformation under compressive stress, often characterized by its ability to form a thin sheet when hammered or rolled.

Example: Gold is highly malleable and can be hammered into very thin sheets.

9. Creep

Definition: Creep is the slow, permanent deformation of a material under constant stress over a long period, typically at high temperatures.

Example: Turbine blades in jet engines undergo creep at high temperatures and stress during operation.

10. Fatigue

Definition: Fatigue is the weakening or failure of a material caused by cyclic loading, leading to the accumulation of damage and eventual fracture.

Fatigue Limit: The stress level below which a material can withstand an infinite number of cycles without failing.

Example: Metal parts in machinery can fail due to fatigue after repeated loading and unloading cycles.

Applications and Importance

Understanding the mechanical properties of materials is essential for selecting the right material for a given application and for designing structures and products that are safe, durable, and efficient. Engineers and scientists use these properties to predict how materials will behave under different conditions, ensuring that structures can withstand the forces they encounter during their lifespan.

Other properties of materials

Strength;

It is the property of material that makes it require a large force to break. The material which has this property is said to strong e.g concrete, metals etc.

Stiffness;

It is the property of material that makes it resist being bent. Materials with this property are said to be stiff e.g steel, iron and concrete.

Ductility;

It is a property of materials that makes it possible to be molded in different shapes and sizes or rolled into sheets, wires or useful shapes without breaking. Materials which have this property are called ***ductile materials e.g.*** Copper wire, Soft iron wire etc.

Brittleness;

This is the ability of a material to break suddenly when force is applied on it. Materials which have this property are called brittle materials e.g. bricks, chalks, glass, charcoal etc.

Elasticity;

This is property that makes material stretch when force is applied on it and regains original size and shape when the force is removed. Materials with this property are called elastic materials e.g. rubber, copper spring etc.

Plasticity;

This is the property which makes materials stretched (deformed) permanently even when the applied force is removed materials which have this property are called plastic materials e.g. plasticine, clay, putty or tar etc.

Hardness;

This is a measure of how difficult it is to scratch a surface of a material. Hard materials include; metals, stones etc.

Timber as a building material;

It is used for making furniture, walls, bodies of vehicles, bridges, making ceilings etc.

Advantages	**Disadvantages**
It is cheap	Can get rotten
It is durable when seasoned and treated	Not fire resistant
They are easier to work with	Needs treating and seasoning

Mechanical properties;

It is strong, stiff and somehow hard.

Bricks and blocks as building materials.

These are stony materials.

Uses; For construction of bridges, walls, floors etc.

Mechanical properties;

- It is hard
- It is strong under compression
- It is stiff.

Advantages;-They are cheap, durable, and easy to work with.

Disadvantages;-They are brittle

- They need firing, and it turn out to be expensive.
- Not suitable under wet conditions i.e can soften and weaken.

Glass as a building material;

Glass is used as a building material because it has a number of desirable properties which include;

- It is transparent
- Few chemicals react with it
- It can be melted and formed into various shapes
- Its surface is hard and difficult to scratch
- It can be re-enforced (strengthened)

Construction materials;

These include concrete, bricks, glass, timber, iron bars, iron sheets etc.

Concrete;

A concrete is a mixture of cement, sand and gravels (small stones) and water.

Concrete is strong under compression but weak under tension. It can with stand tensional forces when it is *re-in forced*.

Re- in forced concrete;

- Pour wet concrete on steel rods when it dries; it gets stuck on the rods which is strong under tension. This forms a re-in forced concrete.
- It can also be re-in forced by putting fibre in concrete when it is wet and leave it to harden.

Other re-in forcing materials include;

- Bamboo stripes
- Wood stands
- Metal rods and wire mesh.

Advantages of re-in forcing concrete;

- It is weather resistant
- It does not need firing and it is fire safety.
- It is ductile when still wet
- It is durable
- It has a high tensile strength
- It is stiff or tough

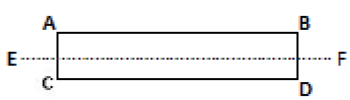
Advantages of concrete over bricks;

- Concrete can be molded in various shapes
- Concrete does not need firing
- Concrete is weather resistant
- Concrete can have a range of properties depending on the proportion of the mixture.
- Concrete can used to fill holes of different shapes.

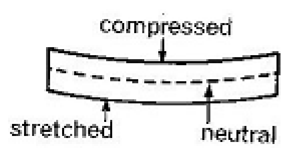
BEAMS:

A beam is along piece of materials e.g. wood, metal, concrete etc. It is usually horizontal and supported at both ends. It carries the weight of the part of the building or other structures.

When a force is applied on a beam it bends on one side of the beam in compressed (under compression), the other side is stretched (under tension) and its centre is unstretched (neutral).



Beam before bending:



Beam after bending

AB – Under compression

DC – Under tension

EF – Unstretched i.e. it neither under tension nor compression.

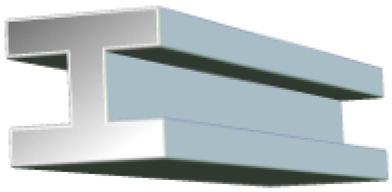
The neutral axis of beam does not resist any forces and can therefore be removed without weakening the stretch of the beam.

GIRDERS

A girder is a beam in which the material's neutral axis can be removed.

Examples of Girders;

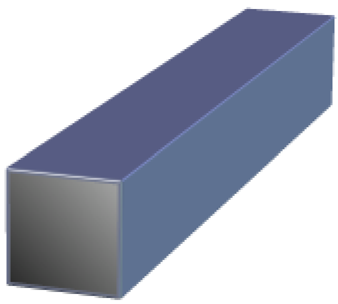
(i) I – Shape girders



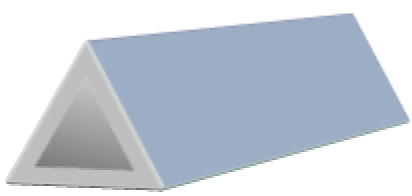
This I – shaped girder is used in construction of large structures like bridges.

(ii) Hollow tube/girder (hollow cylinder)

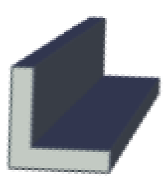
(iii) Square beam/girder



(iv) Triangular beam/girder



(v) L – Shaped girder.



Advantages of hollow beams

- It is light
- Economically cheap
- It is strong than solid beam.

<u>**Disadvantages of solid beams**</u>

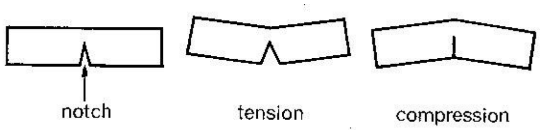
- They are heavier
- They are economically expensive
- They are weak

Disadvantages of a material used in the neutral axis:

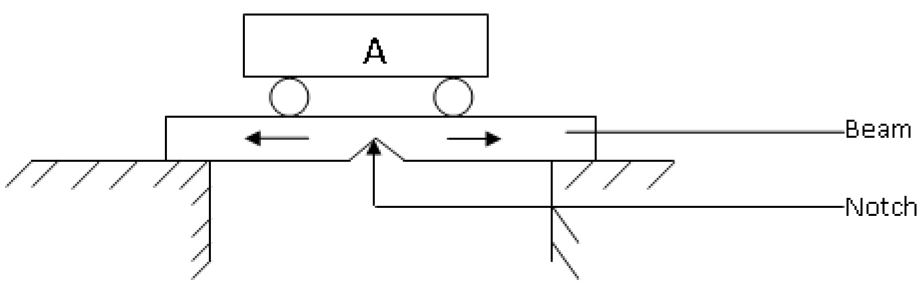
- It is a wastage and un necessary

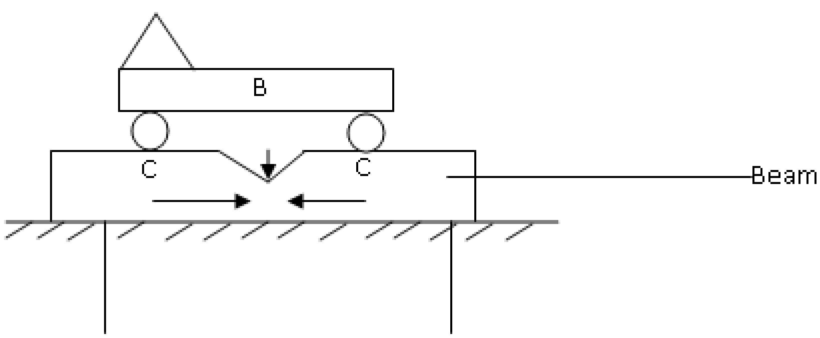
NOTCH AND NOTCH EFFECTS

A notch is a cut on a weak point on a material. It is either a crack or scratch on the surface of the material.



A notch weakens the strength of a material when it is the region of tension than when it is under compression





In 'A' the beam breaks easily when the car crosses the bridge because the notch is in the region of tension and therefore weakens the beam.

In 'B' the beam does not break easily when the car crosses.

Notch effect: This is the effect that the notch has on the strength of the material i.e. the notch weakens the strength of the material.

WAYS OF REDUCING NOTCH EFFECTS

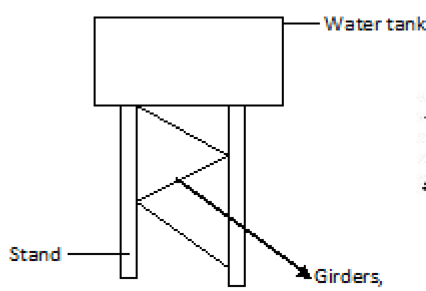
- Designing the structures in such way that all its parts are under compression.
- Making the surface of the construction material smooth.
- Use of laminated rather solid materials in construction.
- Making the notch blunt.

Structures;

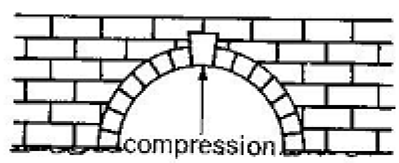
A structure consists of pieces of materials joined together in a particular way. The pieces of materials used to strengthen structures are called girders.

Examples of structures;

(i) Stands of water tank.

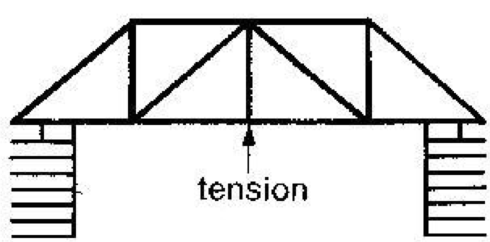


(ii) Arched bridge



-Both the upper and lower parts of the bridge are under compression. The bridge is weak under tension

(iii) Girder Bridge;

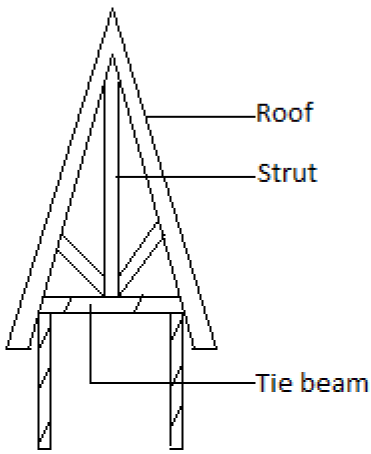


STRUTS AND TIES:

Tie: A tie is a girder under tension and can be replaced by a string.

Strut:

A strut is a girder under compression

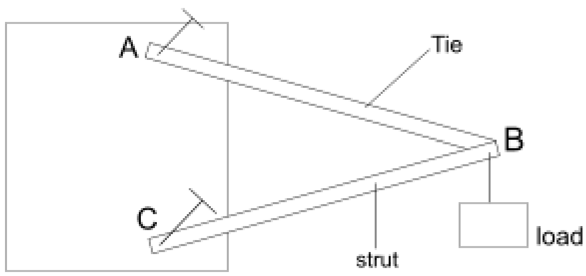


HOW TO IDENTIFY SHUTS AND TIES IN A STRUCTURE

- Remove each of the girder one at a time from the structure of the frame work and the effect it causes on the frame work is noted.
- If the frame work moves further apart the girder is a tie otherwise the girder is a strut

Experiment to distinguish between a tie and a strut

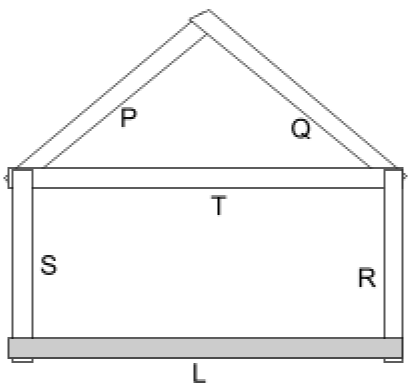
- Two straws are fixed on the side of a piece of soft board.
- A small load is added at the end B. The structure supports the load.
- The straw AB is now replaced by the string of the same length.
- If the structure still supports the load, then AB is under tension hence it is a tie.
- Similarly straw AB is then replaced with the string of the same length. If the structure does not support the load and it collapses then AB was under compression and it is a strut.



Example;

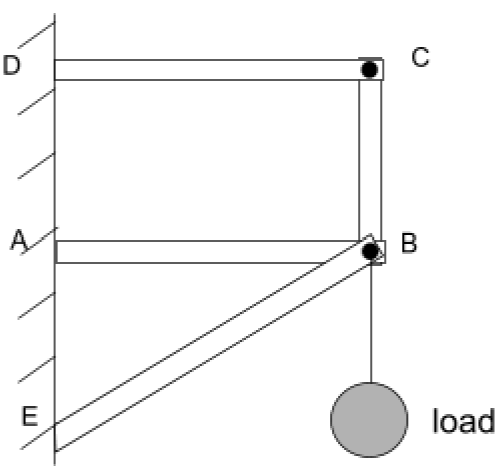
In the frame work below, identify the struts and ties.

(a)

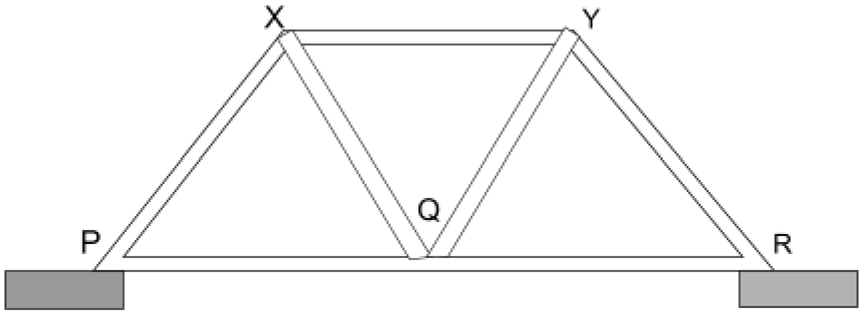


T – Tie	P – Strut	S- Strut
Q – Strut	L – Tie	R- Strut

(b)



(C)



HOOKE'S LAW OF ELASTICITY

It states that the extension of an elastic material is directly proportional to the applied force provided the elastic limit is not exceeded

i.e. applied force F α e   where e-extension or

F=k e   k- Elastic constant of material and F- Applied force.

Example

1. An elastic wire of length 10cm has force applied on it of 3N. If its
   a) Extension   e.
   b) Elastic constant   k.

Extension $e = l - l_0$ =12 -10 = 2cm = 0.02m

Using   F =K e

3= k x 0.02

K =150Nm^{-1}

2. A spring extends by 0.5 cm when a load of 0.4N hangs on it.
   a) Find the load required to cause an extension of 1.5cm.
   b) What additional load causes the extension of 1.5cm?

Method 1

Using F =K e

$0.4 = k \times 0.5$

K = =0.8N/cm

$F_2 = ke_2 = 0.8 \times 1.5 = 1.2N$.

Method 2

= =   =

F_2 = = 1.2N

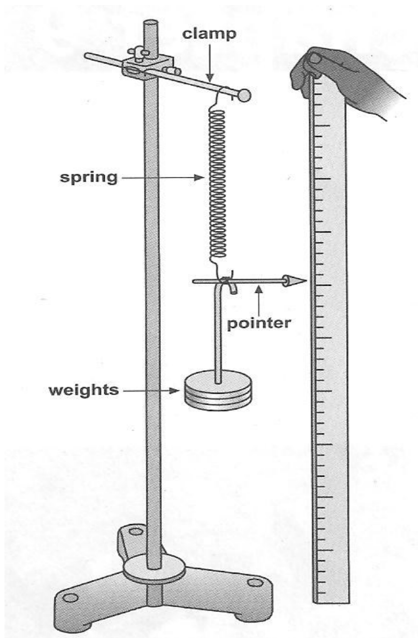
Additional load required = (1.2 – 0.4)   = 0.8N

Exercise;

1. A spring has an un stretched length of 12 cm. When a force of 8N is attached to its length becomes 6cm.
    a. Extension produced
    b. The constant of the spring
    c. Extension which will be produced by a force of 12N

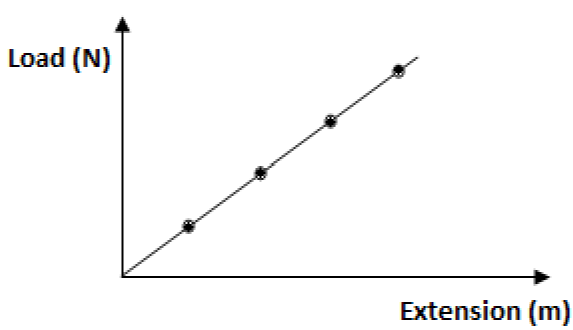
Experiment to verify (prove) Hooke's law

A spring is suspended next to the metre rule with a pointer at the bottom end used to obtain a reading on a scale as shown below



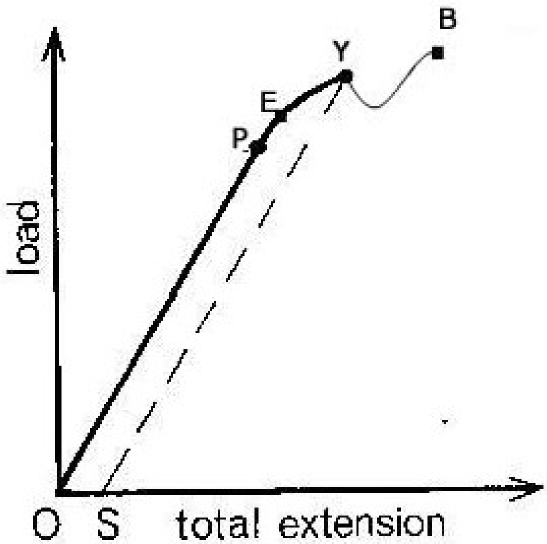
- The initial position X_0 on the pointer is read and recorded
- Uniformly load the spring by adding standard masses on the mass hanger
- The new position X of the pointer whenever the spring is loaded is recorded
- The extension for each load added is recorded from

  $e = X - X_0$.
- A graph of load against extension is plotted as shown



A straight line passing through the origin verified hook's law.

A graph load against extension for a ductile wire



Points;

P- Proportional limit

E- Elastic limit

Y- Yield point

B- Breaking point.

Lines/ regions

OP – Region where hook's law is obeyed or region of proportionality, the materials under goes elastic deformation.

OS – materials undergoes permanent extension.

SY – Material undergoes plastic deformation.

Definitions;

Elastic deformation;

This is the deformation which occurs before the elastic limit. The wire regains its shape and size after deformation. Energy is stored as potential energy.

Plastic deformation;

This occurs after the elastic limit. The wire fails to recover its original shape and size fully. Permanent extension is made and part of the energy is stored as elastic potential energy and the rest is converted into heat in the wire as it stretches. The wire recovers along YS and not OE.

STRESS, STRAIN AND YOUNG'S MODULUS

Consider a force F acting on a material e.g. a wire of length l and cross section area A so that it extends by length e.

Stress for the wire is defined as the ratio of applied force on a material to its cross section area

i.e. Stress =

SI unit: N/m^2

Strain is a ratio of extension of a material to its original length

i.e. Strain or Strain =

Strain has no units.

Young's modulus is defined as the ratio of stress to strain

Y =

SI unit = N/m^2

Young's modulus is determined when the elastic limit is not exceeded and its value is constant

Example;

1. A force of 20N acting on a wire of cross sectional area $10cm^2$ = makes its length to increase from 3m to 5m. Find stress?
   a) Stress = = = $2Nm^{-2}$
   b)

2. A copper wire of length 10cm is subjected to a force of 2N if the cross section area is $5cm^2$ and a force causes an extension of 0.2cm

   Calculate;

(i) **Tensile stress**

(ii)

(iii) Young's modulus

<u>Questions</u>

1. A mass of 200kg is placed at the end of the wire 15cm long and cross sectional $0.2cm^2$ if the mass causes an extension of 1.5cm

   Calculate.

   i. Tensile stress
   ii. Tensile stress.

2. A mass of 200g is placed at the end of a wire 15cm long are cross sectional area 0.2m .if the mass causes an extension of 1.5 calculate

   (i) Tensile stress
   (ii) Tensile strain
   (iii) Young modulus

<u>PRESSURE</u>

Pressure is defined as force acting normally per unit area

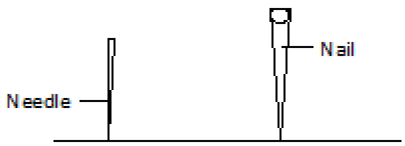
SI unit is Nm^{-2} or Newton per square metre or Pascal

Note:

Other units: Kilo Pascal (kpa) or Kilo Newton per metre squared

Note:

The pressure increases when the surface area is decreased. This can be demonstrated using a needle and a nail as shown



When the same force is applied at the top of the needle and nail, one tends to feel more pain from the needle than the nail.

This is because surface area of the bottom of the needle is smaller therefore the pressure is high

The increase in pressure when the surface area is decreased explains why a tractor can easily move in a muddy area than the bicycle.

Example;

1. A car piston exerts a force of 200N on a cross sectional area of $40cm^2$. Find the pressure exerted by the piston

2. The pressure exerted on foot pedal of cross sectional area $5cm^2$ is $200Nm^{-2}$.Calculate the force.

   =

   = =

<u>**Minimum and maximum pressure**</u>;

Pressure is minimum when area is maximum and on the other hand, pressure is maximum when area is minimum

i.e

Example;

1. A box measures 5m by 1m by 2m and has weight of 60N while resting on the surface. What is the minimum pressure?

2. A box of dimensions of 6m x 2m x 4m exerts its weight of 400N on the floor. Determine its
   a) Maximum pressure
   b) Minimum pressure
   c) Density

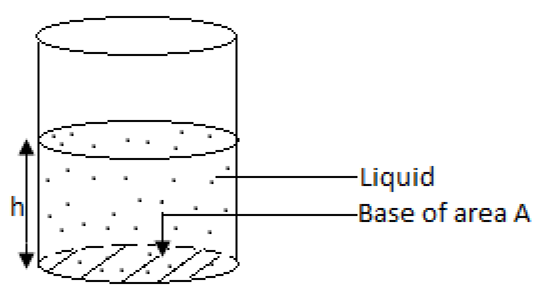
a) Maximum pressure;

b) Minimum pressure;

c) ***Density;***

<u>PRESSURE IN LIQUIDS</u>

Consider a column of liquid to a height h above the base in a cylinder as shown below;



The pressure on the surface of the base of cross sectional area A is due to weight W of the liquid above it

It follows that pressure is the same in all directions and depends on;

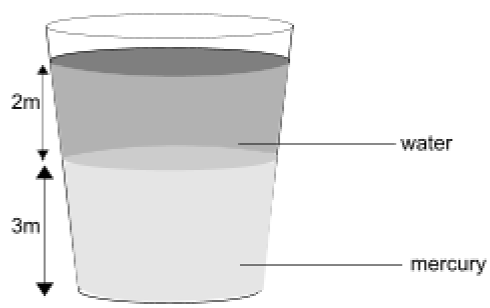
(i) Depth (h) of the liquid

(ii) Density (ρ) of the liquid

Examples

1. The density of liquid X is $800kgm^{-3}$. It was poured in a container to a depth of 400cm. Calculate the pressure it exerts at the bottom of the container

2.



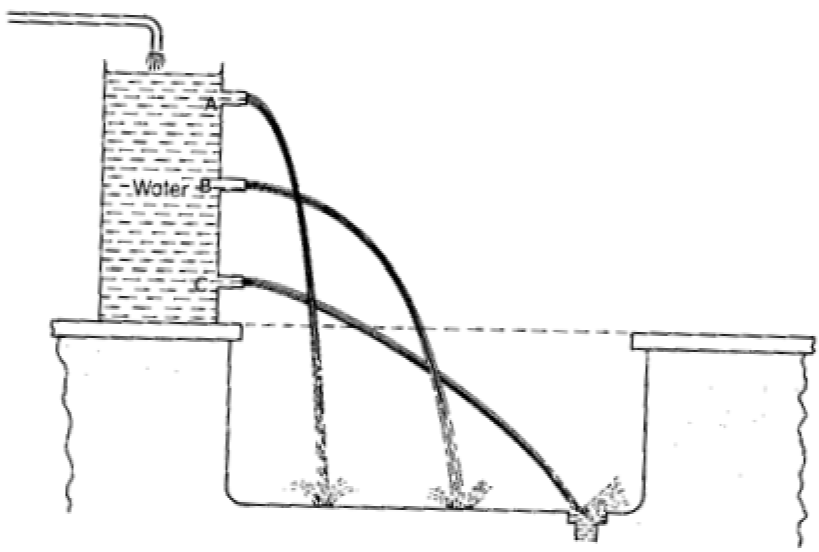
The tank contains mercury and water. The density of mercury is $13600kgm^{-3}$ and that of water is $1000kgm^{-3}$. Find the total pressure exerted at the bottom.

3. A cylindrical vessel of cross section area $50cm^2$ contains mercury to a depth of 2 cm. calculate

i) The pressure that mercury exerts on the vessel

ii) The weight of water in the vessel (density of mercury $=13600kgm^{-3}$)

Experiment to show that pressure in liquids increases with increase in depth (h)



Three equally sized holes A, B and C are made on a tall can at different depths h_1, h_2 and h_3 as shown in the figure above

The holes are blocked with cork and the can is filled with water

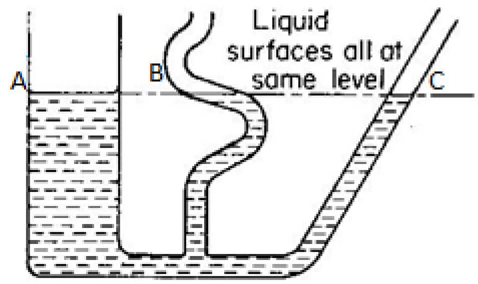
The holes are unblocked and the sizes of water jets noted

Observation;

The speed with which water spurts out is greatest for the lowest jet, showing that pressure increases with depth.

NB: pressure does not depend on shape and cross sectional area of the container. This can be illustrated using communication tube.

<u>Experiment to show that pressure is independent of cross section area and shape of container</u>



The liquid is allowed into the tubes A, B and C as shown above

The liquid reaches the same height h in all the tubes.

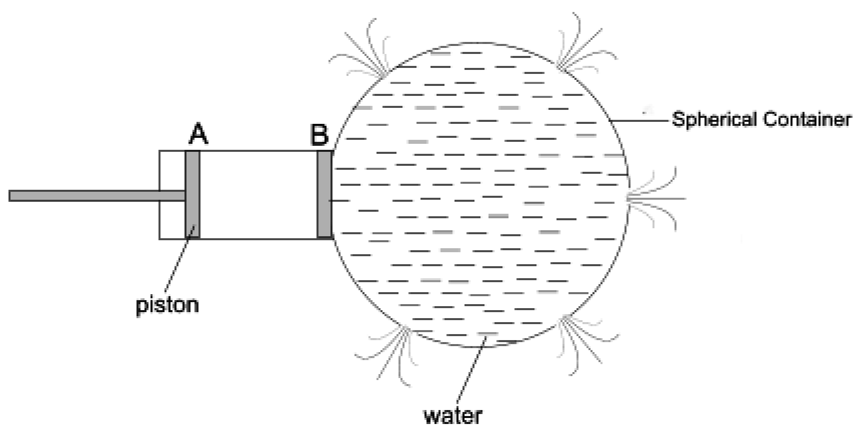
Since the tubes are of different cross sectional area and shape. It follow that pressure does not depend on shape and cross sectional area

<u>PRINCIPAL OF TRANSMISSION OF PRESSURE IN LIQUIDS</u>

(Pascal's principal or Law of liquid pressure)

The principal states that "pressure at a point in a liquid is equally transmitted throughout the liquid. The principal assumes that the liquid is incompressible

<u>Experiment to verify the principal of transmission of pressure in liquids</u>



A spherical container is pinched at different points around it

The piston is moved in such way that it pushes "B" to compress the liquid

The pressure caused is transmitted equally throughout the liquid. This can be observed by having all holes pouring out the liquid at the same rate when the piston is pushed in, hence pressure in liquid is equally transmitted.

Summary;

Experiment above show that pressure in liquids;

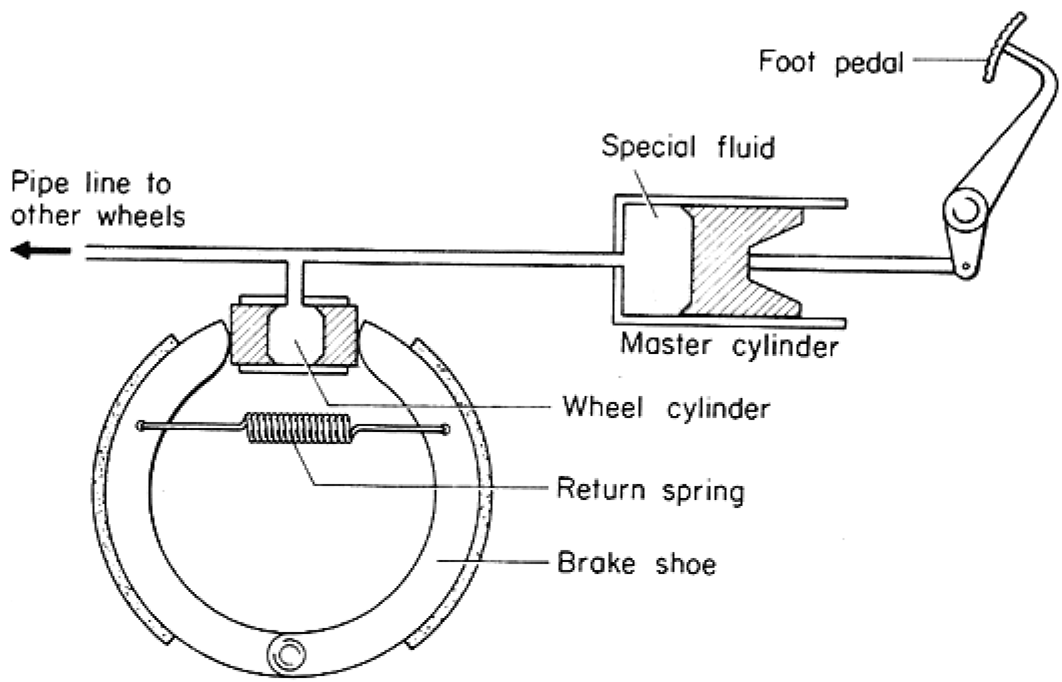
1. Depends on depth and density
2. Equally transmitted throughout the liquids
3. Is independent of shape or cross sectional area of the container in which the liquid is placed.

Application of the Pascal's principle:

Some machines where the Pascal's principle is used include;

1. Hydraulic car brakes
2. Hydraulic press
3. Hydraulic lifts.

THE HYDRAULIC CAR BRAKE SYSTEM



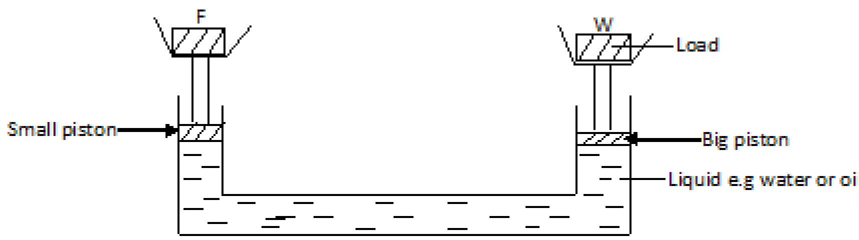
Mode of action:

- When a foot is applied on a foot pedal, the piston in the master cylinder exerts a force on the brake fluid (special fluid)

- The resulting pressure is transmitted to the wheel cylinder of each wheel
- The force caused then moves the wheel piston which push against the break pad, making them squeezed against the car wheel, hence the wheel stops rotating and the car stops.

HYDRAULIC PRESS;

A hydraulic press consists of two connected cylinders of different bores, filled with water or any other incompressible liquid and fitted with piston shown in the figure below

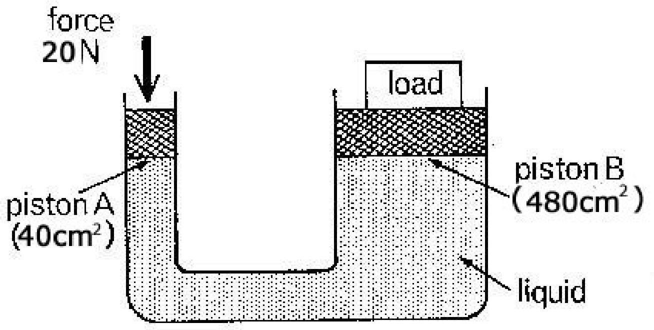


- When the force F is exerted on the liquid via piston A, the pressure produced is transmitted equally through out to piston B, which supports a load W
- The force created at B raises the load squeezing a hard substance

Example;

1. The cross sectional area of the piston A = $2m^2$ and the force applied at piston A is 10N. Calculate the force on B, given the cross section area as $150m^2$

2. Calculate the weight B, lifted by the piston of area $48cm^2$ with a force of 20N whose piston area is $400cm^2$ as shown below;



Pressure at B = pressure at A

=

= 5000 Nm^{-2}

Weight W =pressure at B x piston area B

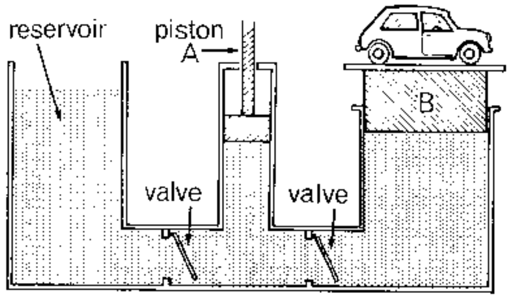
=5000 x0.048

= 240N

Questions

1. Calculate the weight W raised by a force of 56N applied on a small piston area of $14m^2$. Take the area of the large piston to be $42m^2$
2. A force of 32N applied on a piston of area $8cm^2$ is used to lift a load W acting on large area of $640cm^2$. Determine the value of W

Hydraulic lift



This is commonly used in garages; it lifts cars so that repairs and service on them can be done easily underneath the car

A force applied to the small piston, raises the large piston, which lifts the car. One valve allows the liquid to pass from the small cylinder to the wider one. A second valve allows more liquid (usually oil) to pass from oil reservoir on the left to the small cylinder. When one valve is open, the other must be shut

ATMOSPHERIC PRESSURE:

The earth is surrounded by a sea of air called atmosphere. Air has weight therefore it exerts pressure at the surface of the earth. The pressure this air exerts on the earth's surface is called atmospheric pressure.

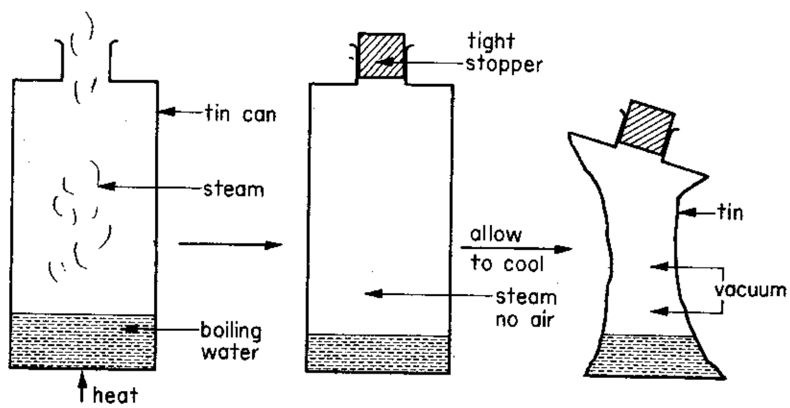
Atmospheric pressure is the pressure exerted by the weight of air on all objects on earth's surface

The higher you go the less dense the atmosphere and therefore atmospheric pressure decrease at high altitude and increase at low altitude

The value of atmospheric pressure is about 101325N/m.

Experiment to demonstrate the existence of atmospheric pressure;

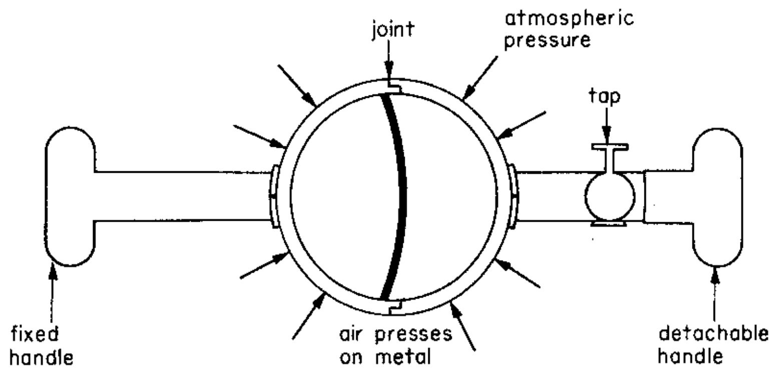
a. <u>Crushing can experiment or collapsing can experiment;</u>



- A metal can with its tight stopper removed, is heated until the small quantity of water in boils.
- When the steam has driven out all the air, the cork is tightly replaced and the heat removed at the same time.
- Cold water is poured over the can. This causes the steam inside to condense reducing air pressure inside the can

- The can collapses in wards. This is because the excess atmospheric pressure outweighs the reduced pressure inside the can.

b. The Magdeburg's hemisphere



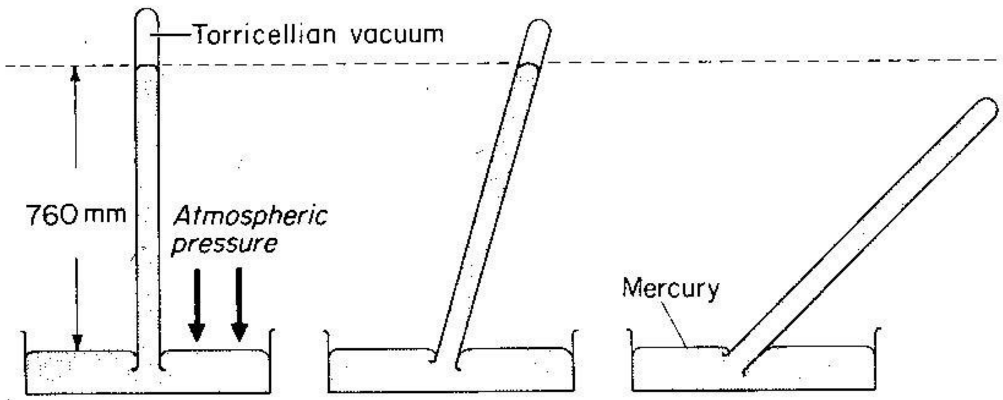
The hemisphere is made of two hollow bronze with a stop cork on one side. The rims are placed together with grease tightening between them to form an air tight joint. The air is pumped out and the stop cork closed. It becomes impossible for even eight horses to separate them. When air is re admitted in the sphere they are easily separable. This indicates the existence of atmospheric pressure.

MEASUREMENT OF ATMOSPHERIC PRESSURE:

Atmospheric pressure is measured using an instrument called Barometer.

Types of barometers	Units of pressure
1. Simple barometer	Nm^{-2}
2. Fortin barometer	Pa
3. Aneroid barometer	atmospheres

Simple barometer



A simple barometer is made by completely filling a thick walled glass tube of uniform bore about 1m long with mercury

The tube is tapped from the open side and inverted several times to expel any air bubbles trapped in mercury

It is inverted over a dish containing mercury as shown in the diagram.

The mercury level falls leaving a column "h" of about 76 cm

The height "h" gives the atmospheric pressure 76cmHg.The empty space created above the mercury in the tube vacuum called Torricellian vacuum

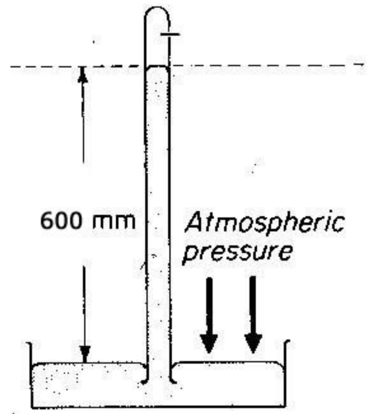
NB; The vertical height of the mercury will remain constant if the tube is lifted as in (2) provided the top of the tube is not less than 76cm above the level of mercury in the dish.

If it is lifted so that "h" is less than 76cm.The mercury completely fills the tube. This shows that vacuum was a trice vacuum and a column of mercury is supported by atmospheric pressure

Generally, Atmospheric pressure = Barometer height x Density of liquid x gravity

Example; 1. Determine the atmospheric pressure (i) in cmHg and in (ii) Pascal's (Nm^{-2}) using the following barometer.

(a)



(i) Height = 600mm p = 60cmHg

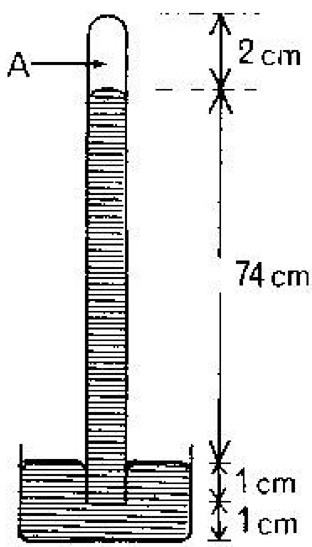
(ii) P = hpg

= 600mm x 13600 x 10

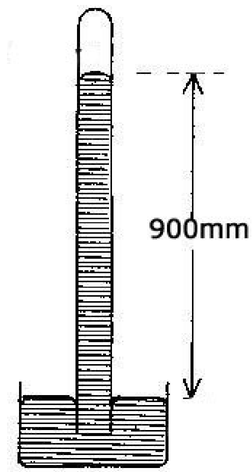
= x 13600 x 10

= 81600pa or 81600Nm^{-2}

(b)



(c)



2. Express (i) 76cm Hg in Nm^{-2} (density = $13600kgm^{-2}$)

P= hpg

= x 13600 x 10 = 103360 Pascals

(ii) 540mmHg in pa

P = hpg = x 13600 x 10 = $73440N/m^2$

3. The column of mercury supported by the atmospheric pressure is 76cm. Find column of water that the atmospheric pressure will support in the same place. Comment on your answer.

P = hpg = x 13600 x 10

= 103360 Nm^{-2}

In the same place atmosphere pressure is the same as using water;

P = hpg

103360 = h x 1000 x 10

h = 103360/ 1000 X 10

h= 1034m

The answer to the question above, explains why water is not used in a barometer because the column will be too long.

Applications of Atmospheric pressure

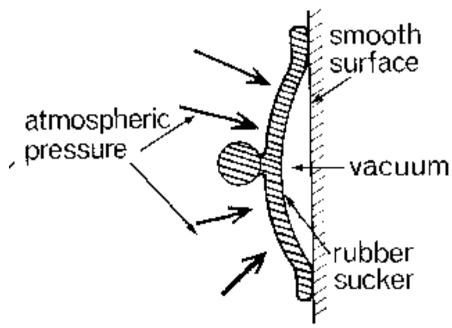
Atmospheric pressure may be made useful in

a. Rubber suckers
b. Bicycle pump

c. Lift pump
d. Force pump
e. Siphon
f. Water supply system
g. Drinking straw

Rubber Sucker

This is circular hollow rubber cap before it is put to use it is moisturized to get a good air seal and firmly pressed against a small flat surface so that air inside in pushed out then atmospheric pressure will hold it firmly against surface as shown below

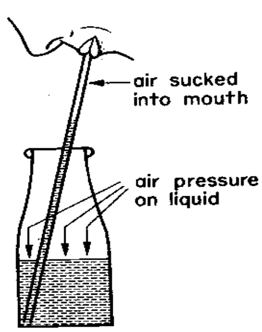


<u>Uses of rubber sucker;</u>

-Fitting sheets against walls

-It is used printing machines for lifting papers to be fed into the printer

Drinking straw;

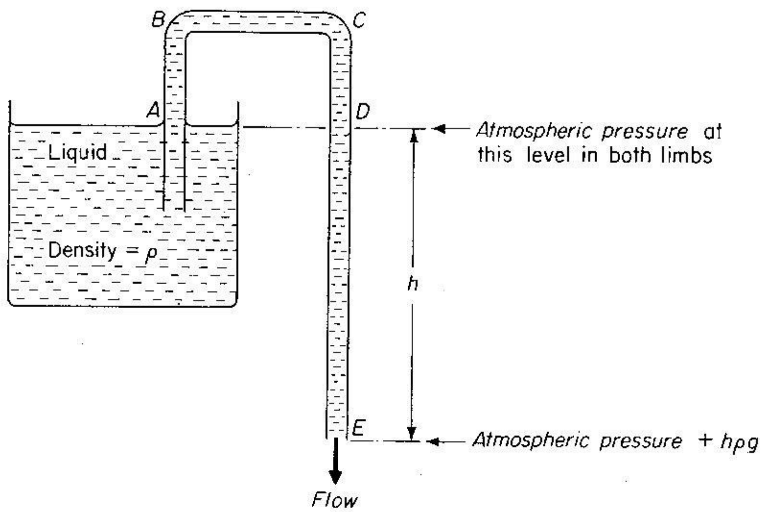


-When drinking using a straw some of the air in the straw goes into the lungs once sucked.

-This leaves space in the straw partially evacuated and atmospheric pressure pushing down the liquid becomes greater than the pressure of the air in the straw

The siphon;

This is used to take the liquid out of vessels (eg. Aquarium, petrol tank)



How a siphon works

The pressure at A and D is atmospheric, therefore the pressure at E is atmospheric pressure plus pressure due to the column of water DE. Hence, the water at E can push its way out against atmospheric pressure

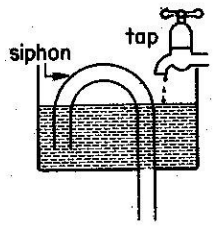
NB: To start the siphon it must be full of liquid and end A must be below the liquid level in the tank.

Applications of siphon principle

1. **Automatic flushing tank:** This uses siphon principle.

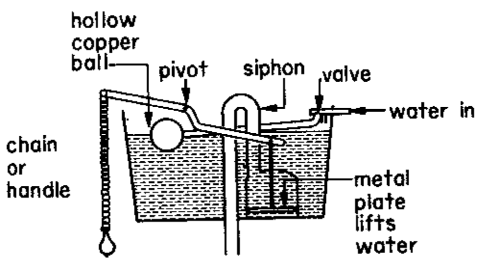
   Water drips slowly from a tap into the tank. The water therefore rises up the tube until it reaches and fills the bend

   In the pipe, the siphon action starts and the tank empties (the water level falls to the end of the tube).The action is then repeated again and again.



2. **Flushing tank of water closet:** This also uses the siphon principle.

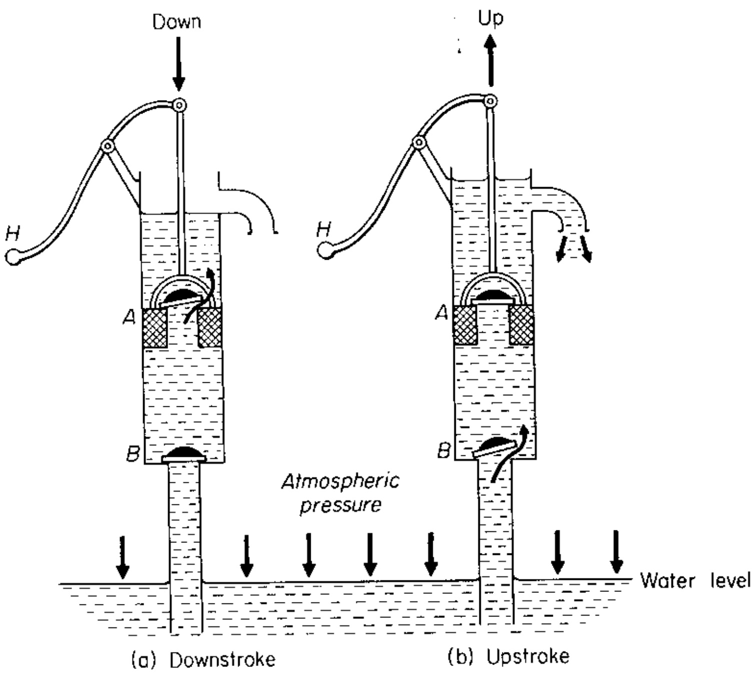
When the chain or handle is pulled, water is raised to fill the bend in the tube as shown below:



The siphon action at once starts and the tank empties.

Lift pump or common pump;

Pumps are used to raise water from walls. They consist of cylindrical metal barrel with side tubes near the top to act as spouts.



Down stroke;

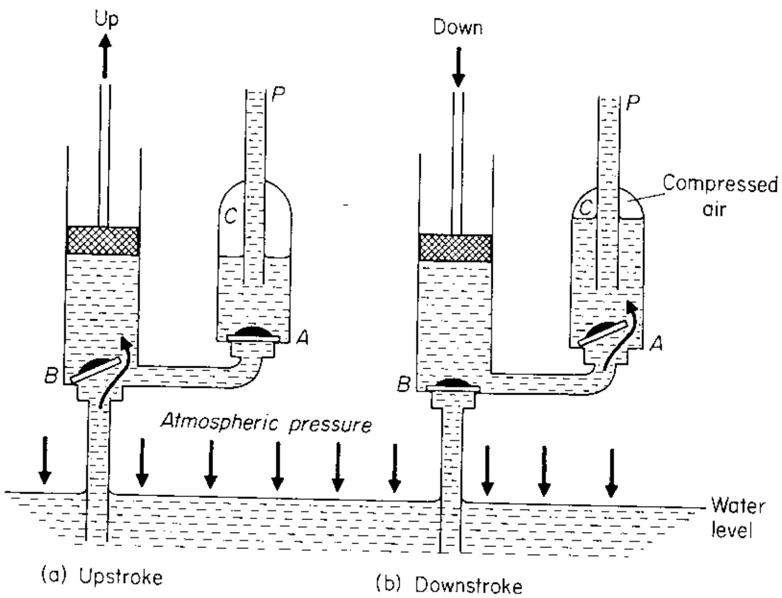
When the plunger moves down wards valve B closes due to force of gravity on it and weight of water above it.

At the same time water inside the barrel passes upwards through A into the space above the plunger.

The upstroke;

- Valve A closes due to the force of gravity on it and weight of water above it.
- As the plunger rises water is pushed up the pipe through valve B by atmospheric pressure on the surface of the water in the well.
- At the same time, the water above it is raised and flows out at the spout.

Force pump;



A force pump is used to raise water from a deep well or reservoir to a storage tank.

It is first pumped to make it air tight.

On the upstroke, valve A closes and atmospheric pressure forces the water up the barrel through valve B.

On the down stroke valve B closes, water is forced into the reservoir through valve A and also out of the spout D.

The air in the spout is compressed and on the next up stroke, it expands so keeping the supply of water at B.

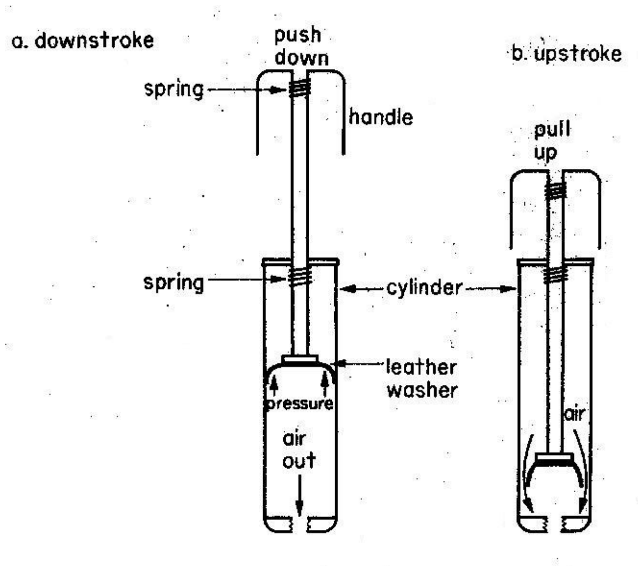
BICYCLE PUMP;

Principle and action of a pump

-The air in the pump barrel is compressed.

-The high pressure of the air in barrel presses the leather washer against the inside of the barrel closing the pump valve.

-When the pressure of compressed air becomes greater than that of air already in the tyre, air is forced past the tyre valve into the tyre.



When the handle is pulled out, the pressure of the air in the barrel is reduced.
The high pressure of air in the tyre closes the tyre valve preventing the air escaping.
The atmospheric pressure being greater than the reduced pressure in the barrel, forces the air past the leather washer opening the valve refilling the barrel with air.

<u>Water supply system</u>:

Water supply in towns often comes from a reservoir on a high groundwater flows from it through a pipe to any tap or storage tank that is below the water reservoir.
In very tall building it may be necessary to first pump water to a large tank on a roof.
Reservoirs of water supply in hydro electric power stations are often made in mountainous areas.

The dam must be thicker at the bottom than at the top to with stand large water pressure at the bottom.

Atmospheric pressure is 760mmHg.When you move on the top of the mountain, the pressure reduces to about 600mmHg.***This shows that pressure reduces with increase in altitude.***

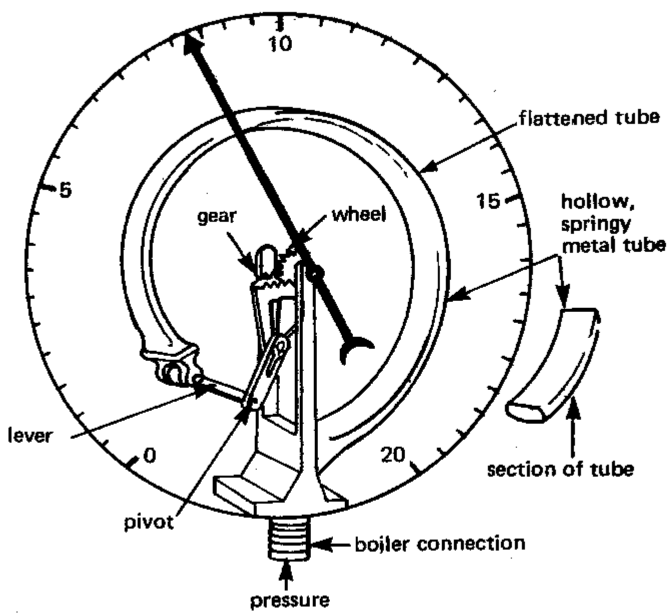
Measurement of fluid pressure:

a. **Bourdon gauge**

This gauge measures the very high pressures of liquids or gases, e.g. the pressure of steam in boilers. It is a hollow curved tube of springy metal closed at one end. The tube straightens slightly when pressure acts on the inside.

The closed end of the tube is joined to a series of levers and gear wheels which magnify the slight movement.

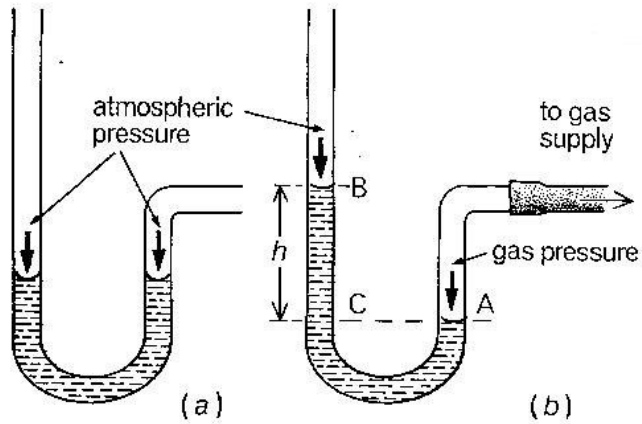
A pointer moving over a scale (usually graduated in 10^5 Pa, which is about 1 atmosphere pressure) records the pressure. The recorded pressure is the excess pressure of liquid or gas over atmospheric pressure, but some gauges can record the actual pressure.



Bourdon gauges are commonly used at fueling stations.

b. Manometer;

It is a U – shaped tube containing mercury



Action;

One limb is connected to the gas or air cylinder whose pressure P is required.

Second limb is left open to the atmosphere

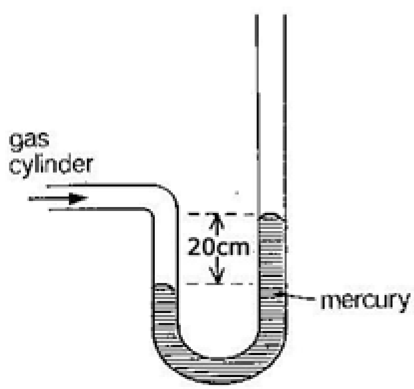
Using a metre rule, pressure P of the gas is calculated as

Pressure at B = Pressure at C

= H + h (when B is above A)

= H – h (when B is below A)

Example;



1 .Find the gas pressure given atmospheric pressure H = 76cmHg

(i) In cmHg

(ii) In Nm^{-2}

Solution

1. (i) Gas pressure P = H + h = 76 + 20 = 96 cmHg

   (ii) P = hpg = x 13600 x 10 = 130560 Nm^{-2}

2. Express a pressure of 75cmHg into Nm^{-2}

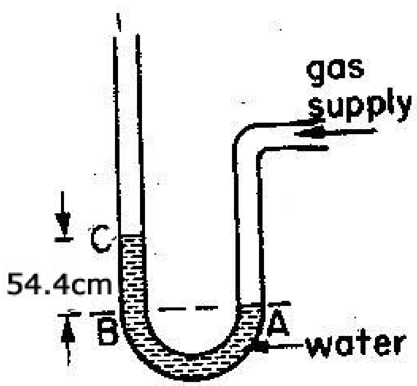
   P = hpg = x 13600 x 10 = 102000Nm^{-2}

3. A man blows in one end of a water U – tube manometer until the level differ by 40.0cm.If the atmospheric pressure is 1.0x 10^5 N/m^2 and density of water is 1000kgm^{-3}.calculate his lung pressure.

   Pressure of air = H + hpg

   = 1.01 x 10^5 + x 1000 x 10 = 105,000Nm^{-2}

   Therefore lung pressure = 105,000Nm^{-2}



4. The manometer contains water, when the tap is opened; the difference in the level of water is 54.4cm. The height of mercury column in the barometer was recorded at 76cm.What is the pressure in cmHg at points A, B, and C.

   Pressure at A = pressure B

   = H + h

   Pressure using mercury = pressure of water

   $h_1\ p_1\ g_1 = h_2\ p_2\ g_2$

   h x 13600 x 10 = 54.4 x 1000 x 10

   =

   h = 4 cm

Therefore at B, P = H + 4

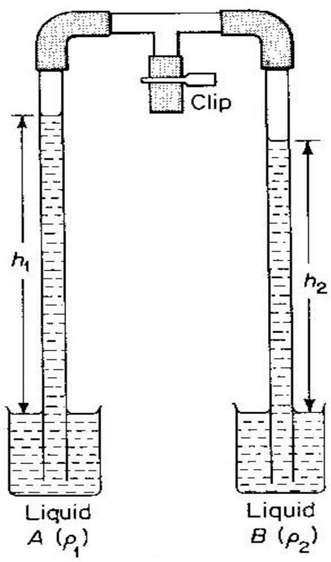
$P = 4 + 76 = 80 cmHg$

5. The difference in pressure at the peak of the mountain and the foot of the mountain is Given that the density of air is $1.3 kgm^{-3}$, calculate the height of the mountain.

Difference of P = hpg $\rightarrow 5.0 \times 10^4 = h \times 1.3 \times 10$

$h = 3846.15m$ or $3.85km$

Comparison of densities of liquids using Hare's apparatus



Liquids of different densities are placed in glass pots as shown above.

When the gas tap is opened each liquid rises to different height h_1 and h_2.Since they are subjected to the same gas supply,

Pressure on liquid 1 = pressure on liquid 2

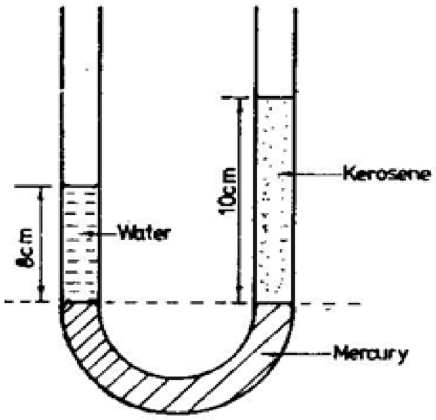
$$h_1 \ p_1 \ g = h_2 \ p_2 \ g$$

$$h_1 \ p_1 = h_2 \ p_2$$

$$=$$

Example;

1.



Water and kerosene are placed in U-tube containing mercury as shown above.

Determine the density of kerosene

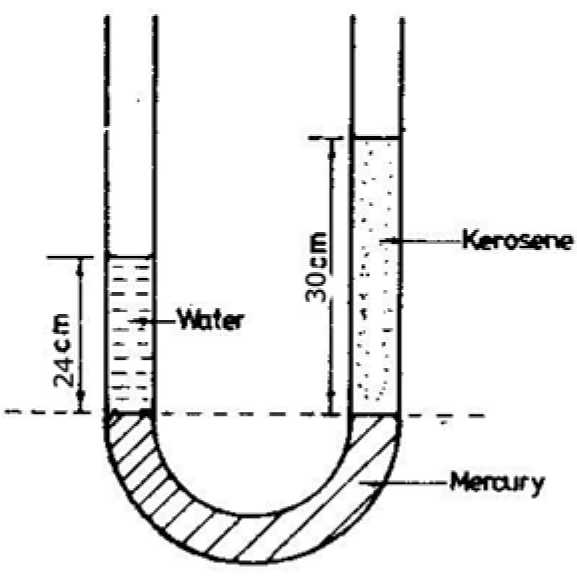
Pressure of kerosene = Pressure of water (since both tube are open to the atmosphere)

$h_x \ \rho_x \ g = h_w \ \rho_w \ g$

2. The level of the mercury in arms of the manometer shown below is equal. Determine

(i) Density kerosene

(ii) Relative density of kerosene



$h_1 \rho_1 \ g = h_2 \ \rho_2 \ g$

$24 \times 1000 = 30 \times \rho_2$

Density $\rho = 800kgm^{-3}$

Relative density of kerosene

STRUCTURE OF MATTER

Matter is anything that occupies space and has weight. It exists in different forms/states of small items called atoms.

STRUCTURE OF MATTER

Solids:

Structure: Solids have a tightly packed and orderly arrangement of particles. The particles are held together by strong intermolecular forces.

Characteristics:

Definite shape: Solids maintain a fixed shape and do not flow.

Definite volume: They have a specific volume that remains constant.

Resistance to compression: Solids are difficult to compress due to their tightly packed particles.

Regular pattern: The particles in solids are arranged in a repeating pattern.

Formation: Solids are formed through processes like cooling of liquids (solidification), deposition of gases, or directly from chemical reactions (e.g., precipitates formed during chemical reactions).

Examples and Applications:

Examples: Metals (like iron, copper), minerals (like quartz, diamond), ice, wood, and plastics are common solids.

Applications: Solids find extensive use in construction (building materials), manufacturing (machinery parts), electronics (semiconductor materials), and daily objects (furniture, utensils).

Liquids:

Structure: In liquids, particles are close together but can move past each other. They have weaker intermolecular forces compared to solids.

Characteristics:

Indefinite shape: Liquids take the shape of their container.
Definite volume: They have a fixed volume that remains constant.
Flow: Liquids flow and can be poured.
Low compressibility: Liquids can be compressed slightly compared to gases.
Formation: Liquids are formed when solids melt or when gases condense. They can also be created through chemical reactions that produce liquid products.

Examples and Applications:

Examples: Water, oil, milk, and alcohol are common liquids.

Applications: Liquids are crucial in industries such as food and beverage (processing and packaging), pharmaceuticals (drug formulations), automotive (engine lubricants), and cosmetics (lotions, creams).

Gases:

Structure: Gas particles are widely spaced and move freely. They have weak intermolecular forces and no fixed arrangement.

Characteristics:

Indefinite shape: Gases take the shape of their container.
Indefinite volume: They expand to fill the available space.
Compressibility: Gases can be compressed significantly under pressure.
Diffusion: Gases mix readily with each other.

Formation: Gases are formed when substances vaporize (evaporate from liquids), sublimate (turn from solids directly into gases), or when gases are released during chemical reactions.

Examples and Applications:

Examples: Oxygen, nitrogen, hydrogen, and carbon dioxide are common gases.

Applications: Gases have diverse uses, including in energy production (natural gas, hydrogen fuel), healthcare (medical gases like oxygen), manufacturing (industrial gases for welding and cutting), and refrigeration (cooling gases like Freon).

Plasma:

Structure: Plasma consists of ionized particles—positively charged ions and free electrons due to high energy levels.

Characteristics:

High conductivity: Plasma conducts electricity and responds to magnetic fields.

Ionized particles: The presence of ions and free electrons distinguishes plasma from gases.

High energy: Plasma is often at high temperatures.

Formation: Plasma is formed when gases are heated to extremely high temperatures or subjected to strong electromagnetic fields, causing ionization of particles.

Examples and Applications:

Examples: Lightning, auroras, stars (like the sun), and fluorescent lights are examples of natural and artificial plasmas.

Applications: Plasma finds applications in technologies like plasma cutting and welding, fluorescent lighting, plasma TVs, semiconductor manufacturing, and experimental fusion reactors.

Understanding the properties and behaviors of these states of matter is fundamental in fields ranging from materials science and chemistry to engineering and everyday life applications.

Kinetic theory

The kinetic theory of matter is a fundamental concept in physics and chemistry that helps explain the behavior of gases, liquids, and solids based on the movement and interactions of their constituent particles.

Particle Model:

According to the kinetic theory, all matter is made up of tiny particles (atoms, molecules, or ions) that are in constant motion.

The particles in a substance are constantly moving and colliding with each other and the walls of their container.

States of Matter:

Gases: In gases, particles are widely spaced and move freely. They have high kinetic energy and are constantly moving in random directions. Gas particles collide with each other and the walls of the container, creating pressure.

Liquids: In liquids, particles are closer together compared to gases. They have moderate kinetic energy and move past each other, allowing liquids to flow. Liquid particles also exhibit random motion but with less freedom compared to gases.

Solids: In solids, particles are tightly packed and vibrate in fixed positions. They have low kinetic energy and limited movement. However, solid particles still vibrate and can transmit vibrations (heat) through the substance.

Assumptions of the Kinetic Theory:

The kinetic theory makes several assumptions about the behavior of particles in matter:

Particles are in constant, random motion.
Particles possess kinetic energy due to their motion.
Collisions between particles are elastic, meaning energy is conserved during collisions.
The average kinetic energy of particles is directly proportional to temperature (Kelvin scale).

Effects of Temperature and Pressure:

Temperature: Increasing the temperature of a substance increases the average kinetic energy of its particles. This leads to faster and more energetic motion, causing changes in state (e.g., melting, boiling).
Pressure: Pressure in gases is the result of particles colliding with the walls of their container. Higher pressure occurs when particles collide more frequently and with greater force, which is influenced by factors like temperature and volume.

Real-World Applications:

The kinetic theory of matter is crucial in understanding and predicting the behavior of gases under different conditions, such as in the ideal gas law and gas laws like Boyle's law and Charles's law.
It is also used in fields like thermodynamics, fluid dynamics, and material science to study heat transfer, phase changes, and properties of materials.

In summary, the kinetic theory of matter provides a framework for understanding how the movement and interactions of particles at the microscopic level contribute to the macroscopic properties and behaviors of different states of matter.

According to kinetic theory, matter is made up of small particles known as molecules which are in a state of continuous random motion. The speed of molecules is increased by increase in temperature.

FORCE BETWEEN MOLECULES

Cohesion /Cohesive force;

This is the force of attraction between molecules of the same substance e.g. water-water molecules, mercury – mercury molecules

Adhesion/Adhesive force;

This is the force of attraction between the molecules of different substances e.g. water – glass molecules.

STATES OF MATTER

Solids;

The molecules are closely packed together, their particles are not free to move from place to another but can vibrate along their mean positions i.e. move to and fro about their mean positions. This is because their cohesive forces between molecules are strong. Molecules in solids are arranged in a regular pattern called lattice. They have shape and size.

Liquids;

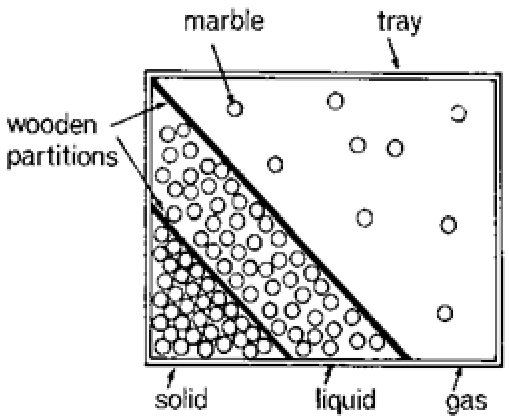
The molecules in liquids are slightly further apart than in solids. Particles are free to move about colliding with each other and with the walls of the container. The cohesive force holding the molecules are weaker than in solids.

They have no definite shape but take up shape of the container.

Gases;

In gases the molecules are much further apart and free compared to those in liquids and so free that they are in constant random motion moving with high speed as they collide with one another and with the walls of a container. The cohesive force is much weaker in gas and can spread easily to occupy the whole volume of a container. Gases lack definite shape and size.

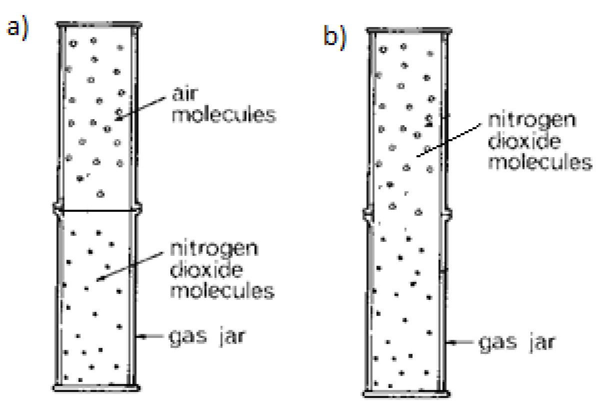
Model illustrating the states matter



Diffusion;

It is the movement of molecules of a substance from a region of high concentration to a region of low concentration.

Demonstration of Diffusion in Gases;

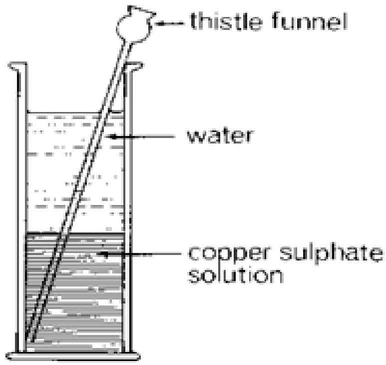


Two Gas jars one full of nitrogen dioxide and the other gas full of air as shown in (a) above.

When the gas cover is removed as shown in (b) the gases mix up and the whole become filled with the brown gas (Nitrogen dioxide)

NB: The lighter gas diffuses faster than the heavier gas.

Demonstration of diffusion in liquids:

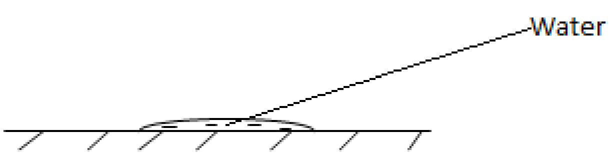


- Half fill a glass beaker with water
- Using a funnel with a long tube reaching the bottom, slowly pour saturated copper (II) sulphate solution down the tube to form a separate layer.
- Carefully remove the funnel so that the liquids are mixed.
- After some time, the blue colour spreads throughout the beaker. This is due to diffusion of liquid molecules.

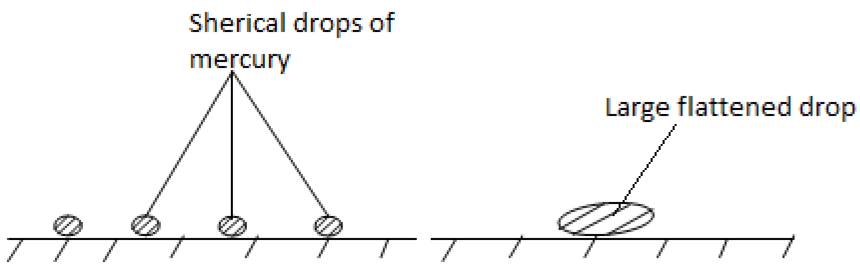
Note: The rate of diffusion increases when temperature is increased.

Behavior of liquids on the surface;

When water is dropped on a glass surface it wets it and spreads out in a thin surface because adhesive force between the water molecules and glass is greater than the cohesive force between water molecules.



When mercury is dropped on a glass surface it forms spherical droplets or large flatten drop because cohesive forces between mercury molecules is greater than adhesive forces between mercury and glass.



SURFACE TENSION

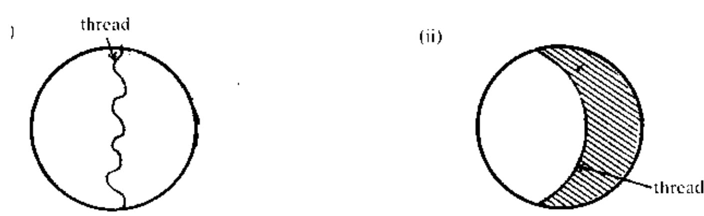
This is the effect of force on the surface of a liquid which makes it behave like a stretched elastic skin.

Or it is a tangential force on surface of a liquid acting perpendicularly per unit length across any line on the surface.

Effects of surface tension;

Because of surface tension,

1. Steel needle when carefully placed on top of water floats, despite its greater density.
2. Some birds and insects can walk on the surface of water.
3. Some drops of water from the top are in form of a spherical shape.
4. Soap film inside the cotton loop when broken makes or forms a circle as shown below



Make a ring of thin wire. Tie a thread loosely across the middle as shown in (i). Dip the ring in soap solution or liquid detergent so that a film forms across it. Break the film on one side of the thread. The thread pulls tight, forming a circle as shown in (ii).This because surface tension stretches molecules on the liquid surface farther apart than normal.

Explanation on surface tension:

Surface tension is due to molecules on liquid surface being slightly further apart like those in a stretched wire. Therefore experience attractive forces from their neighbors in liquid surface. The forces stretch the molecules on the surface, making it behave like a stretched elastic skin.

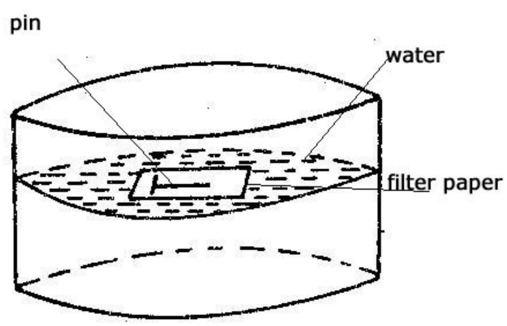
Reduction of surface tension;

Surface tension can be reduced by;

1. Increasing the temperature of the liquids
2. Addition of detergents or soap solution.

Experiment to demonstrate surface tension

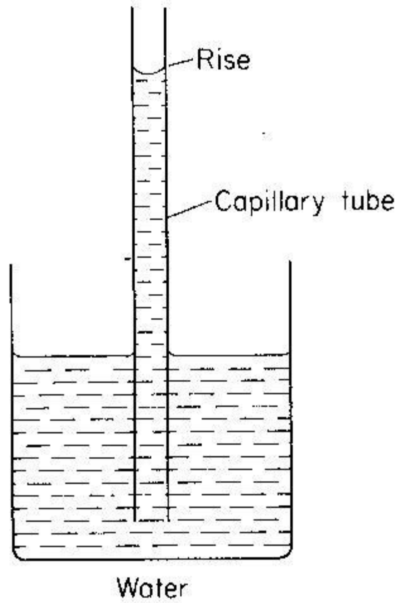
- Some water is poured in a clean trough
- It is then left to settle and a filter paper (blotting paper) is placed on the water surface.
- A pin smeared with Vaseline is carefully placed on top of the filter paper as shown below.



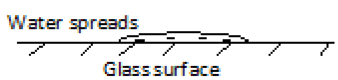
After sometime, the filter paper will absorb water and sink while the pin will remain floating on the water surface.

CAPILARITY/CAPILARY ACTION:

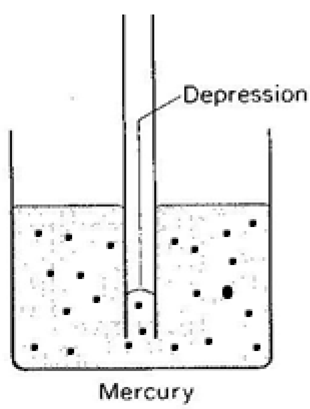
This is the rise or depression of a liquid in a capillary tube.



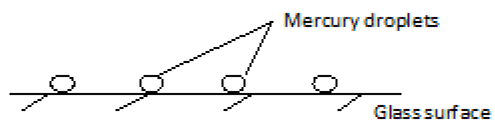
The rise of water in a capillary tube is because the cohesive force between the water molecules is less than the adhesive force between molecules of glass and water. It is also for this reason that water spreads over glass surface



When similar capillary tubes are dipped in mercury, each surface is depressed below the outside level of the beaker and the surface curves down wards as shown below.



Mercury is depressed more in narrow tube than in a large one. This is because cohesive forces between molecules of mercury are greater than adhesive forces between molecules of mercury and glass. It is also for this reason that mercury does not wet glass but forms droplets on glass as shown.



Application of capillarity;

5. The rise of oil in a lamp wick
6. Absorption of water in a towel.
7. The rise of water and mineral salts in plants
8. Action of a blotting paper

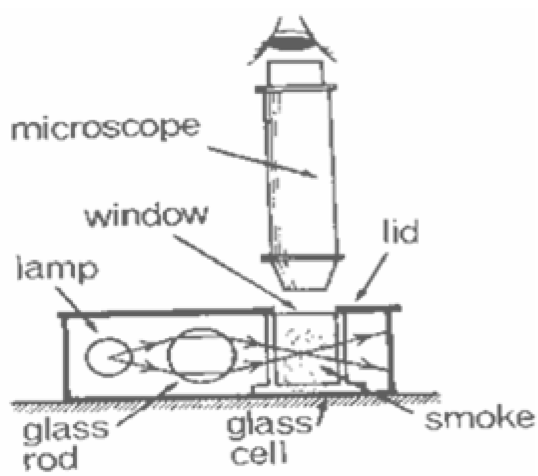
Disadvantages of capillarity;

House bricks and concrete are porous. Capillary action is likely to draw water upwards from the ground through them, making the building dump (wet).This problem is overcome by putting water proof layer made from plastic that is placed in the layers of bricks at the bottom of the house.

BROWNIAN MOTION

It is the random movement of the molecules of a substance in a gaseous state.

When smoke particles are suspended in air and observed through a microscope. They seem to be in a state of continuous random motion.



The smoke particles are seen as bright specks moving in continuous random motion. The bright specks are due to collision between smoke particles and gas molecules.

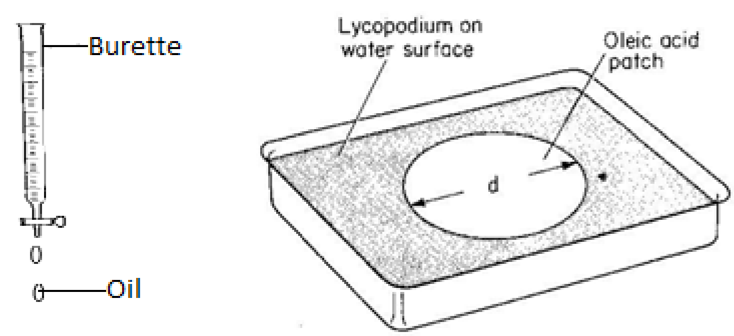
The random motion is due to smoke particles colliding with air molecules which were moving randomly.

When the temperature of the glass cell is increased the random motion increases (smoke particles are seen to move faster), showing that increase in temperature increase the kinetic energy of molecules.

OIL DROP EXPERIMENT

Estimation of the size of an oil molecule

- A trough is cleaned thoroughly and clean water poured on it
- Lycopodium powder is sprinkled on the water surface
- Using a burette a drop of oil of known volume V is allowed to gently fall on the surface of water
- The experiment is left standing for some time
- The oil spreads forming a circular film



The diameter "d" of the patch is measured using a millimeter scale. Several experiments are performed using fresh water and the average diameter "d" of the patch is determined.

Since the patch is cylindrical, the volume of the patch is;

$V = \pi r^2 h$ (where h is the thickness of the oil drop)

$= \pi()^2 h$

$V = \pi h$

$4V = \pi d^2 h$

Therefore the thickness of oil drop

h =

Assumptions made in the experiment;

- The oil spreads to form a film of one molecule thick.
- The oil patch is cylindrical in shape.
- There are no air spaces between the molecules.
- The oil drop is spherical in shape.
- The volume of the oil drop is equal to the volume of oil patch.

Example;

1. In an oil drop experiment the radius of the oil was found to be 10cm and the volume of the used oil was $1.1 \times 10^{-5}cm^3$. Calculate;

(i) The diameter of the film

(ii) The thickness of the patch

(iii) The size of the molecule

Answer

Diameter of the patch d = 2r= 2 x 10 = 20cm

Thickness of the patch h =

Or Thickness h =

=

= 3.5×10^{-8}cm

The size of the drop = thickness of the patch

= 3.5×10^{-8}cm

Note: Thickness h =

i.e. h =

2. A student made an oleic acid oil of volume $0.005cm^3$ to make an oil film on the surface of water. The average diameter of the oil film was found to be 10cm. Find the thickness of the oil film.

Thickness h =

$=$

$=6.37 \times 10^{-5}$m

3. Noah, picked an oleic acid oil drop of diameter 0.5mm using a wire and allowed it to drop on a water surface containing lycopodium powder. The circular patch had an average diameter of 200mm.Find the thickness of oil film.

Diameter = 0.5mm

Volume of spherical drop $V = r^3$

$= (0.25)^3$

$= 0.0208mm^3$

Volume of the patch = volume of spherical drop

$r^2h = 0.0208$

$(100)^2h = 0.0208$

$h = 2.08 \times 10^{-6}$cm

4. If $1.8 \times 10^{-4}cm^3$ of oil spreads to form a patch of area $150cm^2$. Calculate the thicknesses of the oil patch.

Thickness h = =

$= 1.2 \times 10^{-6}$cm

CHANGE OF STATE

1. **Melting**

It is a process by which a solid substance changes into a liquid e.g. ice (solid) changes to water (liquid) when heated. Temperature at which solid substance changes to liquid is called melting point.

NB: There is no change in temperature of substance at its melting point. This is because the heat supplied is used to weaken cohesive forces of attraction between molecules.

2. **Boiling**

This is the process by which a liquid when heated changes to the gaseous state at a fixed temperature e.g. pure water at 100^0c changes to vapour by the process of boiling.

There is no change in temperature at boiling point because the heat supplied is used to weaken cohesive forces of attraction of molecules and the rest is converted to kinetic form of energy.

3. **Evaporation;**

It is the process by which a liquid changes to gaseous state at any temperature. The rate of evaporation is affected by the following factors;

1. Temperature
2. Amount of humidity in the atmosphere
3. Pressure
4. Surface area
5. Nature of the liquid
6. Wind and dryness of air

Temperature;

The higher the temperature, the higher the average speed at which molecules move and therefore there will be more molecules moving to the liquid surface.

Pressure;

Increase in pressure lowers the rate of evaporation.

Surface area;

When the surface area of a liquid is increased, more molecules are brought to the surface and the rate of evaporation is increased.

Nature of the liquid

Different liquids have different cohesive forces, those which have greater cohesive forces tend to evaporate less than liquids with less cohesive forces.

Wind and dryness of air

Dryness of air around the liquid surface causes rapid evaporation. Wind blows away water vapor along the body and this causes rapid evaporation to take place.

Differences between boiling and evaporation

Boiling	Evaporation

Takes place at a fixed temperature called boiling	Occurs at any temperature
Boiling takes place throughout the liquid.	Takes place only on the surface of the liquid
Boiling is a vigorous process	Evaporation is a gentle process
Bubbles are formed with in the liquid	No bubble is formed on the surface of the liquid
Boiling doesn't result into cooling	Evaporation result into cooling.

Cooling by evaporation

The molecules which escape from the surface of liquids are those with greater kinetic energy, the molecules which remain in the liquid are those with very low kinetic energy. The energy the molecules use as their kinetic energy is the latent heat which they absorb. The absorption of this latent heat from the liquids brings about a fall in temperature, thus a body cools.

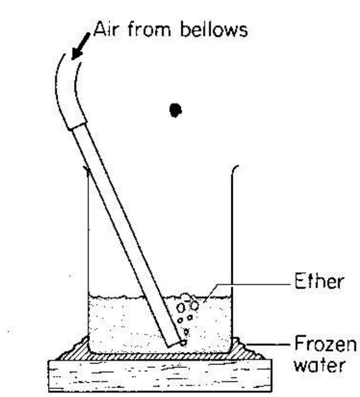
Application of cooling by evaporation

-cooling of a body by evaporation of sweat from the body

-cooling water using a porous pot or refrigerator

-cooling of the dog by the saliva on its tongue evaporation

Demonstration of cooling by evaporation



A beaker about one third full of ether is stood in a small pour of water on a flat piece of wood

Air is then bubbled through the ether. The ether evaporates into bubbles and the vapour is carried quickly away as the bubbles rise to the surface and burst thus increasing the rate of evaporation.

After sometime, the water on the wooden block cools to 0^0c and freezes to form ice. This demonstrates that evaporation causes cooling.

Explanation

As the ether evaporates, it absorbs latent heat from its liquid state with the result that it cools below 0^0c. At the same time heat becomes conducted through the walls the beaker from the pool of water below it and eventually the water cools to 0^0c. After this, it begins to lose latent heat and freezes.

The refrigerator

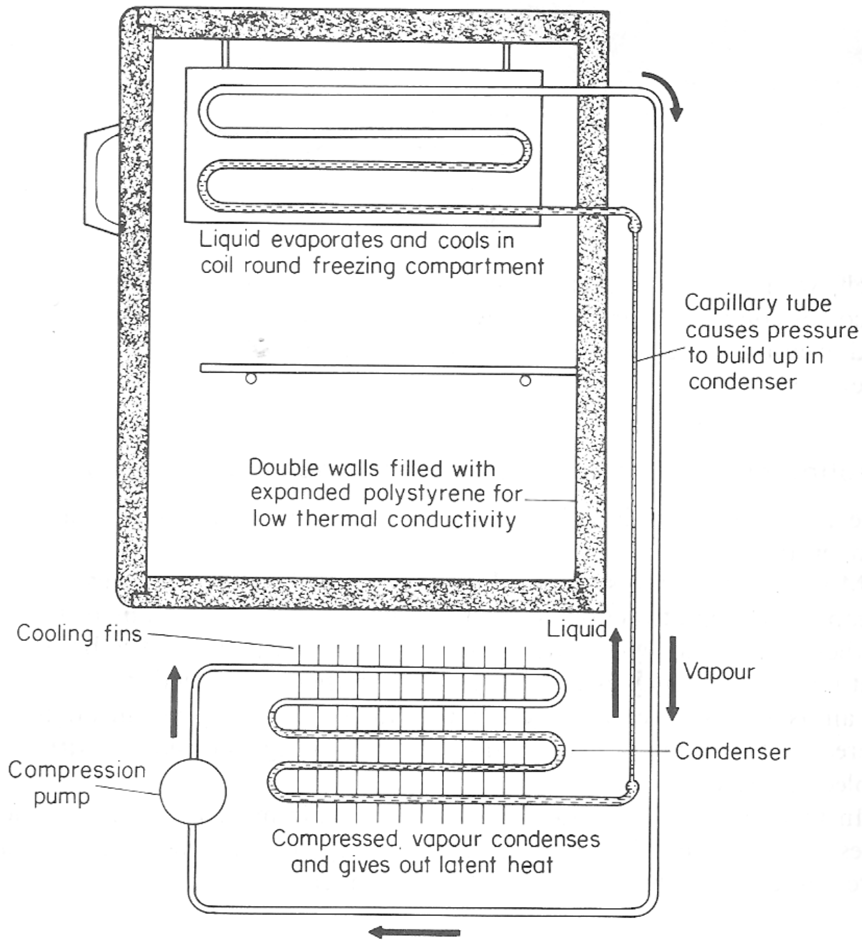


Fig. 19.5. Domestic electric refrigerator

It operates on the evaporation by cooling principle.

The liquid used in a refrigerator is Freon which is volatile (Freon is collective term for suitable refrigerants e.g. dichlorodifluoromethane boiling point about -30^{0}c or 243k)

Operation;

The volatile liquid in the coiled tubes absorbs latent heat from the surrounding air and evaporates. This causes the refrigerators and its contents to cool.

Vapour produced is pumped away and compressed in the condenser where it condenses to liquid again

The heat released during condensation is quickly removed by cooling fins at the back of the refrigerator.

The process of evaporating and condensing of the volatile liquid is repeated on and on, thus causing the refrigerator to cool further.

VAPOUR PRESSURE

It refers to the pressure exerted on the wall of the container by the vapour.

Consider a liquid in a closed vessel. When molecules escape from the liquid, they form vapour on the surface of the liquid. The vapour molecules move in all directions and exert a pressure called vapour pressure on the surface of the liquid and the walls of the container

The less energetic molecules return to the bulk of the liquid, a state of dynamic equilibrium is eventually reached ,in which the rate at which molecules leave the liquid is equal to that at which others returns to it.

When this happens, the space above the liquid is said to be saturated with vapour.

The vapour pressure used in this state is called saturated vapour pressure but before the equilibrium the vapour is said to be unsaturated.

Saturated vapour pressure

Is pressure exerted by vapour in dynamic equilibrium with its own liquid

Boiling point

This is the temperature at which the saturated vapour pressure is equal to the external atmospheric pressure

At this temperature liquid molecules have enough energy to form bubbles of vapour inside the liquid.

The bubbles formed at the bottom contain saturated vapour. When they reach the surface they burst

FACTORS WHICH AFFECT THE BOILING POINT AND FREEZING/MELTING POINT OF WATER

- Addition of impurities
- Increase or decrease in pressure

Effects of impurities on boiling and melting points

a) Melting point

The impurities lower the melting point of a surface e.g. when impurity is added to ice it melts at a lower temperature. This is because impurities weaken the cohesive forces in ice molecules making it easy for them to move freely hence the change of state from solid to liquid.

b) Boiling point

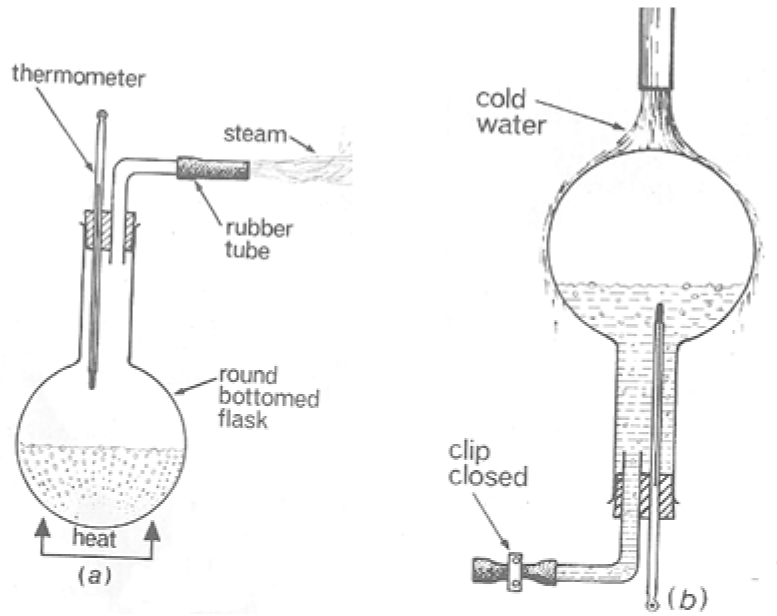
Impurities raise the boiling point of a substance e.g. when salt is added to water, the mixture must be heated at a higher temperature before it boils. This is because impurities strengthen the cohesive forces between water molecules so more heat must be supplied to weaken them.

Effect of pressure on boiling and melting points

Boiling points

Increase in pressure raises the boiling point of liquid.

Experiment to demonstrate the effect of pressure on boiling point



- Water in the flask is heated for a few minutes so that the steam sweeps out most air
- Heating is stopped and the clip is closed

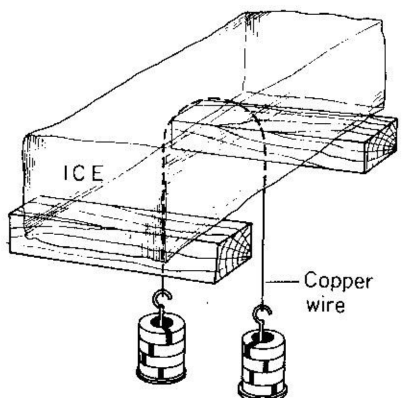
- Cold water is poured on the inverted flask, so condensing the steamed water. This reduces pressure above water.
- The water starts to boil

Note: If cooling is continued, boiling goes on until about 40^0c

Melting point

Increase in pressure lowers the melting point of a solid e.g. ice. This effect makes skating /skiing possible, the pressure of ice skate melts the ice under it, so that there is a thin layer of water between the skate and ice. The layer of water acts as a lubricant and almost completely removes friction between skate and ice.

Demonstration of effect of pressure on melting point (regelation)



A weighted copper wire is allowed to pass over a block of ice

It sinks through without cutting the ice block into two pieces

Explanation

When a copper wire is pulled, a very high pressure is exerted on the ice block, lowering its melting point and the ice melts.

The wire sinks through

The water which is no longer under pressure refreezes above the wire because melting point returns to 0^0c

On freezing, the water gives out its latent heat of fusion and thus conducted down through the wire to enable the ice below it to melt. This effect is called regelation (refreezing).

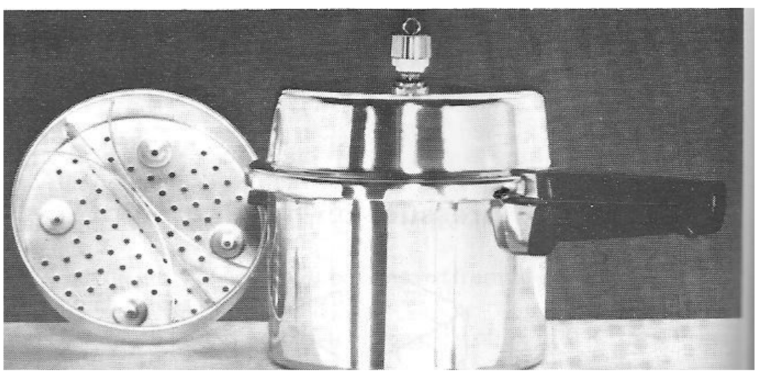
Note: If an iron wire is used in demonstration, it passes through the ice more slowly. No effect is obtained if string is used.

The pressure cooker

This is a strong aluminium pan, whose lid is sealed with a rubber sealing ring to prevent steam from escaping from inside the pan.

As the substance e.g. water is heated to boil, the steam pressure inside builds up causing the boiling point to rise to about 120^0c

The high temperature makes the substance get cooked quickly.



HEAT

Heat is a form of energy which is transferred from one place to another due to difference in temperature between the two places

MODES OF HEAT TRANSFER

Heat is transferred in three different ways, namely; Conduction, convection and radiation

Conduction

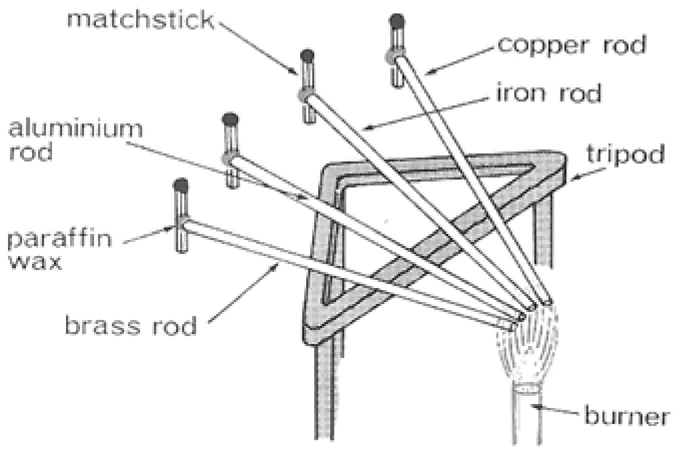
Conduction is the flow of heat from a region of high temperature to that of low temperature through matter without the movement of matter as a whole. e.g. in metals when they are heated their molecules vibrates faster along their mean position and pass on the heat to the molecules on the cooler parts of the metal. Also electrons that are always moving about the metal transfer from the hot to the cold end

Heat conduction is best in metals and worst in gases. Because of the distant spread of molecules in gases it is not highly possible to have heat transfer in gases

Factors affecting conduction in metals

- Increase in the cross section area of the metal increases the rate of conduction.
- Decrease in the length of the metal bar
- Increase in the temperature difference
- Different metals conduct heat differently.

Experiment to compare conduction in metals



Procedure

- Match sticks are fixed with wax at one end of each rod and placed on a tripod stand with their free ends put together
- The free ends are heated with a Bunsen flame
- Heat is conducted along each rod towards the cork
- The match stick on copper drops off first which shows that of all the metals, copper is the best conductor of heat

Application of heat conduction

- Good conductors are used in frying and cooking utensils

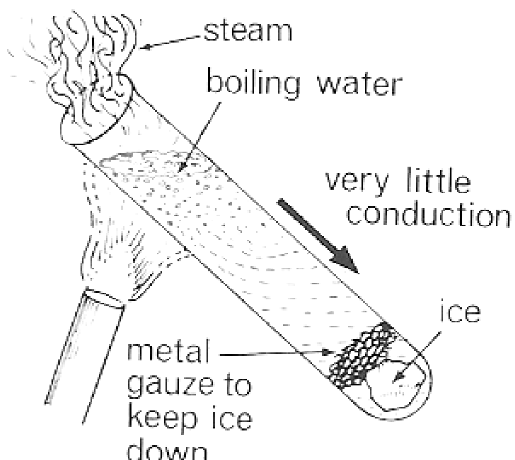
- Bad conductors are used on handles of frying pans i.e. handles are made of plastic, wood, rubber.

Explain why metals feel colder when touched than bad conductors

This is because metals conduct away heat from the hands due to high degree of conduction while bad conductors do not conduct heat

Note: Liquids and gases transfer heat very slowly. This is because their molecules are apart and they do not have free electrons like in metals, so transfer of heat is only by atoms

Experiment to show that water is a poor conductor of heat



Procedure

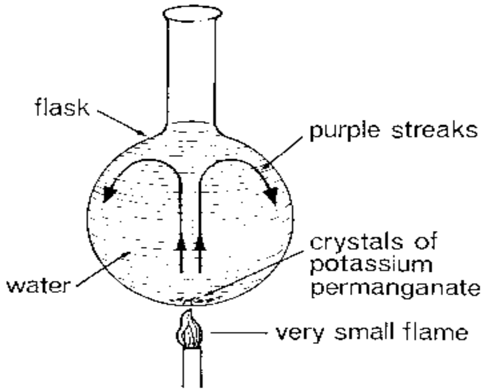
- Water is put in a test tube slanted as shown in the diagram above.
- The upper part of the tube is heated and convection currents are seen at the top of the tube
- Water begins to boil from the top.
- Ice at the bottom remains not melted. This shows that water is poor conductor of heat.

Convection:

This is the transfer of heat in fluids from region of high temperature to that of low temperature with the movement of the fluid molecules

Convection cannot occur in vacuum because it requires a material medium. It occurs in fluids (liquid and gases) because they flow easily.

Experiment to demonstrate convection in liquids:



Procedure;

- The apparatus is arranged as in the diagram above.
- By means of a straw, potassium permanganate crystals are put in water at the bottom.
- When heat is applied, purple streaks are observed moving upwards in the middle of the flask and down wards at the side of a flask in a circular form. The purple streaks show convection currents.

Explanation of convection currents:

When water at the bottom becomes hot, it expands and becomes less dense.

It is therefore displaced by dense cold water from the top.

In displacement of hot water by cold water, it sets up convection currents as observed by the purple loops.

Application of convection:

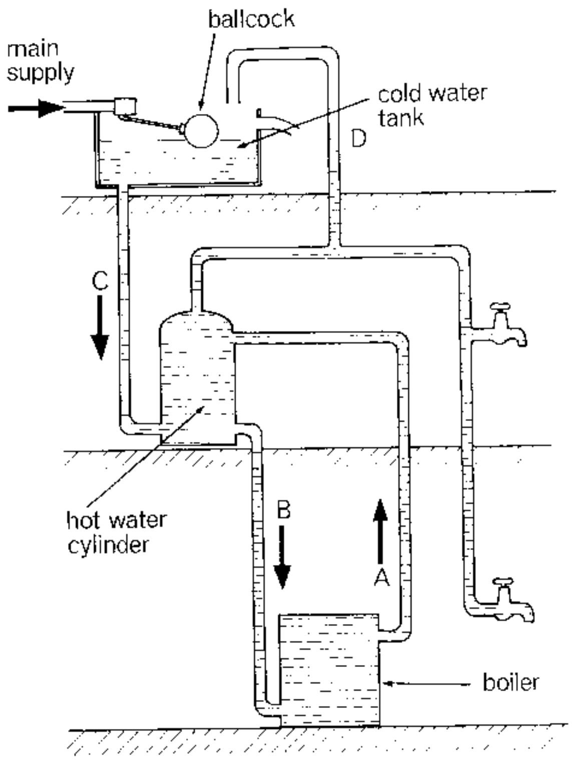
***In electric kettles*:** When warming a liquid, the heating element of an electric kettle is placed at the bottom.

***Domestic hot water system*:**

Cold water is supplied to the boiler along the cold water supply pipe. On warming, in the boiler the cold water warms up, expands and becomes less dense, so it rises up.

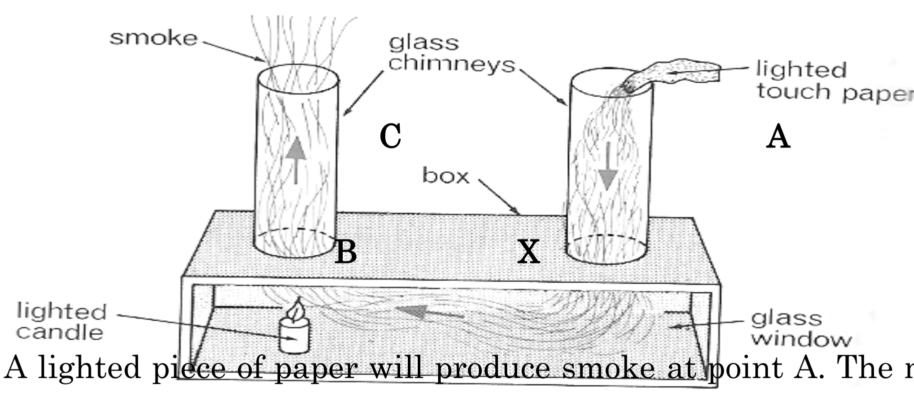
As more cold water is supplied to the boiler, hot water is displaced upwards and supplied to the hot water taps along hot water pipes.

The ventilation pipe is used to release steam.



Convection in gases

Experiment to demonstrate convection in gases:



A lighted piece of paper will produce smoke at point A. The movements of smoke from A to B across point X and out through C shows convection.

Explanation of how smoke moves:

Smoke moves by convection because;

- The air above the candle warms up, becoming less dense and then rises up through C.
- The dense cold air from the paper (smoke) enters X through chimney A to replace the risen air (smoke) causing convection currents.

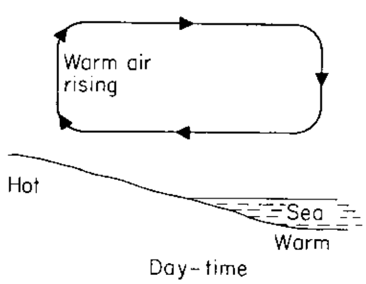
Application of convection in gases:

- Chimneys in kitchens and factories
- Ventilation pipes in VIP latrines
- Ventilators in houses
- Sea and land breezes

SEA AND LAND BREEZES

Sea breeze:

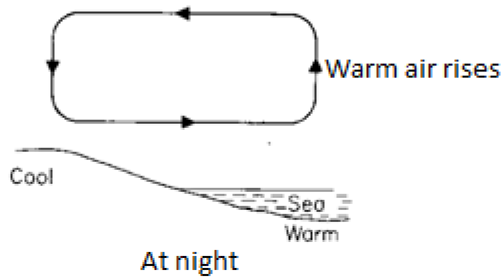
Sea breeze occurs during day. During day, the sun heats up both the land and the sea. The land heats up faster than the sea because of its low specific heat capacity and becomes warmer than the sea. So warm air rises which is replaced by the cold air from the sea.



Land breeze;

It occurs at night. At night land loses heat faster than sea water causing land to be cooler than the sea. As a result, air above the sea becomes warm and less dense, so it rises.

The air above the land which is cold, replaces the warm air resulting in the land breeze.



Ventilation:

During hot days, rooms get heated up and it is why they are usually provided with ventilators above the floor, through which warm air finds its way out while fresh air enters through the doors and windows. In this way a circulation of air convection is set up.

RADIATION:

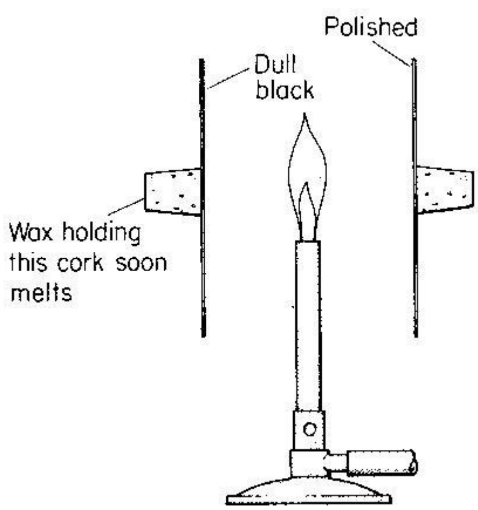
This is the transfer of heat from a region of high temperature to that of low temperature by means of electromagnetic waves

Radiation is the only way through which heat can travel through a vacuum

Radiant heat is mainly comprised of infrared which makes the skin feel warm. It travels as fast as light and it is the fastest means of heat transfer

Good and bad absorbers of heat radiation:

Some surfaces absorb heat radiation better than others as illustrated below;



The experiment is setup as shown above

A source of heat is placed mid – way between a polished and dull surface

Cork is fitted with wax on the two surfaces and the experiment left standing for a few minutes

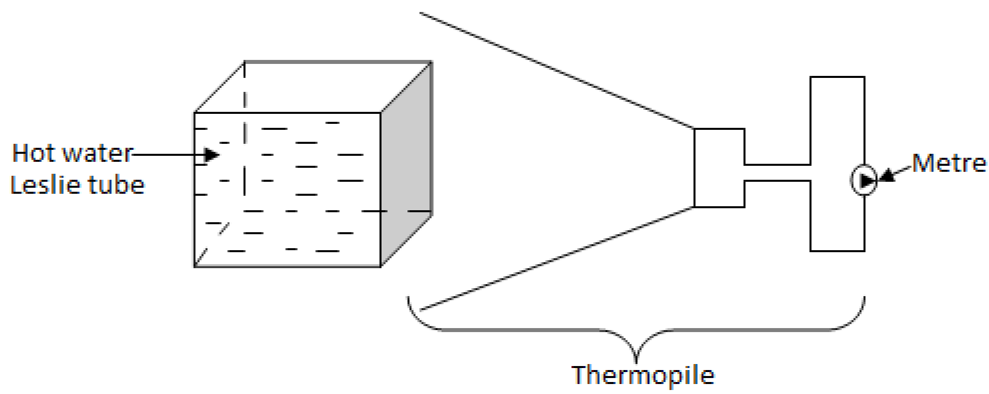
After a few minutes the wax on the dull or black surface begins to melt and cork eventually falls off while the one on the polished surface remains not melted for some time

This shows that a dull black surface is a good absorber of heat radiation while a polished surface is a poor absorber of heat radiation because shiny surfaces reflect heat radiation instead of absorbing it

Comparison of radiation of different surfaces:

Requirements: - A Leslie tube

- Thermopile (instrument that converts heat to electrical energy)



One side of the tube is dull black, the other is dull white and the last one is made shiny polished.

The tube is filled with hot water and radiation from each surface is detected by a thermopile

When the radiant heat falling on the thermopile is much, it registers a large deflection of the pointer

With different surfaces of the tube made to face the thermopile one at a time, the following results are obtained:

- The greatest deflection at the pointer is obtained when dull black surface faces the thermopile
- The least deflection is obtained when a highly polished shiny surface faces the thermopile.
- The dull surface is a good radiator or emitter of heat radiation while a polished shiny surface is a poor emitter of heat radiation.

Laws of radiation:

- Heat radiation travels in a straight line.
- Good absorbers of heat radiation are also good emitters.
- Temperature of the body remains constant when the rate at which it absorbs heat radiation is equal to the rate at which it radiates heat energy.
- Bodies only radiate heat when their temperature is higher than that of the surrounding and absorb heat from the surrounding if their temperature is lower than that of the surrounding

Application of radiation:

a. Black and dull surfaces

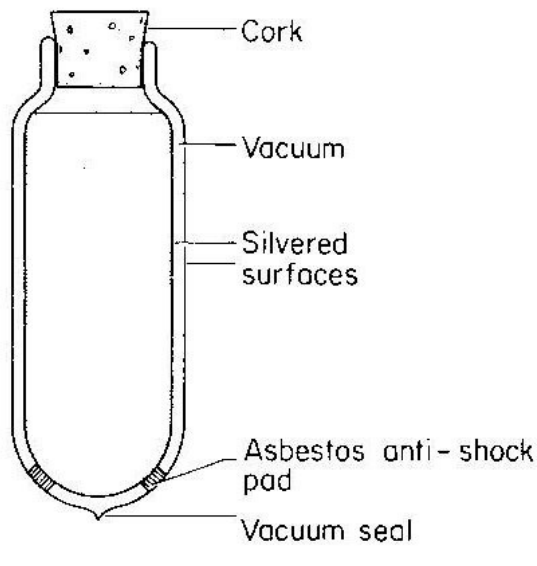
i) Car radiators are painted black to easily absorb and emit heat
ii) Cooling fins of a refrigerator are black to easily absorb and emit heat
iii) Solar plates or panels are black to easily absorb and emit heat

b. Polished and white surfaces

i) White washed buildings keep cool in summer.
ii) Roots and petro tanks are aluminum painted to reflect radiant heat.
iii) White coloured clothes are won in summer to keep us cool.
iv) Silver tea pots, kettles and saucepans retain heat for a long time

c. **The vacuum flask:**

It keeps hot liquids hot and cold liquids cold. It is very difficult for heat to travel in or out of the flask.



How a flask minimizes heat loss

Through the function of the various parts of the vacuum flask, heat loss by conduction, convection and radiation are minimized

- *The cork.* This minimizes heat loss by conduction and convection
- *Vacuum* prevents heat loss by conduction and convection
- *Silvered walls* minimize heat loss by radiation
- *Vacuum seal* keeps air out of the vacuum
- *Asbestos anti – shock pad* keeps the walls apart to avoid damage

NB

The thermos flask becomes useless when the vacuum seal breaks, because the vacuum will no longer exists and heat loss by conduction and convection will occur.

Choice of dress

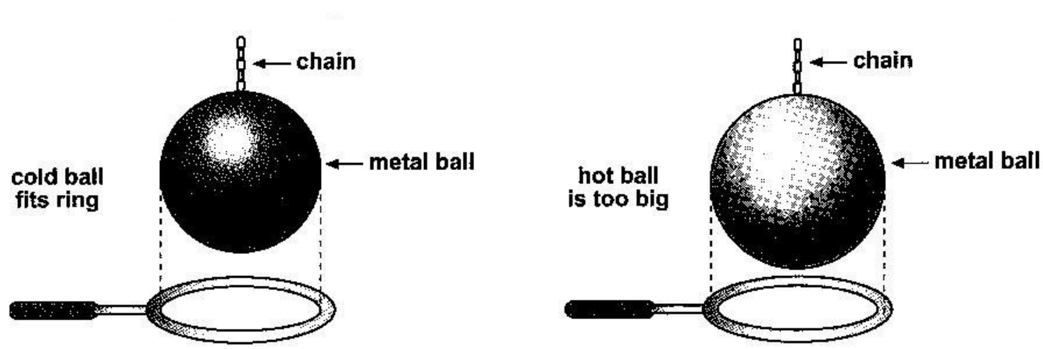
The choice of dress one puts on depends on conditions of the environment. On hot days, a white dress is preferable because it reflects most of the heat radiations falling on it

On cold days a dull black woolen dress is preferred because it absorbs most of the heat incident on it and can retain for a longer time.

EXPANSION OF SOLIDS

Expansion is an increase in size of a substance. When heated, solids increase in size in all directions

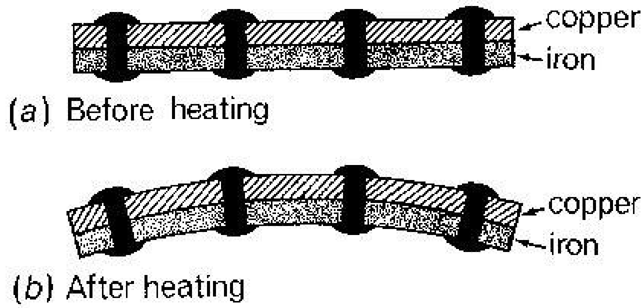
Expansion of solids can be illustrated using a metal ball with a ring as shown below



The metal ball passes through the ring when it is cold but when heated, the ball doesn't pass through the ring any more, showing that it has expanded. It passes through the hole again when it cools, meaning that the metal contracts when it loses heat

Experiment to demonstrate that metals expand at different rates when heated equally

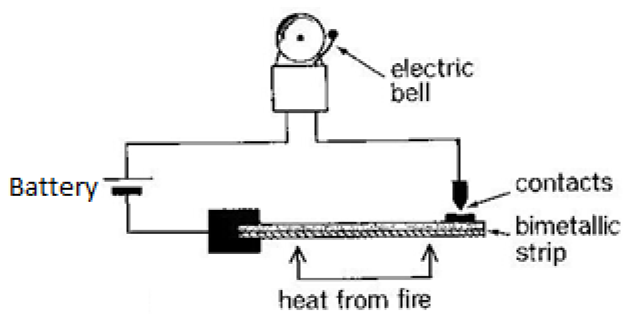
Different metals expand at different rates when equally heated, this can be shown using a metal strip made of two metals such as copper and iron bounded tightly together (bi- metallic strip) when the bi metallic strip is heated, the copper expands more than iron and the strip bends as shown



Uses of a bi – metallic strip (application of expansion of solids)

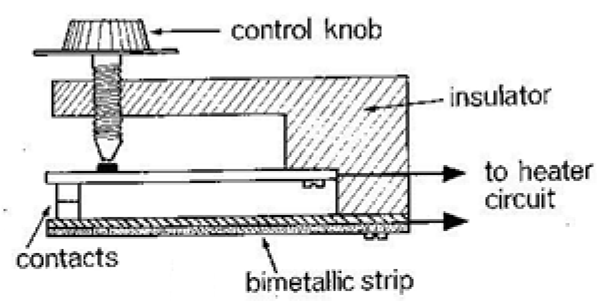
a) **Fire alarm**

Heat from the source makes the bi metallic strip bend and completes the electric circuit and the bell rings.



b) **Thermostat**

This is a device that makes temperature of appliances or room constant. The thermostat shown below uses a bi – metallic strip in the heating circuit of a flat iron.



When the flat iron reaches the required temperature, the strip bends and breaks the circuit at the contact and switches off the heater.

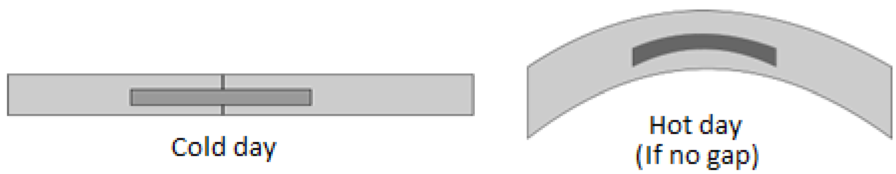
The strip makes contact again after cooling a little and the heater is on again. A nearly steady temperature results

If the control knob screwed, the strip has to bend more to break the circuit and this needs higher temperature

Disadvantages of expansion

Expansion can cause a number of problem;

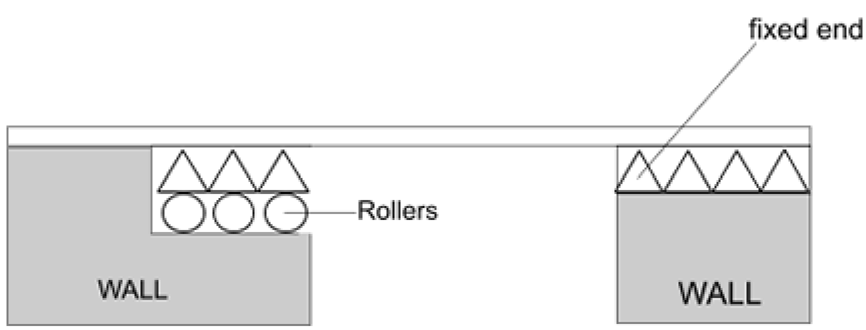
Railway lines are constructed with gaps left in between consecutive rails such that on hot days when the rails expand, they have enough room for expansion.



If no gap is left in the rails, they bend on hot days.

Steel bridges

These are constructed in such a way that one end is rested on rollers and the other end is normally fixed. This is to ensure that the structure can contract and expand freely at various temperatures without damaging the bridge.



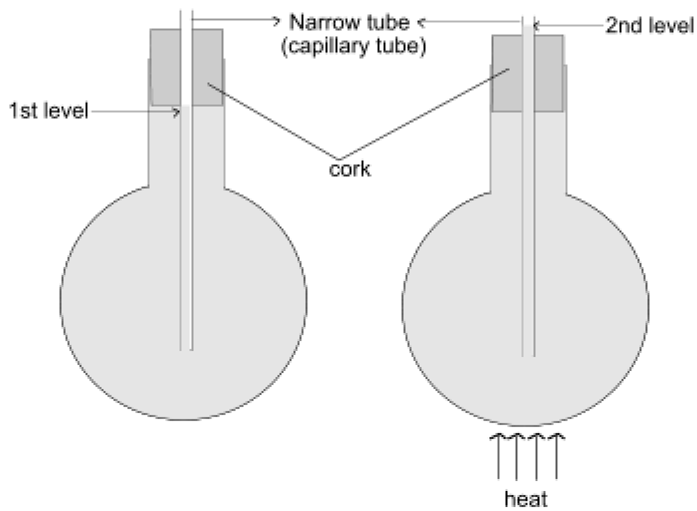
Transmission cables

Wires or cables in transmission or telephone cables are normally not pulled tightly during installation in order to allow room for expansion and contraction during extreme weather conditions.

EXPANSION IN FLUIDS

When liquids or gases (fluids) get hot , they expand just as solids do, but their expansion is greater than that of solids for the same amount of heat

Experiment to demonstrate expansion in liquids



Procedure

- The flask is filled completely with coloured water.
- A narrow tube is passed through the hole in cork and the cork fitted tightly
- The first level of water on a narrow tube is noted
- Water is heated from the bottom of the flask as its level is observed
- The level of water in the tube first drops then rises steadily as heating is continued

Explanation

Water level first drops because the flask first expands then the water expands steadily due to continued heating

Application of expansion property of liquids

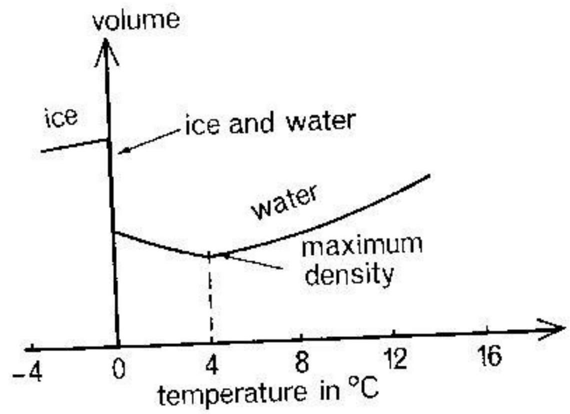
This property is used in thermometers

The liquids used include alcohol and mercury

Anomalous expansion of water

As water is cooled up to 4^0C, it contracts as we would expect. Between $4^0 - 0^0C$, water expands and this is unusual. It is between 4^0C and 0^0C that the anomalous expansion of water occurs

The volume of water is minimum at 4^0C and its density is maximum at 4^oC

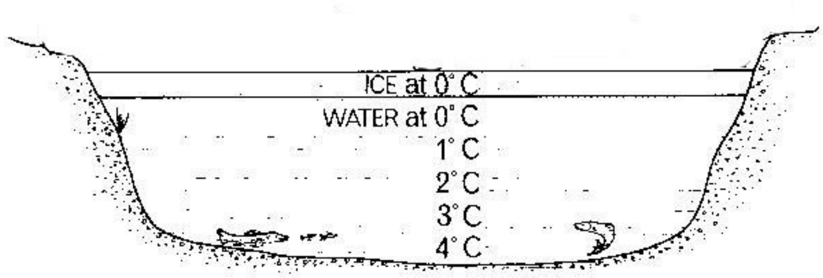


Application of anomalous behavior of water

It is used to preserve aquatic life during cold weather

As the temperature of the pond or lake falls, the water contracts and becomes denser then sinks. A circulation is thus set up until all the water reaches its maximum density at 4^0C. If further cooling occurs any water below 4^0c will stay at the top due to its lighter density thus ice forms at the top of water

The lower layer of water at 4^0C can only lose heat by conduction. So in deep water there will always be water beneath the ice in which fish and other creatures can live



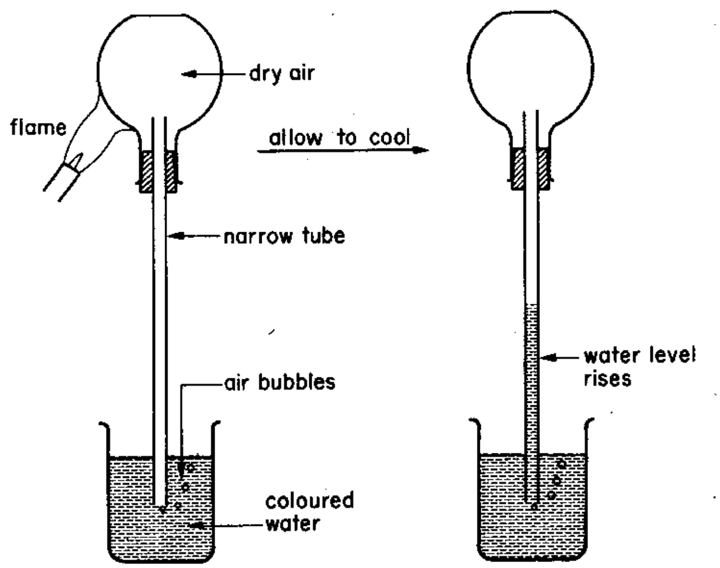
Disadvantages of anomalous behavior of water

- It causes weathering of rocks due to its expansion and contraction
- It can cause water pipes to burst due to formation of ice inside the pipe
- Cannot be used as a thermometric liquid.

EXPANSION OF GASES

A gas expands when heated almost 10,000 times more than solids. This is due to the fact that cohesion between molecules is extremely weak

Experiment to demonstrate expansion in gases



- In the above set up the flask is slightly heated.
- Air bubbles will be seen coming out from the other end of the tube
- This shows that air expand when heated.
- In the second set up, when the source of heat is removed and the flask is allowed to cool by pouring cold water, the level of water will rise. This shows that air contacts when cooled.

Application of expansion of air

1) Hot air balloon

Expansion of air is used in hot air balloon. When air in the balloon is heated, it expands and becomes less dense and as a result the balloon rises up

THERMOMETRY

Thermometers:

These are instruments used for measuring temperatures

Thermometric properties

A thermometric property is a property of a substance which continuously changes with temperature and may be used for temperature measurements. These include:

- Change in length
- Change in resistance
- Change in volume
- Change in pressure

THERMOMETER SCALES (Temperature scales)

There are 3 thermometer scales commonly used

1) Celsius / centigrade scale(^{0}C)
2) Fahrenheit (^{0}F)
3) Kelvin/ absolute(k)

a) Relation between Celsius and Fahrenheit

If Celsius scale reads 0^0C, then

And if Celsius scale reads 100^0C then

b) Converting from Fahrenheit to Celsius.

The formula is

c) Relationship between Celsius scale and Kelvin scale.

Where C is temperature on Celsius scale and K is temperature on Kelvin scale.

d) Convert 0^0C to Kelvin scale

e) Convert 100^0C to Kelvin scale (Absolute scale)

To obtain a standard scale on a thermometer, two fixed points must be marked out on it, these are the upper and lower fixed points.

LOWER FIXED POINT:

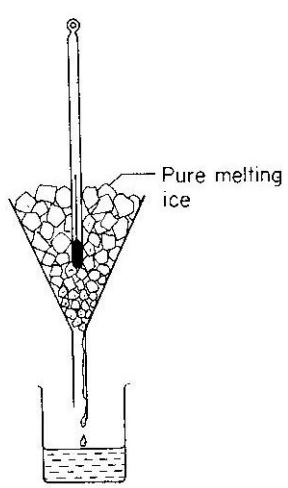
This is the temperature of pure melting ice at standard atmospheric pressure

The standard atmospheric pressure is 76cmHg or 760mmHg

On the Fahrenheit scale, the lower fixed point = 32^0F

- On Celsius scale = 0^0C
- Kelvin scale = 237K

DETERMINATION OF LOWER FIXED POINT:



Procedure;

-The filter funnel is supported on a retort stand as shown above.

-A thermometer is placed in the funnel and surrounded with pure melting ice.

- The thermometer is adjusted so that the mercury thread is clearly seen.

-The point at which the mercury thread is steady is marked off with a scratch as the lower fixed point.

UPPER FIXED POINT:

This is the temperature of steam above water boiling under standard atmospheric pressure.

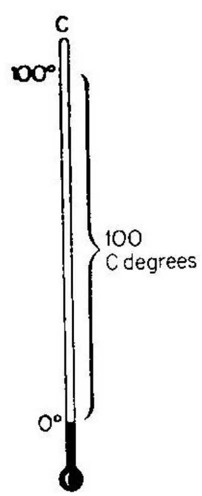
On Celsius scale it is 100^0C

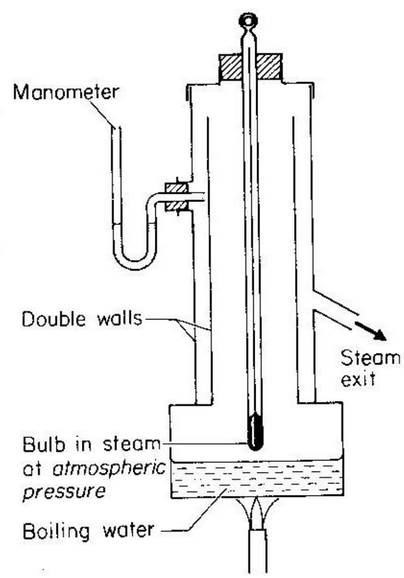
On Kelvin scale it is 373K

On Fahrenheit scale it is 212^0F.

Determination of upper fixed point using a hypsometer

A hypsometer is a two walled vessel made out of a round bottom flask.





Procedure;

-Partly fill vessel with water and arrange the apparatus as in the diagram.

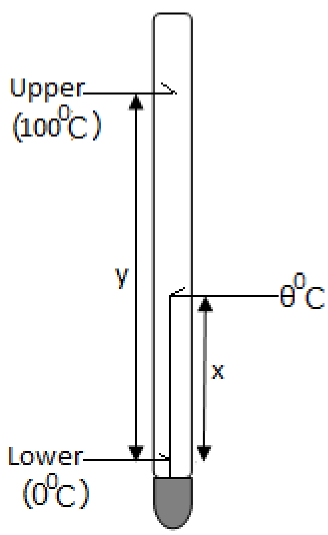
-Gently heat water in vessel using a Bunsen flame to its boiling point.

-Adjust the thermometer so that mercury thread is seen clearly when water is boiling.
-Mark the steady point of mercury thread as the **upper fixed point.**

With the upper and lower fixed points marked on the thermometer, the distance between them is divided into 100 equal degrees so that the thermometer gets the Celsius scale. In the way it is said to be calibrated.

Using an un calibrated thermometer to measure temperature:

Fundamental interval is the difference between the upper fixed point and the lower fixed point. This is divided into a hundred equal parts to calibrate in Celsius scale and each is called a degree.



Example:

1. The top of a mercury thread of a given thermometer is 3cm from the ice point, if the fundamental interval is 5cm, determine the unknown temperature θ.

X = 3cm

Y = 5cm

θ = x 100

= x 100

$= 60^0C$

2. The length of a mercury thread at a low fixed point and upper fixed point are 2cm and 8cm respectively for a certain liquid X. Given that the length of mercury thread at un known temperature θ is 6cm determine the value of θ

3. Find the temperature in ^oC if the length of mercury thread is 7cm from the ice point and fundamental interval is 20cm

4. Find the unknown temperature θ given the following length of mercury.
   - Length of steam = 25cm
   - Length of ice point = 1cm
   - Length of known temperature θ= 19cm

Thermometric liquids

These are liquids used in a thermometer, they include;

- mercury
- Alcohol

Water is not suitable for use in a thermometer because of the following reasons;

-It is transparent i.e. its meniscus is difficult to see and read

-It does not expand regularly

-It sticks on glass

-It has relatively low boiling point

-It is poor conductor of heat

QUALITIES OF A GOOD THERMOMETRIC LIQUID

- Must easily be seen (opaque)
- Must expand regularly with temperature
- Must have a high boiling point to measure high temperature
- Must have low freezing point to measure low temperature
- Must not stick on glass
- Must be a good conduct of heat
- Must not be very expensive
- Must not be poisonous and it should be available.

Advantages of mercury over alcohol when used as thermometric liquid

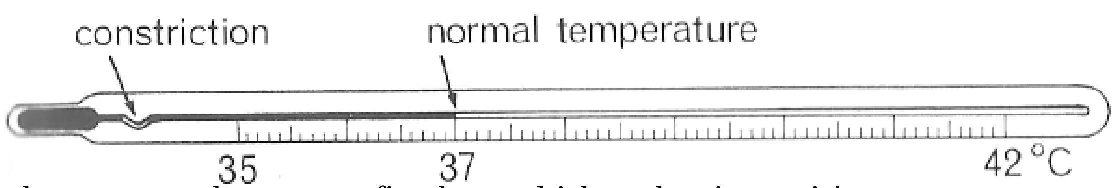
Mercury	Alcohol
• It is opaque	• It is colourless
• Good conduct of heat	• Poor conduct of heat as compared to mercury
• Expands regularly	• Does not expand regularly as mercury
• Has a high boiling point (357^0C) and can be used to measure high temperature	• Has low boiling point 78^0C
• Mercury does not stick on glass	• Sticks on glass
• It does not distill easily	• Distills easily.

Advantages of alcohol over mercury

Alcohol	Mercury
• Has a low freezing point (-115^0C)	• Has a high freezing point of -39^0C hence unsuitable to measure very low temperatures.
• Has a high linear expansivity(expands so much for small temperature range)	• Has a low linear expansivity (expands little for the same temperature range)

CLINICAL THERMOMETER

This thermometer is used to measure the human body temperature



-The thermometer has a very fine bore which makes it sensitive

-Expansion of mercury makes it shoot along the tube

-The glass from which the tube is made is very thin which makes the body heat reach the mercury quickly to read body temperature

-When thermometer bulb is placed into the mouth or armpit, the mercury expands and it is forced past the constriction along the tube

-When removed, the bulb cools and the mercury in it contracts quickly

-The mercury column breaks at the constriction leaving mercury in the tube. The constriction prevents flow back of mercury to the bulb when the thermometer is temporary removed from the patients mouth or armpits.

The thermometer is reset by shaking the mercury back in the bulb.

Effect of heat on matter

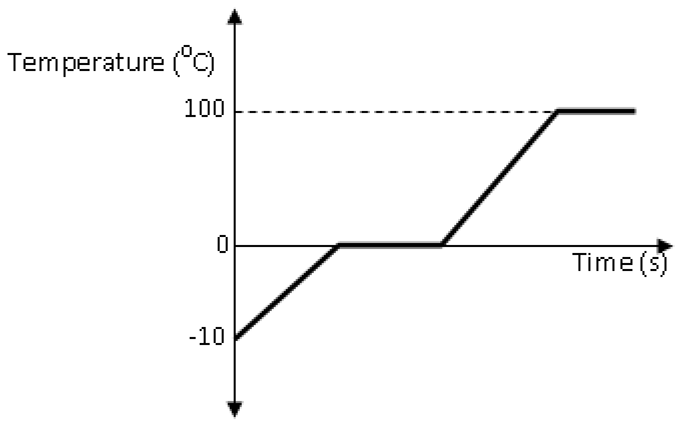
-When a solid is heated, the cohesive forces between its molecules are weakened and the molecules begin to vibrate vigorously causing the solid to change into a liquid state

-The temperature at which a solid changes into liquid is called the melting point. At melting point the temperature remains constant until the solid has melted

-When the entire solid has melted and more heat is applied, the temperature rises. The heat gained weakens the cohesive forces between the liquid molecules considerably causing the molecules to move faster until the liquid changes into gaseous state

-The temperature at which a liquid changes into gaseous state is called the boiling point. At boiling point temperature of the liquid remains constant since heat supplied weakens the cohesive forces of attraction in liquid molecules

-If the heated substance is water its temperature rises with time as shown below



Properties/qualities of a thermometer

- *Quick action*

  This refers to the ability of a thermometer to measure temperature in the shortest time possible. This is attained by using a thin walled bulb using a liquid which is a good conductor of heat e.g. mercury.

- Sensitivity

  This is the ability of a thermometer to detect a very small temperature change.

It is attained by;

i) Using a thermometer with a big bulb

ii) Use of a liquid which has a high linear expansivity

iii) Using a narrow bore or reducing the diameter of the bore hole

HEAT CAPACITY

This is the heat required to raise the temperature of a substance by 1^0C or 1K. S.I unit is $J/^0C$ or J/K

Specific heat capacity

This is the quantity of heat required to raise the temperature of one kilogram of a substance by 1^0C. S.I unit is $Jkg^{-1}\,{}^oC^{-1}$

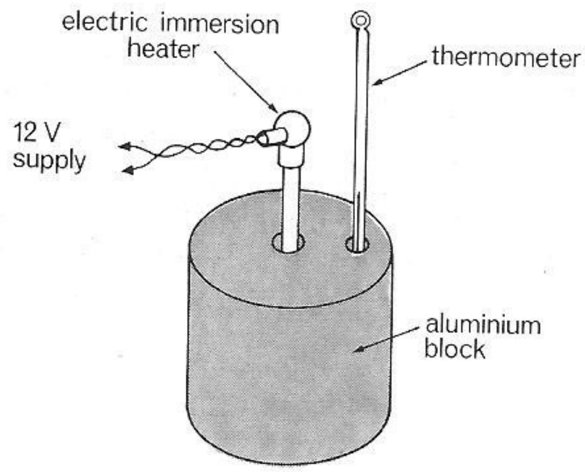
Example

1. 6000J of heat is used to heat a liquid of mass 3kg from 25^oC to 45^0C. Find the specific heat capacity of the liquid

2. 10,000J of heat is used to heat the metal block of mass 400m from 20^0C - 100^0C.find the (C) of the metal block.

3. Find the heat required to raise the temperature of a block of mass 200g from25^0C to 65^0C (specific heat capacity of the block is $130Jkg^{-1o}C^{-1}$)

DETERMINATION OF SPECIFIC HEAT CAPACITY OF A METALIC BLOCK



The mass (m) of the metallic block is first measured and recorded using a beam balance

The heater of known power (P) and thermometer are placed in the block

The initial temperature of the block is recorded

The heater is switched on and left to heat for some time (t)

The purpose of cotton wool is to ensure that no heat is lost to the surrounding

Assume no heat is lost to the surrounding

Heat supplied = heat absorbed or gained by the metal

$$Pt = m\, c_m \times \theta$$

$$C_m \;=$$

Where c_m is the specific heat capacity of the metal and θ is the temperature change i.e. ($\theta = \theta_2 - \theta_1$)

Question

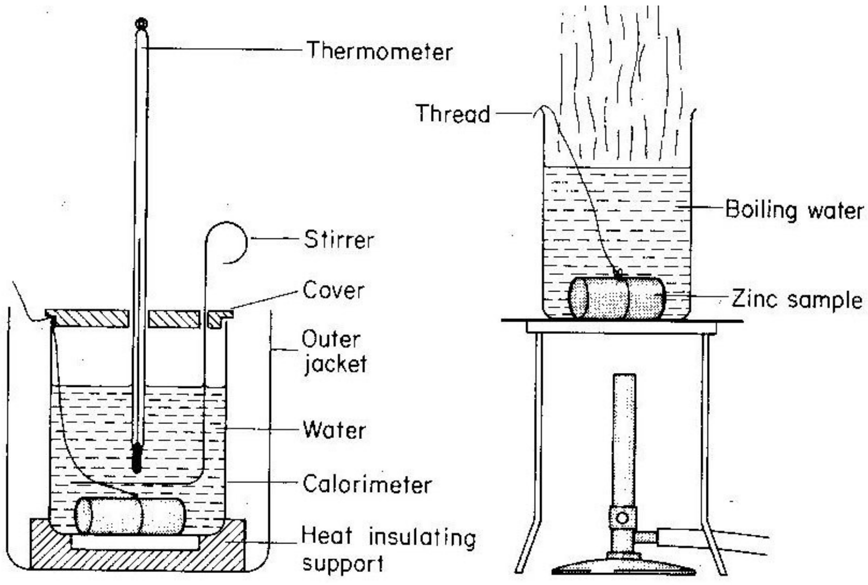
A heater is rated 2kw, find the heat supplied in

i) 5 seconds

ii) 10 minutes

iii) 2 hours

DETERMINATION OF SPECIFIC HEAT CAPACITY OF A SOLID BY METHOD OF MIXTURES



Heating sample to b.p. of water

Procedure

- Water of mass m_1 is put in a container of heat capacity c_1
- The calorimeter and its contents are put in a calorimeter jacket and the initial temperature θ_1 recorded
- Mean while, the solid of mass m is put in boiling water in a beaker as shown in figure(i) above for 5 minutes
- The boiling point θ_2 is recorded
- Quickly the solid from boiling water is transferred to the calorimeter using a string
- The mixture is stirred thoroughly until the final steady temperature θ_3 is obtained. The heat shield is to prevent the heat from boiling water to reach the calorimeter
- Assume neligible heat to the surrounding

Heat lost by solid = heat gained by the calorimeter + heat gained by water

$MC_S\,(\theta_3 - \theta_2) = M_1C_1\,(\theta_3 - \theta_1) + M_2\,C_2\,(\theta_3 - \theta_1)$

$C_s =$

Knowing values of C_1, M_1, M_2, C_2, M and temperature changes, specific heat capacity of a solid C_s can be obtained from the above expression

Examples:

1. 252,000J of heat are supplied to 4kg of water at 40^0C. Find the final temperature of water (specific capacity of water is $4200JKg^{-1o}C^{-1}$)

2. In an experiment to determine the specific heat capacity of a solid, it was put in boiling water for 5min. It was then quickly transferred in 5kg of liquid at 46^0C in plastic beaker. The final temperature of the mixture was found to be 50^0C. Find the specific capacity of the solid (specific heat capacity of liquid is $2000JKg^{-1}\,{}^0C^{-1}$

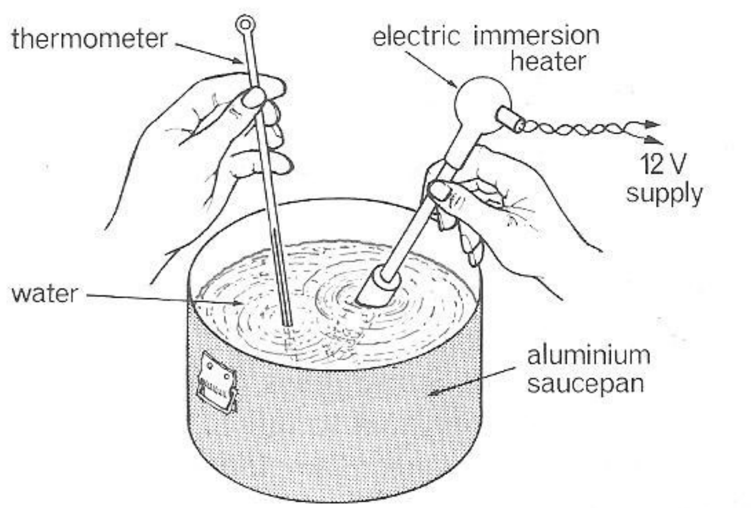
Heat lost by solid = Heat gained by liquid

$MC (\theta_3-\theta_2) = M_1C_1 (\theta_2-\theta_1)$

$2 \times C (100-50) = 5 \times 2000 (50 – 46)$

$C = 400JKg^{-1o}C^{-1}$

Determination of specific heat capacity of a liquid by electrical method



Procedure;

- Pour the liquid of known mass (m) in a plastic beaker or insulated aluminium pan

- Put the heater of known power (P) and the thermometer in the plastic beaker containing a liquid.
- Measure and record the initial temperature θ_1 of the liquid.
- Switch on the heater to warm the liquid for time (t).
- Read and record the final stable temperature θ_2 of the liquid.

Calculate the specific capacity from;

Heat gained by liquid = Heat supplied by the heater

$$MC(\theta_2 - \theta_1) = Pt$$

Specific heat capacity of the liquid C =

Assumptions made;

- The amount of heat absorbed by the plastic beaker is negligible.
- No heat is absorbed by water (liquid) from the surroundings.

Example;

1. An immersion heater of 60W was used to heat a liquid of 1Kg for a minute. Find the specific heat capacity of the liquid if the initial temperature was 27^0C and changed to 87^0C

Heat absorbed by water = Heat supplied by the heater

$$MC(\theta_2 - \theta_1) = Pt$$

$$1x\ C(87 - 27) = 60 \times 30$$

$$C = 30JKg^{-1o}C^{-1}$$

2. Atifa was to have a warm bath. She mixes 5Kg of hot water at with 15Kg of cold water at taking C to be $4200JKg^{O}C^{-1}$. Find the final temperature of the mixture.

Heat lost by hot water = Heat gained by cold water

$$M_hC(\theta 2 - \theta_3) = M_cC(\theta_3 - \theta_1)$$

$$5 \times 4200(85 - \theta_3) = 15 \times 14200(\theta_3 - 25)$$

$$\theta_3 = 40^oC$$

Importance of high specific capacity of water

Because of its high specific heat capacity, water is used as a coolant in cooling systems such as car radiators. Due to its high specific heat capacity it takes a higher quantity of heat to rise in temperature.

What it means for the specific heat capacity of water to be 4200Jkg^{-1}K^{-1}

It means 4200J of heat is required to raise the temperature of 1kg of water by one kelvin

LATENT HEAT

Latent heat is the heat lost or absorbed by the body during change of state at constant temperature.

There two types of latent heat

(i) latent heat of vaporization (L_v)

(ii) Latent heat of fusion (L_f)

Latent heat of vaporization

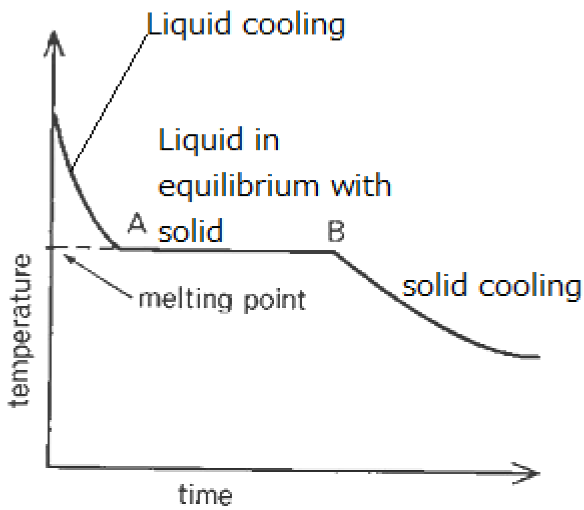
This is the amount of heat absorbed by a body to change its state from liquid to vapour at constant temperature

NB: The constant temperature is the boiling point of the liquid.

Latent heat of fusion

This is the amount of heat absorbed by a body to change its state from solid to liquid at constant temperature. The constant temperature is the melting or freezing point.

Cooling curve of a substance



Specific latent heat of vaporization L_v

This is the amount of heat required to change 1Kg of a substance from liquid to vapour at constant temperature.

$H = ML_v$ where H is amount of heat supplied or lost by a body.

M = mass of the body, L_v = Specific latent heat of vaporization of the body.

Examples

1. Find the amount of heat required to convert 5kg of water at boiling point to steam (Take L_v of steam as $2.3 \times 10^6\ Jkg^{-1}$)

   Quantity of heat $H = ML_v$

   $= 5 \times 2.3 \times 10^6$

   $= 11.5 \times 10^6$

   $= 1.15 \times 10^5 J$

2. How much heat is needed to change 4kg of water at 10^0C to steam at 100^0c

   $H = mL_v$

   $H = 4 \times 2.3 \times 10^6$

   $H = 9.2 \times 10^6 J$

3. A 3kW electrical kettle is left on for 2 minutes after the water starts boiling. What mass of water is boiled off in this time?

Latent heat absorbed by water = Heat supplied by heater

$M \times 2.3 \times 10^6 = 3 \times 1000 \times 2 \times 60$

$M = 0.1565kg = 156.5g$

4. Find the heat given out when 10g of steam at 100^0C condenses and cools to water at 50^0C

Heat given = heat required to condense steam to water +heat required to cool water from 100^0C to 50^oC

$H = mL_v + mc\ (\theta_2 - \theta_1)$

= +

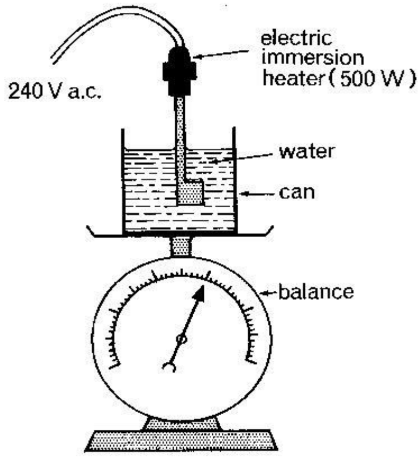
= 25100J

Since the amount of heat in steam is 5 times of heat in boiling water, therefore steam is more fatal than boiling water.

Importance of high value of specific latent heat of vapourization

1. Because of high value, steam is used as a heating agent e.g. cooking
2. Can be used for sterilizing medical tools e.g. blades, forceps.

Determination of specific latent heat of vaporization of water



Procedure

- Arrange the apparatus as in the diagram above
- Weigh the mass of the beaker and record it as m_1
- Switch on the heater to heat water in the beaker
- While water is boiling, read the position of the pointer on the stop clock
- After time (t) weigh the mass of water (m_2)
- Calculate the mass of steam from

$M = m_1 - m_2$

Obtain specific latent heat of vaporization from

Latent heat absorbed by boiling water = heat supplied by heater

$$ML_v = Pt$$

Where L_v is the specific latent heat of vaporization

SPECIFIC LATENT HEAT OF FUSION (L_F)

Specific latent heat of fusion is the amount of heat required to change the state of 1 kg mass of a substance from solid to liquid at constant temperature. S.I unit is J/kg

Example

1. How much heat will change 10g of ice at to water (take specific latent heat of fusion of ice to be 340,000J/kg)

   $H = mL_v$

   $H = = 3400J$

2. What quantity of heat must be removed from 20g of water at 0^0C to change it to ice at 0^0C

   $H = mL_f$

   $= = 6800J$

3. How much heat is needed to change 5g of ice at -5^0C to water at 10^0C

   $H = mc_{Ice}\Theta_{ice} + mL_f + mc_{water}\Theta_{water}$

   $= + +$

   $=1962.5J$

Question

1. (a)What is meant by specific heat capacity?

   (b) 2 kg of ice initially at -5^0C is heated until it changes to steam at 100^0C

   i) Sketch a graph to show how the temperature changes with time.

   ii) Calculate the thermo energy required at each section of the graph sketched in b(i) above .

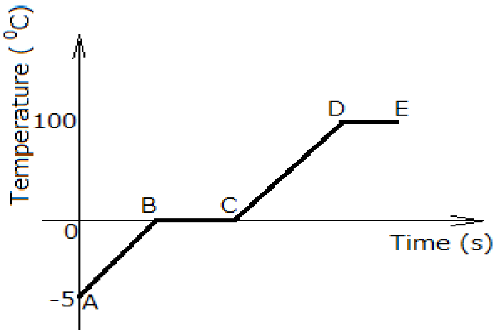
   Specific latent heat of fusion of ice is = $3.36 \times 10^5 Jkg^{-1}$

   Specific latent heat of vapourization of water is = $2.26 \times 10^6 Jkg^{-1}$.

   Specific heat capacity of water = $42 X10^3$ J/kgk

   Specific heat capacity of ice is = 2.1×10^3J/kgk.

GRAPH TO SHOW HOW TEMPERATURE CHANGES WITH TIME



(iii) Thermal energy along AB,

$H= MC_{ice}\ \theta_{ice}$

$= 2 \times 2.1 \times 10^3\ (0 - {}^-5) = 2.1 \times 10^4 J$

Thermal energy along BC

$H = ML_f$

$= 2 \times 3.36 \times 10^5 = 6.72 \times 10^5 J$

Thermal energy along CD,

$H = MC_{water}\Theta_{water}$

$= 2 \times 4.2 \times 10^3 \times (100-0)$

$= 8.4 \times 10^5 J$

Thermal energy along DE,

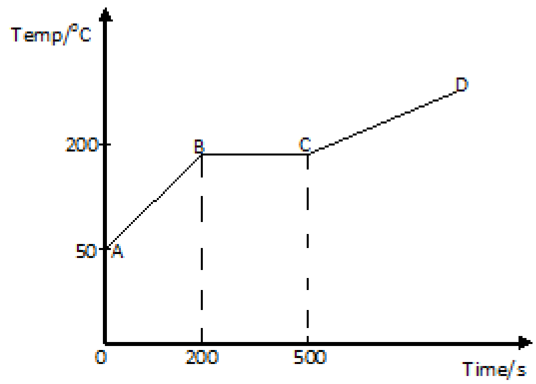
$H= ML_v$

$= 2 \times 2.26 \times 10^6 = 4.52 \times 10^6 J$

Exercise;

1. State and define the 3 major methods of heat transfer.
2. (a) Distinguish between specific heat capacity and specific latent heat of a substance

   (b)Describe an experiment to determine the specific latent heat of fusion of ice
3. The Graph shows a heating curve of a metal



i. Explain what happens to the metal

ii. If the metal absorbs heat at the rate of 3000J/S and specific heat capacity is $400JKg^{-1o}C^{-1}$, calculate mass of the metal.

iii. Find the specific latent heat of the metal

4. (a) Find the ways you would modify a liquid in glass thermometer so that it can register temperature more quickly.

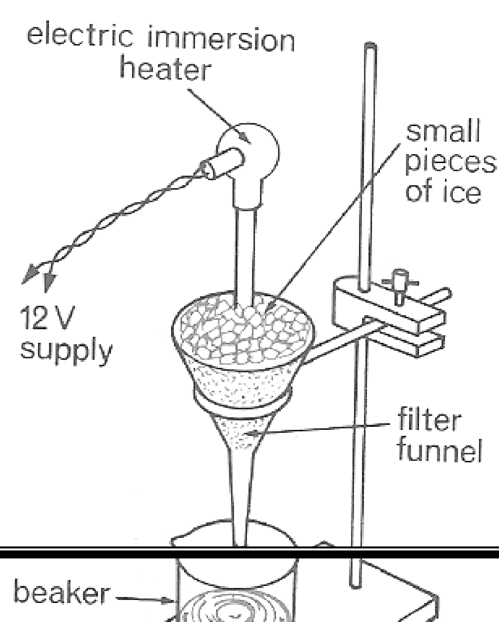
(b) Why is it usually not a good idea to have a thermometer with high heat capacity?

5. (a) Explain why the freezing compartment of a refrigerator is at the top.

(b) A glass of orange squash contains 0.2 kg of water at temperature of 24^0C.What is the minimum amount of ice you would need to add in order that the temperature of the drink is 0^0C?

Experiment to determine the specific latent heat of fusion of ice

<u>Set up</u>



Procedure;

Support the plastic funnel using the retort stand

Arrange the apparatus as in the diagram without the beaker

When the water in the funnel starts dripping at a uniform rate, switch on the immersion heater and place the beaker under the funnel at the same time

After sometime (t) of warming ice using the heater of known power, p, remove the beaker and the mass (m) of the water collected in the beaker is weighed

Calculate the specific latent heat of fusion of ice from:

Heat absorbed by ice = Heat supplied by heater

$ML_f = Pt$

$L_f =$

Assumption;

-No heat is absorbed from the surrounding

- All heat supplied by the heater has been absorbed by the ice only

Significance of high value of specific latent heat of fusion

Ice is often used as a cooling agent e.g. ice cubes are added to juice to keep it cold.

Example:

An aluminum tray of mass 400g containing 300g of water is placed in a refrigerator, after 80 minutes, the tray is removed and it is found that 60g of water remain un frozen at 0^0C. If the initial temperature of tray and its content was 200^0C, determine the average amount of heat removed per minute by the refrigerator.

Specific capacity of aluminum = $1J/g^0C$

Specific capacity of water = $4Jg^{-1o}C^{-1}$

Specific latent heat of fusion of ice = 340J/g

Heat removed by the fridge = Heat loss by water from 20^0C to 0^0C + Heat loss by water to ice + heat loss by tray.

$= M_wC_w (\theta_2 - \theta_1) + M_{ice} L_f + M_tC_1 (\theta_2 - \theta_1)$

$= 0.3 \times 4000 (20 - 0) + 0.24 \times 340{,}000 + 0.4 \times 1000 (20 - 0)$

$= 113600J$

Heat removed per minute =

$= 1420J/min$

Question

In an experiment to determine specific latent heat of fusion of ice, the following results were obtained:

Mass of water obtained in the beaker = 20g

Power of the heater = 50W

Time heater is switched on = 2min 6seconds

Determine specific latent heat of fusion of ice.

Latent heat and kinetic theory

(a) Latent heat of fusion

During change of state from solid to liquid (melting at constant temperature) the heat supplied weakens the intermolecular forces of attraction, the molecular spacing increases, changing from static molecules of solid to the relatively moving molecules in liquid state.

The average K.E of molecules remaining constant because melting takes place at constant temperature.

(b) Latent heat of vaporization

During change of state from liquid to vapour, the molecules must overcome of intermolecular forces of attraction so that they gain freedom to move about independently. As a result, the supplied is used to overcome these forces resulting in gain molecular potential energy but not their kinetic energy and also the work to expand against atmospheric pressure.

Why specific latent heat of vaporization of a substance is always greater than specific latent heat of fusion for the same substance

Specific latent heat of vaporization is always greater than specific latent heat of fusion because for molecules of a liquid to escape, they require a lot of heat which increases the kinetic energy in order to overcome the intermolecular forces of attraction while for latent heat of fusion very low amount of heat is required to weaken the intermolecular forces of attraction

GAS LAWS

Gases when heated will show a significant change in pressure volume and temperature unlike solids and liquids which show an insignificant change in volume.

There are three gas laws -:

1. Boyle's law
2. Charles's law
3. Pressure law

BOYLE'S LAW

It states that the pressure of a fixed mass of a gas is inversely proportional to its volume provided temperature remains constant.

Mathematically

P at constant temperature

$PV = k$ (constant)

So, in calculation we use;

$P_1V_1 = P_2V_2$

Example 1

The pressure of a fixed mass of gas is 5atmospheres when its volume is 200cm^3. Find its pressure when the volume

(i) Is halved

(ii) Is doubled

(iii) Is increased by 1 times provided temperature remains constant

Solution

(i) $P_1 V_1 = P_2V_2$

$5 \times 200 = P_2 \times 100$

$P_2 = 10$ atmospheres.

(ii) $P_1V_1 = P_2 V_2$

$5 \times 200 = P_2 \times 400$

$P_2 = 2.5$ atmospheres

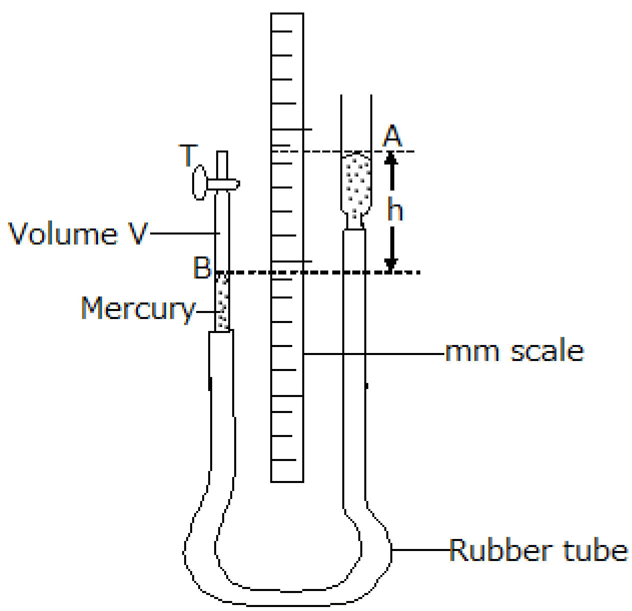
(iii) $P_1 V_1 = P_2 V_2$

$5 \times 200 = p_2 \times 300$

= 3atmospheres

When pressure is doubled the volume is halved and vice versa

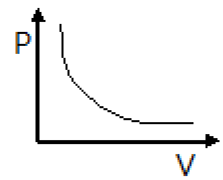
EXPERIMENT TO VERIFY BOYLE'S LAW

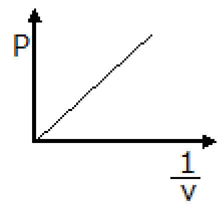


- Trap dry air in a bulb by pouring mercury through the reservoir
- For each volume (v) of trapped air , determine the height differences (h) between mercury levels A and B
- Find the pressure (p) = H + h where H is the atmospheric pressure
- Record results including as in the table below

$V(cm^3)$	H(cmHg)	P=(H+h) (cmHg)	

Graphs of Boyle's law





CHARLES' LAW

It states that volume of a fixed mass of gas at constant pressure is directly proportional to its absolute temperature

Mathematically

Volume v T where T is absolute temperature

V = kT

In calculation we use

=

Example 1

i) A fixed mass of gas occupies $500cm^3$ at 27^0C. At what temperature will the volume of the gas double if pressure remains constant?

ii) Find the volume of gas at $^-123^0C$ if pressure remains constant.

$T_1 = 27 + 273 = 300K$ $\qquad$ $T_2 =?$

i) =

=

$T_2 = 600K$

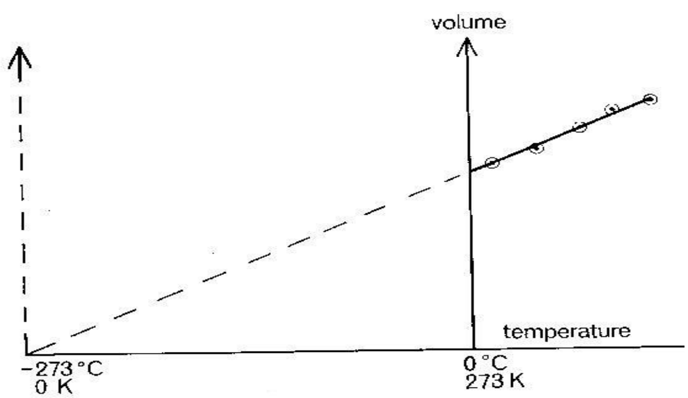
ii) $T_1 = 27 + 273 = 300K$ $T_2 = ^-123 + 273 = 150K$

=

=

$V_2 = 250cm^3$.

Graph of Charles' law



The graph is a straight line

It crosses the temperature axis at -273

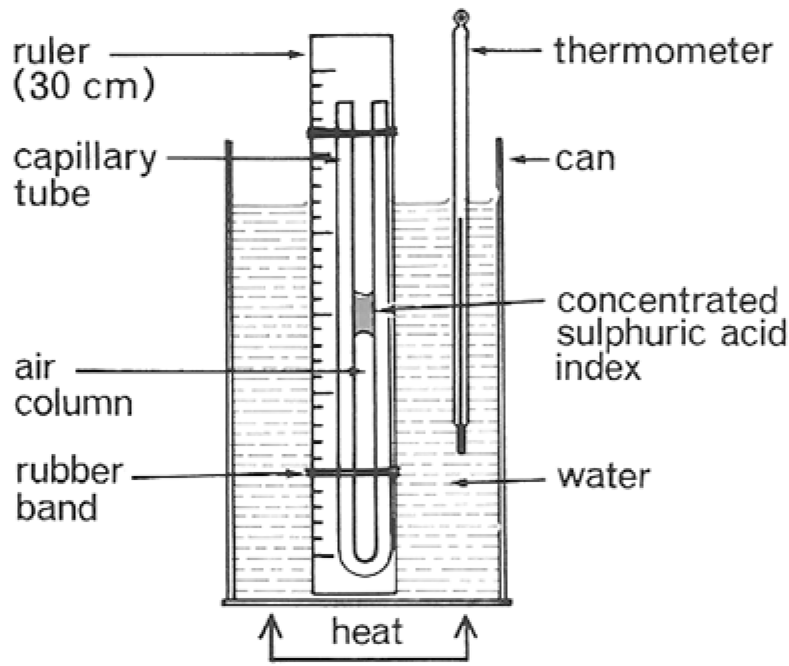
Absolute zero temperature (0k)

This is the lowest temperature possible where all molecules of gases have zero kinetic energy.

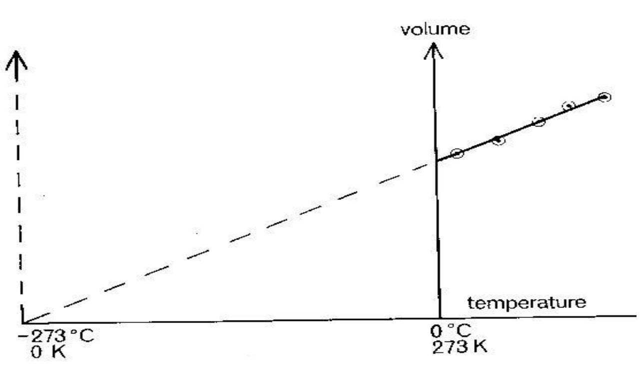
All gases liquefy before this temperature and don't obey gas laws at this temperature because they have turned into liquid.

Experiment to verify Charles' law

- Trap air in a capillary tube using a sulphuric acid index
- Set the apparatus as in the diagram above
- Vary the volume of trapped air by gently warming water in the beaker



- For every temperature of water in the beaker record corresponding volume of trapped air using the scale on the meter rule
- Record the results in a suitable table
- A graph of volume against temperature is plotted as shown



- The graph is a straight line and crosses temperature axis at $^-273^0C$. This verifies Charles' law.

NOTE

- Trapped air acts as gas
- Constant pressure will equal to the atmospheric pressure of the trapped air
- Pressure due to the weight of the index is equal to zero
- Concentrated sulphuric acid is used for trapping air in capillary tube and drying the trapped air.

PRESSURE LAW

The pressure of a fixed mass of gas at constant volume is directly proportional to its absolute temperature.

Mathematically

P T

P = KT

=K (Constant)

In calculation we use

Example

The pressure of gas in a cylinder is 15atm at 27^0C. What will it be at 177^0C and at what temperature will the pressure be 10 atmospheres?

$T_1 = 27 + 273 =$ $T_2 = (177 + 273)K = 450K$

=

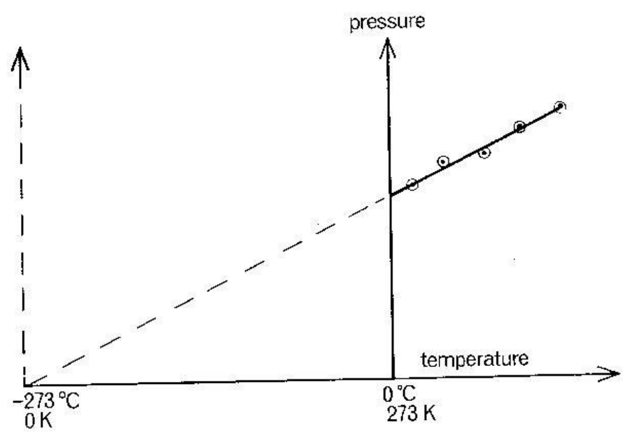
$P_2 = 22.5atm.$

(iii) $P_1 = 15atm$ $P_2 = 10atm$

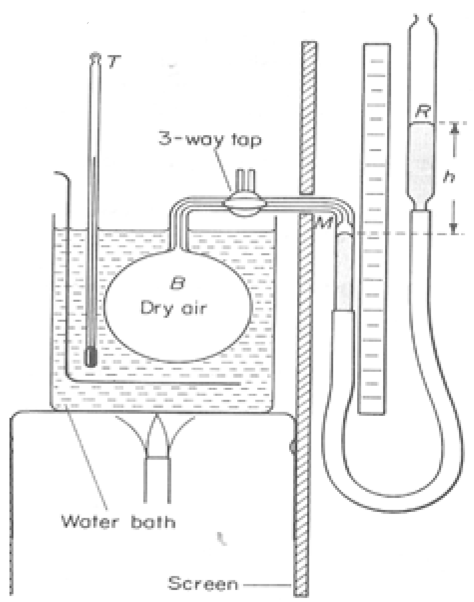
$T_1 = 300K$ $T_2 = ?$

$T_2 = 200K$.

Graphical form of pressure law

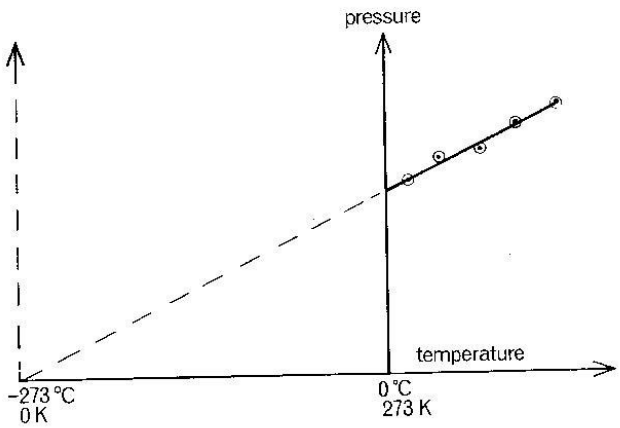


Experiment to verify pressure law

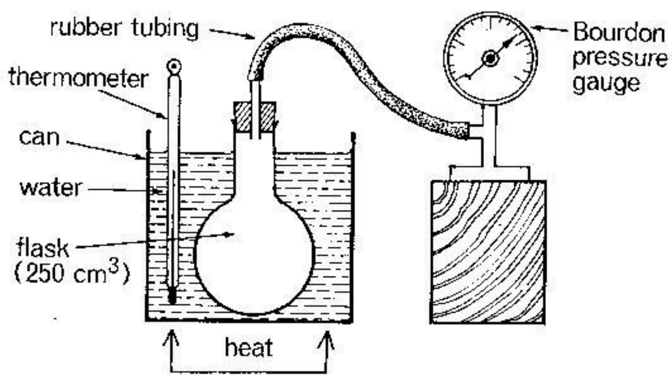


- Set the apparatus as shown in the diagram.
- Gently heat the water in the beaker to vary temperature.

- Read and record the height h for every temperature T
- Determine the pressure p = H + h, where H is atmosphere pressure.
- Plot a graph of p against T as shown.



Method 2



- The apparatus is set up as shown above
- The rubber tubing from the flask to the pressure gauge should be as short as possible

  The flask must be in water almost to the top of its neck.

- The can is heated from the bottom; the pressure is then recorded over a wide range of temperature. The heating is stopped to allow steady gauge reading for each reading taken.
- The results are tabulated and a graph of pressure against temperature plotted. A straight line graph touching the temperature axis at -273^oC verifies pressure law

Equation of state (ideal gas equation)

This is an equation which relates pressure, volume and absolute temperature of a fixed mass of a gas in different states. It is written as = constant where T is the absolute temperature.

But in calculation we use

EXAMPLE

The pressure and volume of a fixed mass of gas at 27^0C is 5atm and $3000cm^3$ respectively. Find the temperature of a gas in ^oC occupying the volume of $4500cm^3$ at pressure of 4 atmospheres.

$T_1 = 27 + 273 = 300K$ $T_2=?$

$T_2 = 360K$

In Celsius scale $T_2 = 360 – 273 = 87^0C$

Question

5. A cycle pump contains $50cm^3$ of air at 17^0C at 1 atmosphere. Find
   i) The pressure when the air is compressed to $10cm^3$. and its temperature rises to 27^0C

ii) Volume of air at pressure of 4 atmospheres and temperature of 77^0C

Standard temperature and pressure (S.T.P)

This is the physical condition of temperature equal to 0^0C and pressure is equal to 76cmHg. At S.T.P, 1 mole of any gas occupies 22.4 litres.

GAS LAW AND KINETIC THEORY

Kinetic theory can be used to explain

i) Cause of gas pressure

ii) Boyle's law

iii) Charles' law

iv) Pressure law

1. **CAUSES OF PRESSURE**

Gas molecules are in constant random motion colliding with each other and bombarding the walls of the container. As they bombard the walls of the container, they exert a force on the walls. These forces cause gas pressure.

2. **BOYLE'S LAW**

At constant temperature, the average speed of gas molecules is constant. When the volume of the container is decreased, the rate of collision and bombardment increases resulting in increase of force exerted on the walls and increase in pressure. Likewise increase in volume at constant temperature result in decrease in pressure.

3. **CHARLES 'S LAW**

When temperature of gas molecules increases, they move faster. To maintain the pressure constant, the volume of the gas must increase simply because when temperature increases, the volume has to increase to maintain the pressure constant.

4. **PRESSURE LAW**

When the temperature of gas increases, molecules move faster. When the volume is less, this increases the rate of bombardment resulting in increase in gas pressure.

MOMENTS AND EQUILIBRIUM

The turning of a force is the moment of force.

Moment of a force about a point depends on

i) The size of force

ii) perpendicular distance from a line of action of force from the pivot.

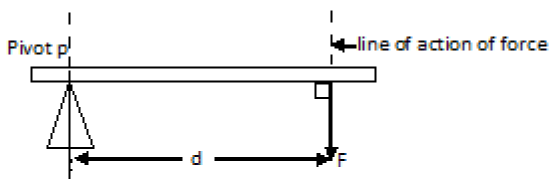
Moment of a force is = force x perpendicular distance

m = f x d where m is moment of force f is the force and d is the perpendicular distance.

Definition

Moment of a force about a point is the product of the force and the perpendicular distance of its line of action from the pivot. S.I unit is Nm

ILLUSTRATION



Moment of force about p

m = F x d

Types of moments

i) Clock wise moment

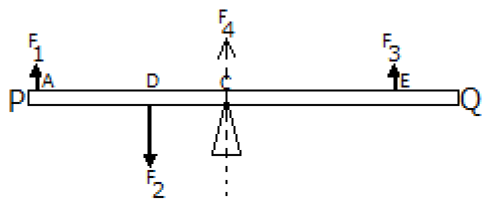
These are moments which produce clockwise turning effects

ii) Anti - clock wise moments

These are moments that produce anti - clockwise turning effects

Static equilibrium

A body acted upon by several forces is in static equilibrium when sum of clockwise moments about any point = sum of anti - clock wise about the same point.



If PQ is in equilibrium then:-

1. Sum of upward forces = sum of downward forces

$$F_1 + F_3 + F_4 = F_2$$

2. Sum of clockwise = sum of anti clock wise moment

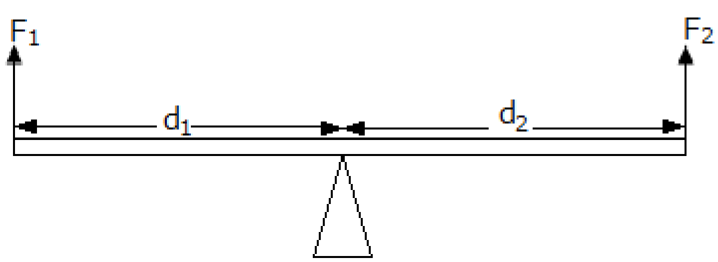
$$F_1AC = F_2DC + F_3EC$$

Conditions for a body to be in a mechanical equilibrium

1. The resultant force on body must be zero
2. The sum of clockwise moments about a turning point must be equal to the sum of anti - clockwise moments.

PRINCIPAL OF MOMENTS

It states that for a body in equilibrium, under the action of several forces, the sum of clockwise moments about a point is equal to the sum of anti - clockwise moments about the same point.

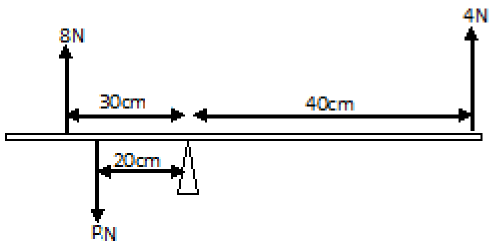


Sum of clockwise moments = sum of anti-clockwise moments

$$F_2 \text{ X } d_2 = \quad F_1 \text{ X } d_1$$

Example 1

Forces of 8N, pN and 4N act on a body as shown;



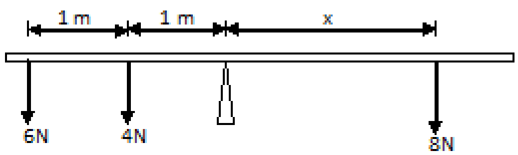
Find the value of P if the system is in equilibrium.

Sum of Anti-clockwise moments = Sum of clockwise moments

$4 \times 40 + p \times 20 = 8 \times 30$

$P = 4N$

3. Forces below act on the plank as shown



If the body is in equilibrium find the distance x

Anti clockwise = clockwise moments

$6 \times 2 + 4 \times 1 = 8x$

$X = 2m$

Centre of gravity

Centre of gravity is a point on the body through which the weight of the body acts.

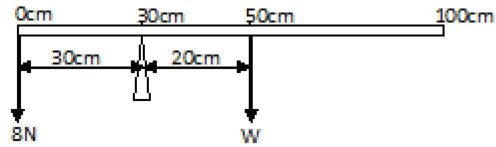
Object	**Centre of gravity**
Cube or Cuboid	It is the intersection of diagonals
Uniform rectangular square sheet	At the intersectional of the diagonal
Uniform cylinder	At the centre of its axis
Uniform sphere	At the centre
Uniform rod or bar	At the centre

Example: 1

(a) What is meant by centre of gravity?

(b) i) Define moment of a force

ii) A uniform metre rule is balanced at 30cm mark. When a load of 8N is hang at zero mark. Find the weight of the metre ruler



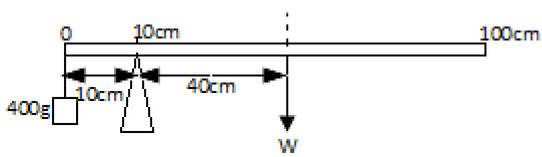
Sum of clockwise moments = Sum of anticlockwise moments

W x 20 = 8 x 30

W = 12N (W is the weight of metre rule)

Example: 2

A uniform metre rule pivoted at 10cm mark balances when a mass of 400g is suspended at 0cm mark as shown below.



Calculate the weight of the metre rule.

Sum of clockwise moments = Sum of anticlockwise moments

W x 40 = 400 x 10

W = 100g

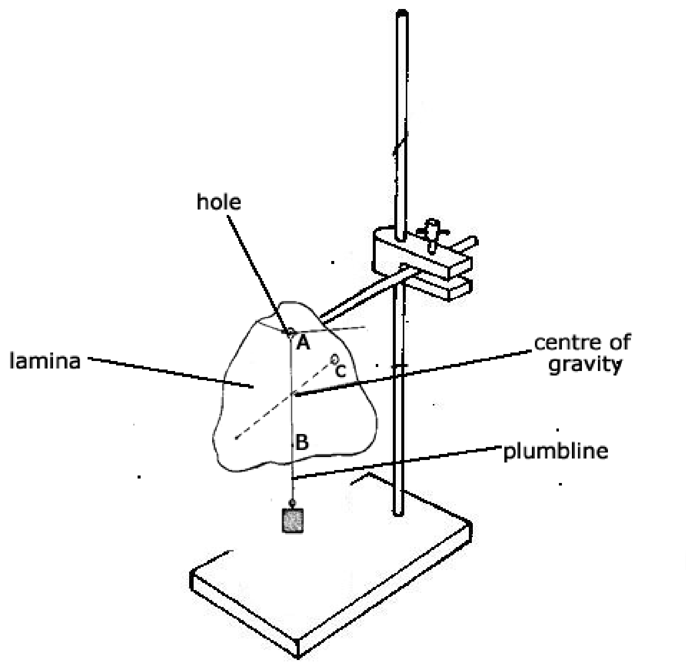
Weight = Mg

= x 10

= 1N

Determination of centre of gravity of an irregular object e.g cardboard

Plumb line method;



Make 3 holes A, B, C at different points near the edge of the lamina.

Suspend the lamina in hole A and the plumb line on a nail on a retort stand.

Mark the path of the thread of the plumb line on the lamina.

Repeat the procedure on holes B and C

The intersection of the three lines gives the centre of gravity (C.G)

STABILITY:

The stability of a body depends entirely on two factors namely:-

i) Position of the centre of gravity

ii) Size of base area

To increase the stability of a body, the following should be done.

- Increase the base area
- Lower the centre of gravity by making the base heavier

Types of stability equilibria

- Stable equilibrium
- Unstable equilibrium

- Neutral equilibrium

Stable equilibrium

This occurs when the center of gravity is in the lowest possible position

The body doesn't over turn when slightly displaced but returns to its original position after the displacement.

When slightly displaced, the center of gravity is raised and the line of action of the weight acts with in the base

Moment decreases when a body is slightly displaced

Unstable equilibrium

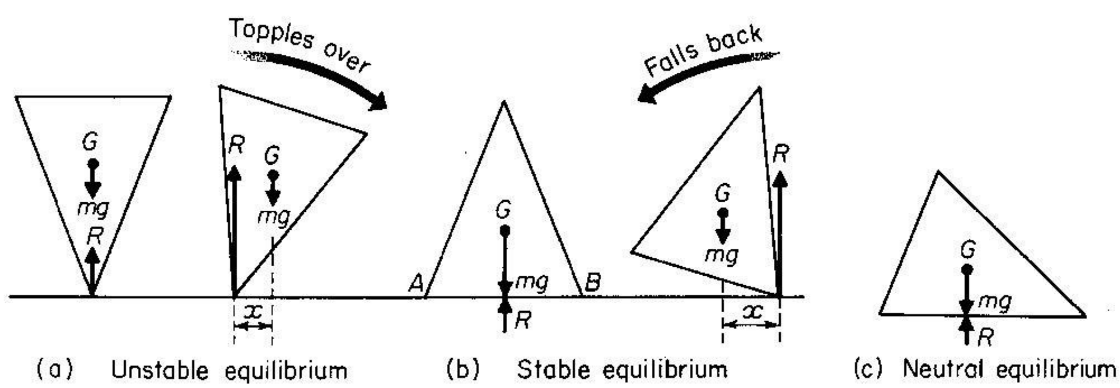
This occurs when the centre of gravity is in the highest position. The body overturns when slightly displaced.

When the center of gravity is lowered and the line of action of the weight acts outside the base

Neutral equilibrium

This is when a body is slightly displaced but the position of its center of gravity remains at the same height

Illustration

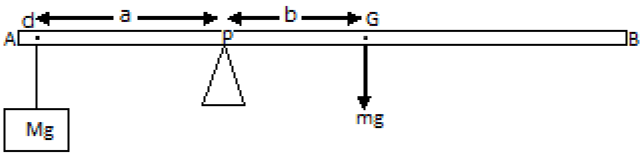


Application of principal of moments

- Action of a beam balance / weighing scale.
- Action of a sea saw.
- Determination of centre of gravity of a beam

- Determination of mass or the weight of a beam.
- Determination of relative density of a solid.

Determination of mass of a beam or rod or any straight material



Procedure

- Locate the centre of gravity of the beam AB by balancing it horizontally on a knife edge
- Note the position of the center of gravity
- Again balance AB horizontally on a knife edge using a mass M at a point d as shown in the diagram
- Measure distance dP = a and PG = b
- Calculate the mass m from;

Sum of clockwise moments = sum of anticlockwise moments

mg x b = Mg x a

m = =

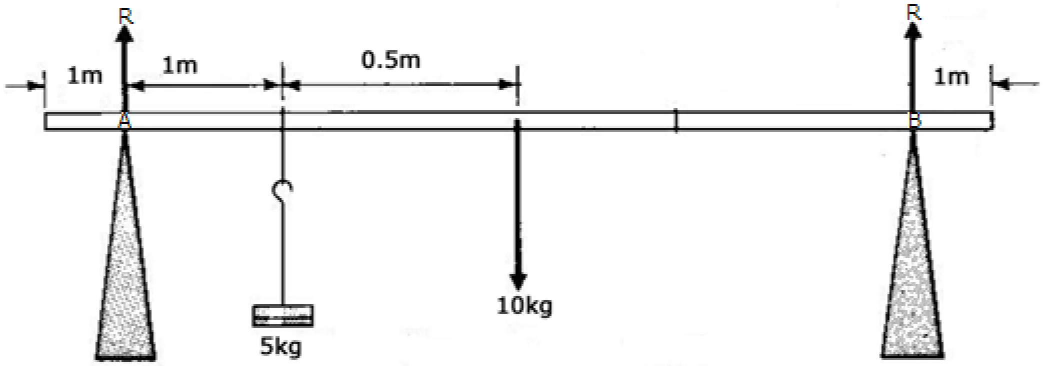
m =

Weight of beam, W = mg

Example

A uniform beam 5m long weighing 10kg is carried by 2 men each 1m from either ends of the beam if the mass of 5 kg rests 2m away from one end

i) Draw a diagram showing all forces acting on the bar
ii) Calculate the reaction due to the men acting on the bar



Taking moments about A

Sum of clockwise moments = sum of anticlockwise moments

50 x 1 + 100 x 1.5 = RB x 3

200 = 3RB

RB =

RB = 66.67N

Sum of upward forces = sum of downward forces

RA + RB = 50 + 100

RA + 66.67 = 150

RA = 83.33N.

Reaction at A= 83.33N

Reaction at B = 66.67N.

MOTION

Terms used

Speed

This is the rate of change of distance with time

Speed =

S.I unit is m/s

Distance

This is the length between two points

S.I units is metres

Displacement

This is the distance moved in the specified direction

S.I unit is meters

Velocity

This is the rate of change of displacement

OR

This is the rate of change of distance moved in a specified direction

S.I unit is m/s

Acceleration

This is the rate of change of velocity

A body travelling with increasing velocity is said to be accelerating

Acceleration a =

But change in velocity = final velocity – initial velocity

= v –u

Acceleration in velocity a =

S.I unit is m/s^2

Example 1

A car increases its speed steadily from 30 km/hr to 60km/hr in one minute

a) Determine its average speed during this time in

i) km/hr

ii) km/min

iii) m/s

b) How far does it travel whilst increasing its speed?

i) average speed = where v is final velocity / speed

=

= 45km/ hr

ii) average speed =

= 0.75km/min

iii) Average speed =

= 12.5m/s

b) Distance = speed x time

=12.5 x 60

=750m

2. A motor car is uniformly retarded and brought to rest from a speed of 108km/hr in 15seconds. Find its acceleration

Initial velocity u =

=

= 30m/s

Final velocity = 0 m/s

Acceleration =

$= -2m/s^2$

The minus (-) sign means the car is accelerating in opposite direction to its initial velocity i.e. the body is decelerating.

Uniform speed

A body is said to move with uniform speed if its rate of change of distance moved with time is constant.

Uniform velocity

This is the constant rate of change of displacement

A body is said to move with uniform velocity if its rate of change of displacement is constant.

When a body moves with uniform velocity, it travels equal distances in equal time intervals. A graph of distance against time is a straight line.

Its initial velocity must be equal to its final velocity.

Non uniform velocity

This is when the rate of change of displacement is changing. The body covers different distances in equal time intervals.

Uniform acceleration

This is when the rate of change of velocity is constant. When a body moves with uniform acceleration, the final velocity is not equal to the initial velocity

Equations of motion (Newton's equations of motion)

1st equation

Consider a body moving at initial velocity u accelerates with uniform acceleration a to the final velocity v in time t

Then acceleration a =

a =

$\mathbf{V = u + at}$ 1st equation

2nd equation

A body moving with uniform acceleration has an average velocity equal to half of the sum of its initial velocity u and final velocity v.

Average velocity = substituting for v in equation 2

Total distance s = average velocity x time

$S = (\ )\ t$ but from equation 1, $V = u + at$

$S = (\ t = ()t$

$\mathbf{S = u\ t + at^2}$ 2^{nd} equation

3^{rd} equation

This is obtained by eliminating time t from equation 1 and 2.

$S =$

$S = (\ )$

$(v + u)(v - u) = 2aS$

$\mathbf{V^2 = u^2 + 2aS}$ 3^{rd} equation.

The three equations of motion are

i) $V = u + at$

ii) $S = u\ t + ½at^2$

iii) $V^2 = u^2 + 2as$

Example

1. A car starts from rest and is accelerated uniformly at a rate of 1 m/s^2 in 20 seconds. Find;

a) Its final velocity.

b) The distance covered.

a) $V = u + at$

$= 0 + 1 \times 20$

$= 20 m/s$

b) $S = u\ t + ½\ at^2$

$= 0 \times 20 + ½ \times 1 \times 20^2$

$= 200m$

2. A car accelerates uniformly at a speed of 20m/s for 4 seconds. Find
   a) Final velocity if acceleration is 2 m/s^2
   b) Distance traveled.
   a) $V = u + at$
      $V = 20 + 2 \times 4$
      $V = 28m/s$

   b) $S = ut + \frac{1}{2}at^2$
      $S = 20 \times 4 + \frac{1}{2} \times 2 \times 4^2$
      $S = 96m.$

3. A body moving with velocity of 20 m/s accelerates to a velocity of 40m/s in 5 seconds. Find
   a) Acceleration to 40m/s
   b) Distance traveled in 5s.

   a =

   =

   $= 4m/s^2$

   $S = ut + \frac{1}{2}at^2$
   $S = 20 \times 5 + \frac{1}{2} \times 4 \times 5^2$
   $S = 150m$

4. A body at rest at height of 20m falls freely to the ground. Calculate
   i) The velocity with which it hits the ground
   ii) The time before striking the ground.

   Solution

i) $a = g = 10$

$V^2 = u^2 + 2as$

$V^2 = 0^2 + 2 \times 10 \times 20$

$V = 20 m/s$

ii) $V = u + at$

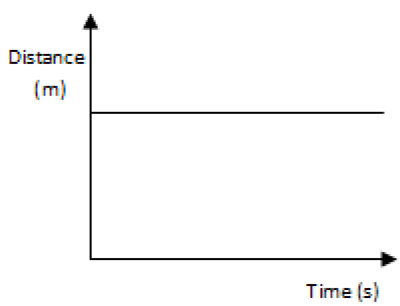
$20 = 0 + 10 \times t$

$t = 2s$

Graphs of motion

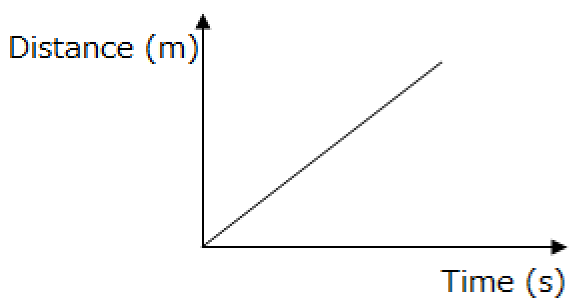
Distance – time graphs

i) For a body at rest



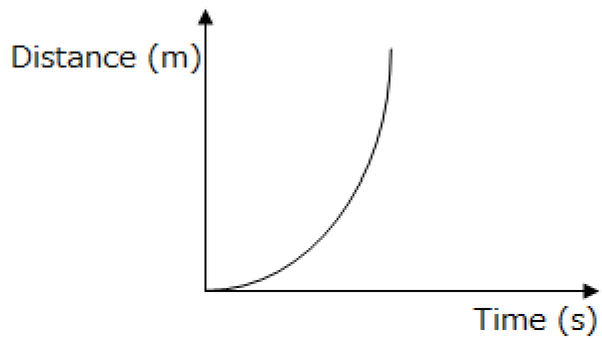
If a body is at rest its distance from a certain point does not change as time passes

ii) For a body moving with uniform velocity



If a body is moving with the same velocity it travels equal distance in equal intervals of time i.e. the object distance increases by equal increase in time.

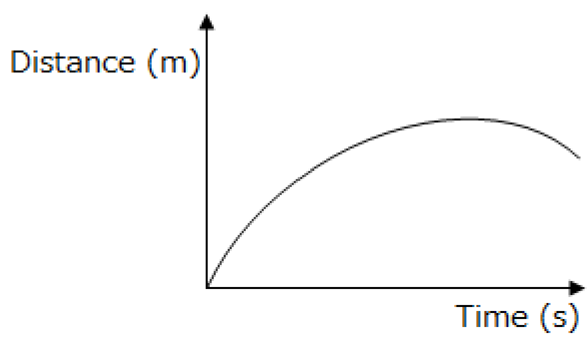
iii) Body moving with non uniform velocity



Varying distances are moved in equal intervals of time

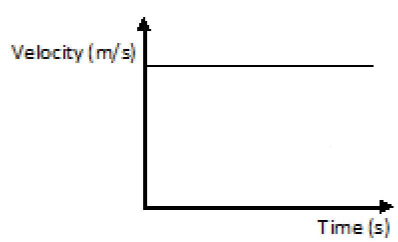
iv) Body moving with decreasing acceleration (retardation)

For a body whose velocity is decreasing the graph bends towards the horizontal. Velocity decreasing (retardation)

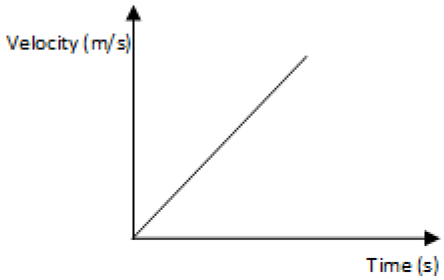


Velocity time graphs

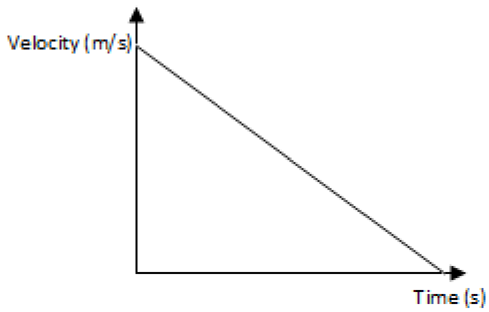
i) Body moving with uniform velocity



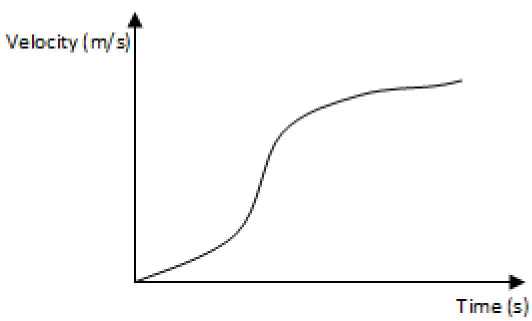
ii) Body moving with uniform acceleration



iii) Body moving with uniform deceleration.



iv) Body moving with non uniform acceleration.



Note

i) The area under a velocity time graph gives the distance covered by the body.

ii) The slope of a uniform velocity time graph gives the uniform acceleration.

Examples

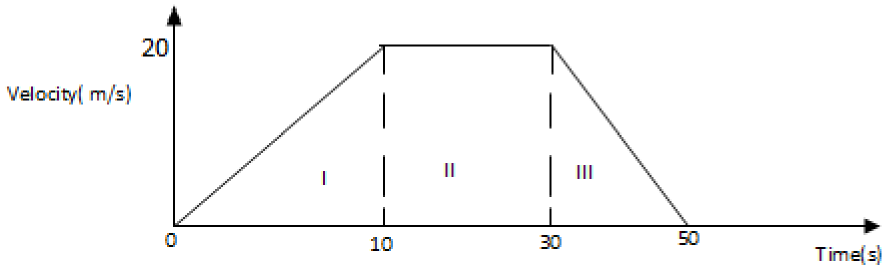
1. A car starts from rest and steadily accelerates for 10s to a velocity of 20m/s. It continues with this velocity for a further 20s before it is brought to rest in 20s
   a) Draw a velocity time graph to represent this motion.
   b) Calculate

i) Acceleration

ii) Deceleration

iii) Distance travelled

iv) Average speed



b (i) acceleration

a = = = = 2m/s^2

ii) Deceleration

a = = = =-1m/s^2

Deceleration = -a = 1m/s^2

iii) Distance

Distance traveled = area under a velocity time graph

S = ½bh+ L x w + ½bh

= ½ x10 x20 + 20 x 20 + ½ x 20 x 20

= 700m

Iv) Average speed =

=

= 14m/s

2. A car from rest accelerates to velocity 30m/s in 10s. It continues at uniform velocity for 30s and then decelerate so that it stops in 20s
   a) Draw a velocity time graph to represent its motion
   b) Calculate

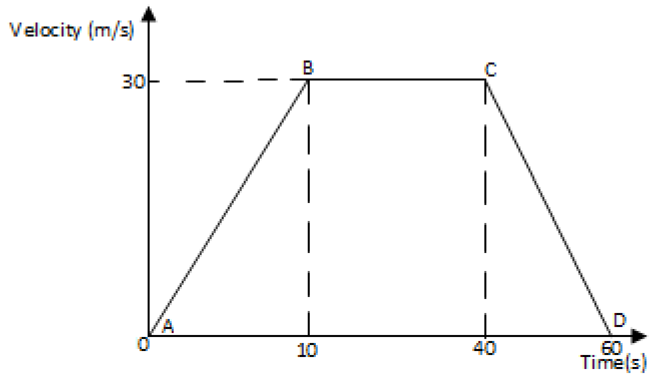
i) Acceleration

ii) Deceleration

iii) Distance travelled

iv) Average speed

a)



i. Acceleration a = = = $3m/s^2$

ii. Deceleration

a == = $^-1.5m/s^2$

Deceleration = $1.5m/s^2$

iii. Distance travelled

Total distance Covered = total area under a v –t graph

= ½bh + L x w +½bh

= ½ x10 x30 + 30 x30 +½x20 x30

= 1350m

iv. Average speed

Average speed = = 22.5m/s

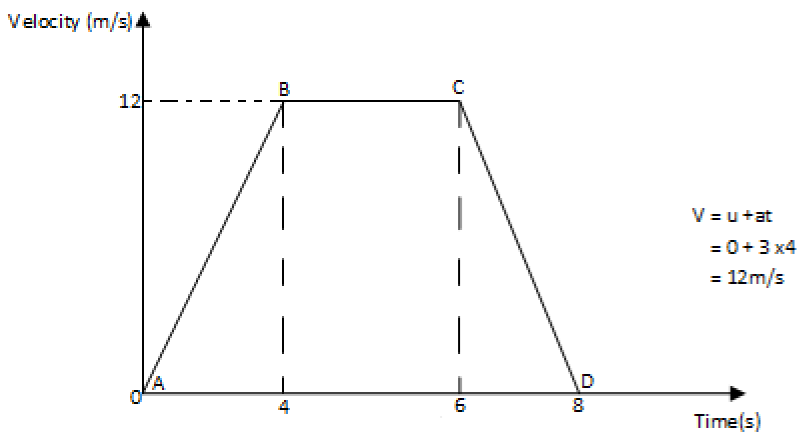
3. A racing car starts from rest and moves with uniform acceleration of $3m/s^2$ for 4 seconds. Then moves with uniform velocity for 2 seconds. It is brought to rest after a further 2 seconds

a) Draw a velocity time graph for motion of the car

b) Find total distance travelled

c) Average speed

a)



b) Total distance covered

Total distance = total area under a velocity time graph

$=\frac{1}{2}bh + L \times w + \frac{1}{2}bh$

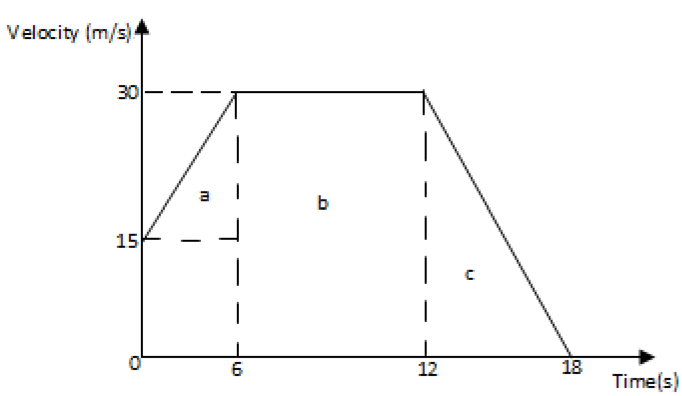
$= \frac{1}{2} \times 4 \times 12 + 2 \times 12 + \frac{1}{2} \times 2 \times 12$

$= 60m$

c) Average speed = ==7.5m/s

Question

1) The graph below represents a velocity time graph of a body in motion.



a. Describe the motion of the body.

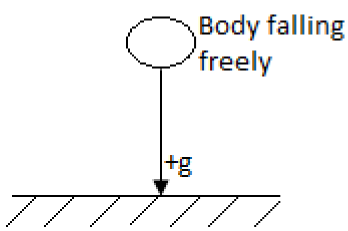
b. Calculate the total distance travelled
c. Total distance travelled = total area under a v- t graph
d. Determine the average speed.

2) A body of mass 60 kg starts moving with an initial velocity of 15 m/s and accelerates at a rate of $4m/s^2$ in 5s, then maintains a constant velocity for another 5s and brought to rest in 7s.
   a. Draw a velocity –time graph to represent this motion.
   b. Calculate the total distance travelled
   c. Calculate the retarding force

MOTION UNDER GRAVITY

For a body falling under gravity, acceleration due to gravity is positive but for a body thrown vertically upwards, acceleration due to gravity is negative. At maximum height, the body is momentarily at rest therefore final velocity is 0m/s

Equations of motion for a body falling freely under gravity, g



$V = u+gt$

$S = ut +\frac{1}{2}gt^2$

$V^2 =u^2 +2gs$

Equations of motion for a body thrown vertically up wards

$V = u -gt$

$S =ut -\frac{1}{2}gt^2$

$V^2 = u^2- 2gs$

Examples

1) A stone is raised from rest at point 20m above the ground so as to fall freely vertically down wards. Find

I. Time to land on the ground.

II. Velocity with which the body lands

I. Using $s = u t + gt^2$

$20 = 0 + \frac{1}{2} \times 10 t^2$

$t = 2s$

II. Using

$V = u + g t$

$= 0 + 10 \times 2$

$= 20m/s$

2) A ball is thrown vertically upwards with an initial velocity of 30m/s. Find

a. The maximum height reached

$u = 30m/s$

$V^2 = u^2 - 2gs$

$0 = 900 - 2 \times 10 \times s$

$= 900 - 20s$

$S = 45m$

b. Time taken to reach the maximum height

$S = u t + \frac{1}{2}gt^2$

$45 = 0 + \frac{1}{2} \times 10t^2$

$t = 3s$

c. Time taken to return to the starting point.

$V = u + gt$

$30 = 0 + 10t$

$t = 3$ seconds.

3) A stone thrown vertically upwards with an initial velocity of 14m/s neglecting air resistance, find

i. The maximum height reached

$v^2 = u^2 - 2gs$

$0 = 196 - 2 \times 10s$

$0 = 196 - 20s$

$S = 9.8m$

ii. The time taken before it reached the ground

$v = u + g\,t$

$14 = 0 + 10t$

$t = 1.4\ s$

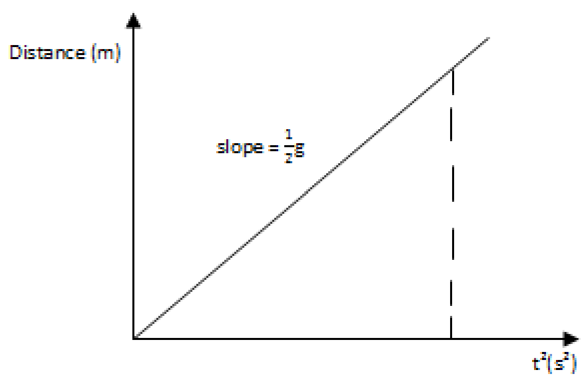
Acceleration of free fall is constant for a body falling from rest

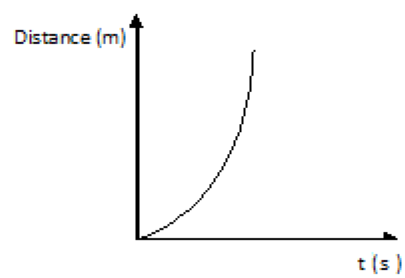
$S = u\,t + \frac{1}{2}gt^2$

$S = \frac{1}{2}gt^2$

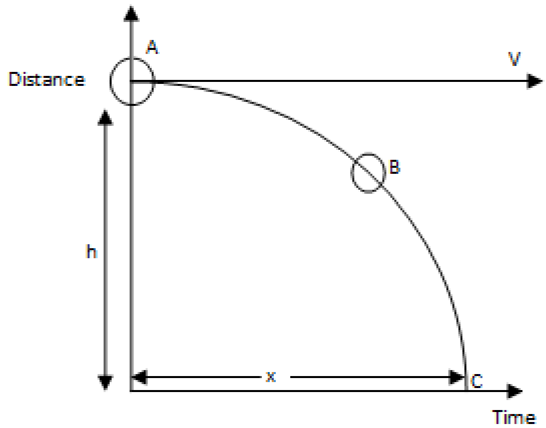
$S = (\text{constant})t^2$

$S\ t^2$





Projectile motion



In projectiles, the horizontal velocity of the body in motion remains the same throughout whole journey (trajectory). Acceleration due to gravity continues to act on the body vertically downwards and it doesn't affect the horizontal motion of the body.

Horizontal motion, distance is x

$x = v_x t$

Vertical motion, distance is s =h

$h = gt^2$

i.e. $S = ut + {}^2$

$S = h$ and $u = 0$

$S = \frac{1}{2}gt^2$

Where v_x is horizontal velocity of a given body and t is the time of flight.

Example

1. An object is dropped from a helicopter. if the object hits the ground after 2 seconds, calculate the height from which object was dropped

   t =2s, g = 10mls

   $h = \frac{1}{2}gt^2$

   $= \frac{1}{2} \times 10 \times 4 = 20m$

2. An object is dropped from helicopter at a height of 45m above the ground.
   a) If the helicopter is at rest, how long does the object take to reach the ground and what is its velocity on arrival.

b) If the helicopter falls with a velocity of 1m/s when the object is released, what would be the final velocity of the object?

a) $h = gt^2$

$45 = ½ \times 10t^2$

$t = 3$ seconds

b) Velocity on arrival

$v = u + g t$

$= 0 + 10 \times 3$

$= 30m/s$

Question

An object is released from an air craft travelling horizontally with a constant velocity of 200m/s at a height of 500m. Ignoring air resistance;

a) How long does it take the object to reach the ground?

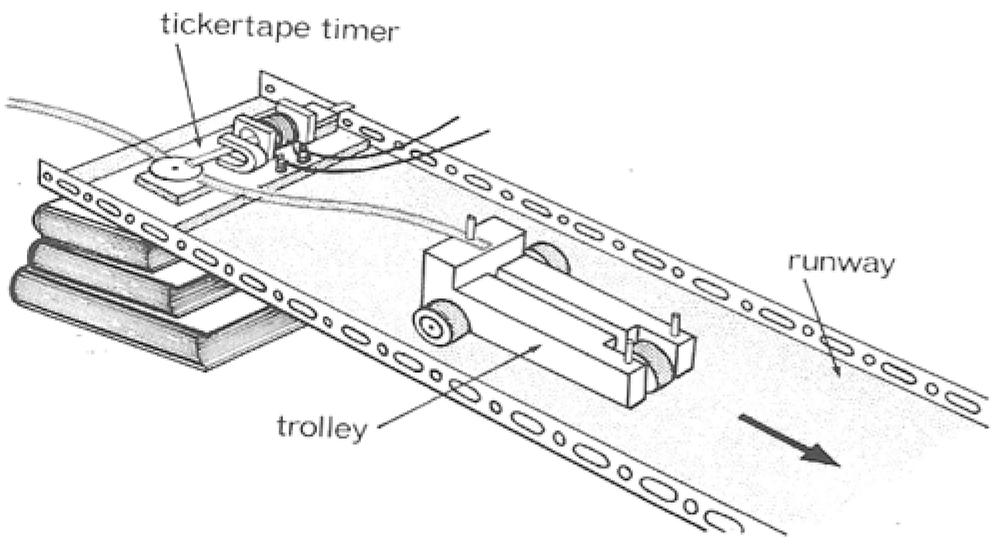
b) Find the horizontal distance covered by the object leaving the air craft and reaching the ground.

TICKER – TAPE TIMER

A ticker timer is a steel strip which vibrates rapidly and print dots on a length of a paper tape pulled through it. It prints 50 dots on a tape every second (frequency, f = 50Hz)

A ticker timer is used to measure speed or velocity and acceleration of bodies in motion.

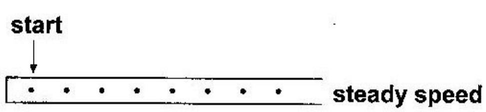
Experiment with a ticker – timer



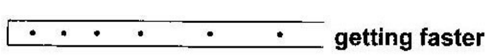
The paper tape is pulled by a trolley moving down an inclined plane as shown above. Different results are obtained on the speed of the trolley.

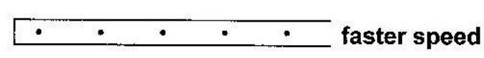
Typical results

- Trolley moving with uniform speed, spacing between successive dots is the same throughout.

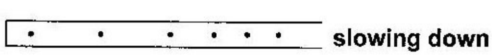


- The trolley is accelerating, the spacing between dots gets bigger and bigger.





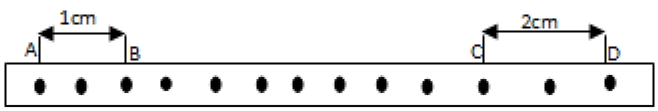
- Trolley decelerating, the spacing between successive dots gets smaller and smaller.



Example

1. The paper tape shown below was made by a trolley moving with uniform acceleration. if the ticker timer operated with a frequency of 100Hz, determine
   i) Initial velocity
   ii) Final velocity

iii) Acceleration.



i) t = = time taken to print successive dots, where n is the number of spaces between dots.

Number of spaces between AB = 2

Time taken a long AB = = 0.02s

Initial velocity or speed u = = = 0.5m/s

Number of spaces between CD = 2

Time taken a long CD = =0.02

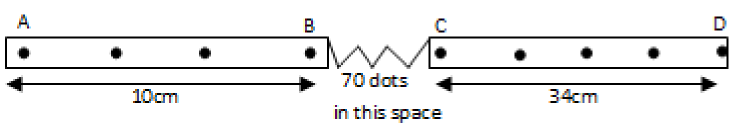
Final velocity / speed = = = v =1m/s

ii) Acceleration a = where t is time taken from B to D, Hence

=

= 5m/s^2

2. Below is a tape by a ticker – timer of frequency 50Hz



Calculate

i) Initial velocity

ii) Final velocity

iii) The acceleration of the trolley

Solution

i) Initial velocity

Time taken along AB = = 0.06s

Initial velocity or speed u = = = 1.67m/s

ii) Time taken long CD= = 0.08s

Final velocity/ speed = = =4.25m/s

iii) Acceleration a = where t is time taken from B to D

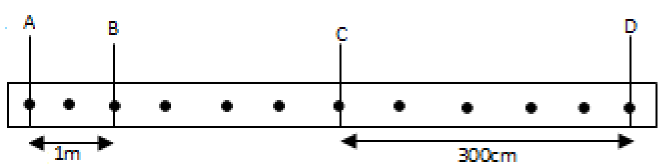
= t= =1 .46s

= 1.77m/s^2

Note

Usually, the first and last sections of the tape are ignored in experiments because the motion of the trolley is unsteady and the dots are near each other.

3. The ticker timer below printed dots. Assuming it vibrates at frequency of 20Hz, calculate
    i) Initial velocity
    ii) Final velocity.
    iii) Acceleration



Solution

i) Time taken along AB = = 0.1s

Initial velocity or speed = = =10m/s

ii) Time taken a long CD = =0.25s

Final velocity or speed = = = 12m/s

iii) Acceleration a = where t is time taken from B to D i.e. t = = 0.45m/s

a = = 4.5m/s

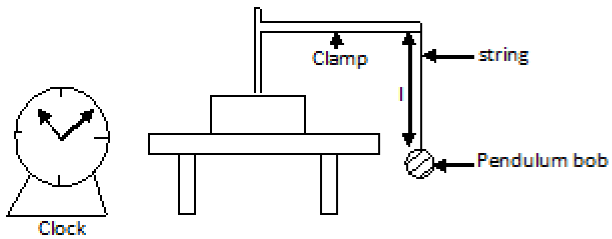
ACCELERATION DUE TO GRAVITY

Acceleration due to gravity is the rate of change of velocity with time of a freely falling object.

Experiment to determine acceleration due to gravity

Using a simple pendulum

The apparatus is arranged as below.



Measure and record the length, l of the pendulum

Displace the bob slightly and let it oscillate freely

Determine the time for 20 oscillations and calculate the period T

Repeat the procedure for various values of l

Record your results in a suitable table including T^2

Plot a graph of l against T^2

Obtain acceleration due to gravity from:

$g = - 4\pi^2 S$ where S is the slope of the graph.

NEWTON'S LAWS OF MOTION

1ST law of motion (law of inertia)

It states that a body continues in its state of rest oruniform motion in a straight line, unless acted upon by an external force.

This law suggests that everybody has inertia.

INERTIA

Inertia is the tendency of the body to remain at rest or if moving, to continue in its motion in a straight line with uniform velocity

The larger the mass of the body, the greater is its inertia, therefore the mass of the body is a measure of its inertia.

2nd law of motion

It states that the rate of change of momentum of a body is directly proportional to the applied force and takes place in the direction of the force.

Momentum of a body is the product of its mass and velocity i.e momentum = mass x velocity

S .I unit is kg m/s or kg ms^{-1}

Change in momentum = = where – final momentum and

– initial momentum

Applied force F

Where k is constant of proportionality.

From the definition of a Newton which is a force which gives a mass of 1kg an acceleration of $1m/s^2$.

If F = 1N, m = 1kg, a = $1m/s^2$

Example;

1. A 20 kg mass travelling at 5m/s is accelerating to 8m/s in 10s. calculate
   i) The change in momentum.
   ii) The rate of change in momentum
   iii) The applied force

Change in momentum =

=

=

i) Rate of change of momentum =

ii) Applied force = rate of change of momentum

= 6N

2. A body of mass 600g moving at 10m/s is accelerated uniformly at 2m/s for 4s. Calculate the;
   i) Change in momentum
   ii) Rate of change in momentum
   iii) The force acting on a body.

i)

Change in momentum

Change in momentum =

=

i) Rate of change in momentum.

=

=

= 1.2N

ii) The force acting on a body = rate of change of momentum

= 1.2N

3rd law of motion

It states that action and reaction are equal but opposite.

This means that whenever force acts on a body, an equal and opposite force act on the same body. Examples include:

i) A person walking exerts his weight (action) on the ground and the ground exerts an equal upward force (reaction) on him or her

ii) Two cars which collide both get damaged because each car exerts equal but opposite force

Example

1. A one turn car travelling at 20 m/s is accelerated at $2ms^{-2}$ for 5 seconds. Calculate the
   i) Change in momentum
   ii) The rate of change of momentum
   iii) Accelerating force acting on a body

i) Change in momentum =

=

ii) The rate of change of momentum =

=

= 2000N

iii) Accelerating force acting on the body = rate of change of momentum

= 2000N

Question

1. A block of mass 500g is pulled from rest on a horizontal frictionless bench by a steady force (F) and travels 8m in 2 seconds

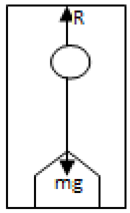
Find

(a) Acceleration

(b) Value of F

MOTION OF A BODY IN A LIFT

a) Lift at rest

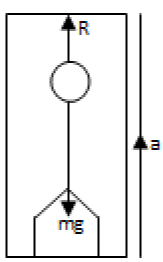


R – Reaction of a body

Mg – person's weight

When the lift is at rest, a person feels his / her normal weight using

b) Lift ascending (moving upwards)



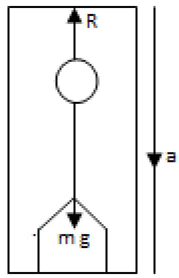
$$R - mg = ma$$

$$R = mg + ma$$

$$R = m(g + a)$$

The person feels heavier than his normal weight.

c) Lift descending (moving down wards)



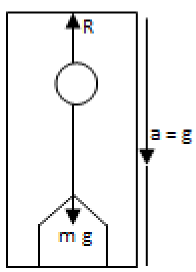
mg – R = ma

R = mg – ma

R = m(g - a)

The person feels loss in weight

d) Lift descending with acceleration a = g



mg – R =ma

R =mg –mg

R=m(g –g)

R = 0N

Some one feels weightless.

1. Find the reaction on a woman of mass 70 kg standing in a lift if the lift is
   (a) at rest
   (b) ascending upwards with uniform acceleration of $4m/s^2$
   (c) moving down wards with uniform acceleration of $4m/s^2$

Solution

a) $R = mg$

$= 70 \times 10$

$= 700N$

b) $R - mg = ma$

$R = ma + mg$

$= m(a + g)$

$= 70(4 + 10)$

$= 980N$

c) $mg - R = mg$

$R = mg - mg$

$R = m(g - g)$

$= 70(10 - 10)$

$= 0N$

d) $R = m(g - a)$

$= 70(10 - 4)$

$= 420N$

COLLISION AND LINEAR MOMENTUM

Linear momentum is the product of mass and velocity for bodies moving in a straight line. S.I unit is kgm/s

Collision

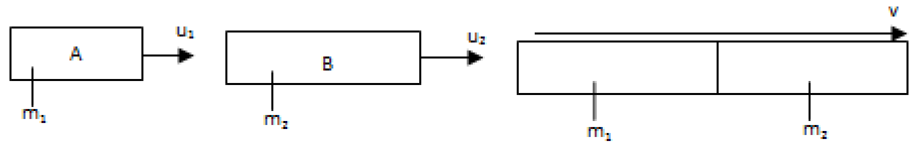
There are two types of collision

i) Inelastic collision

ii) Elastic collision

INELASTIC COLLISION

This is a type of collision where colliding bodies stick together and move with the same velocity after collision e.g. a bullet shot at a thief



$m_1 u_1 + m_2u_2 = (m_1 +m_2)\ v$

ELASTIC COLLISION

This is a type of collision where colliding bodies separate after collision and move with independent velocities

$m_1u_1+ m_2u_2 = m_1v_1 +m_2v_2$ where u_1 and u_2 are initial velocities v_1 and v_2 are final velocities

PRINCIPLE OF CONSERVATION OF LINEAR MOMENTUM

It states that when two or more bodies collide, the total momentum of the bodies remains constant provided no external forces act i.e.

Total momentum before collision = total momentum after collision

Example

1. A body of mass 2kg travelling at 8m/s collides with a body of mass 3kg travelling at 5m/s in the same direction. If after collision the two bodies move together. Calculate the velocity with which the two bodies move.

By principal of conservation of linear momentum

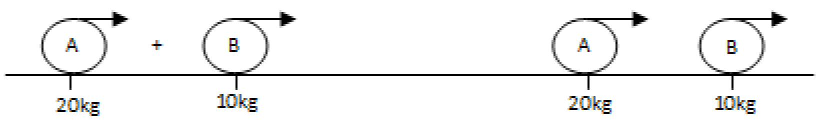
Total momentum before collision= total momentum after collision

$M_1u_1 + m_2u_2 \quad = \quad (m_1+m_2)v$

$2 \times 8 + 3 \times 5 \quad = \quad (2 + 3)v$

$v = 6.2m/s$

2. A body of mass 20 kg travelling at 5m/s collides with another stationary body with a mass of 10kg and they move separately in the same direction. If the velocity of the 20 kg mass after collision was 3m/s, calculate the velocity with which 10kg mass will move.



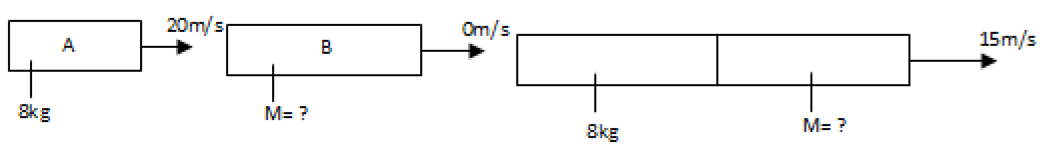
Total momentum before collision = Total momentum after collision

$m_1u_1 + m_2u_2 = m_1v_1 + m_2v_2$

$20 \times 5 + 10 \times 0 = 20 \times 3 + 10v_2$

$v_2 = 4m/s$

3. A body of mass 8kg travelling at 20m/s collides with a stationary object and they move together with a velocity of 15m/s. Calculate the mass of the stationary body.



$m_1u_1 + m_2u_2 = (m_1 + m_2)v$

$8 \times 20 + 0 = (8 + M)v$

$M = 2.7kg$

EXPLOSION

Momentum is conserved in explosions such as that which occurs when a rifle is fired. Before firing, the total momentum is zero since both rifle and bullet are at rest. During firing, the riffle and the bullet receive equal but opposite momentum, so the total momentum after firing is zero

$M_f v_f + M_b V_b = 0$

$M_b V_b = -M_f V_f$ where M_b –mass of bullet

M_f – mass of riffle

V_b- velocity of bullet

V_f – recoil velocity of the riffle

Recoil velocity

When the bullet leaves the barrel, the total momentum must be conserved. Therefore the bullet moves forward, the gun jacks backwards (recoils) with a velocity called recoil velocity.

Example

1. A bullet of mass 50g is fired with a velocity of 400m/s from a gun of 5kg. Calculate the recoil velocity of a gun.

$M_g v_g + m_b v_b = 0$

$V_g = -4$m/s (negative means opposite direction)

2. A 50kg girl jumps out of a rowing boat of mass 300kg to the bank with a horizontal velocity of 3m/s. With what velocity does the boat begin to move backwards

$M_g v_g + m_b v_b = 0$

$300 \times v_g + 50 \times 3 = 0$

$V_g = -0.5$m/s

Question

1. (a) Outline the similarities and the differences between elastic and inelastic collisions

b) Fatimah of mass 60kg running at 64 km/hr jumps on a stationary trolley of mass 20kg. If the collision is perfectly inelastic, Find

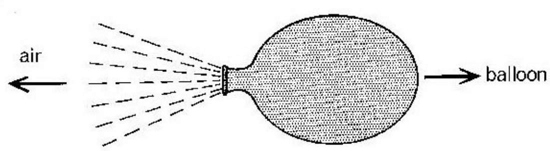
i) Loss in kinetic energy

ii) Final kinetic energy

APPLICATION OF NEWTON'S 3RD LAW OF MOTION AND CONSERVATION OF MOMENTUM

i) Inflated balloon

When a balloon filled with air is released in space so that the air can escape from the balloon. The balloon darts forward in space until all the air has escaped.



Explanation

As air escapes from the balloon at a high speed backwards, it does so with a big force. According to Newton's law of motion, the air exerts a reaction on the balloon causing it to move forward with the same force.

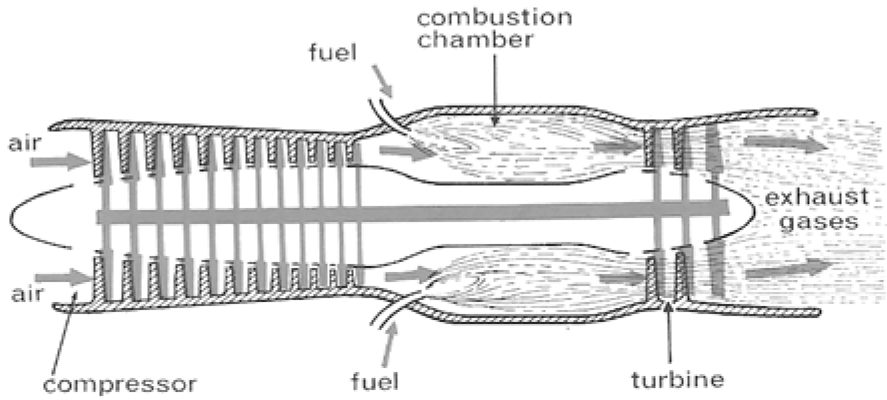
From the principle of conservation of momentum, a backward momentum due to the air escaping sets up equal but opposite forward momentum, on the balloon causing it to move forward.

ii) Rocket and jet engines.

Jet engine

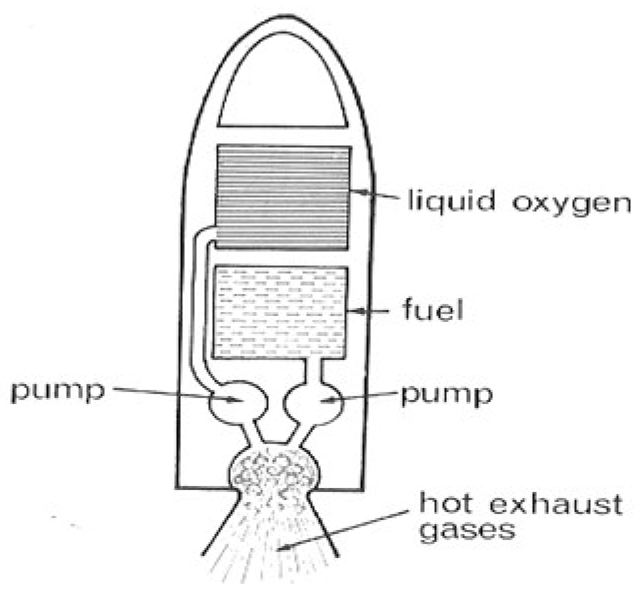
To start the engine, an electric motor sets the compressor to rotate. The compressor is like a fan; its blades draw in and compress air at the front of the engine. Compression raises the temperature of the air before it reaches the combustion chamber.

Fuel (kerosene) is injected and burns to produce a high speed stream of hot gas which escapes from the rear of the engine, as a result, the gaseous product set a reaction of equal but opposite momentum to the plane making it propel forward.



Rocket engine

Rockets, like jet engines, obtain their thrust from the hot gases they inject by a fuel. They can however, where there is no air since they can carry the oxygen needed for burning instead of taking it from the atmosphere as does the jet engine. Space rockets use liquid oxygen (at -183^{o}C). Common fuels are kerosene and liquid hydrogen (at -253^{o}C), but solid fuels are also used.



Differences between a rocket and jet engine

A jet engine doesn't go outside atmosphere because it uses atmospheric oxygen to burn its fuel while, a rocket engine goes out of atmosphere since it burns fuel when it is in space because it can be loaded with liquid oxygen cylinders.

ARCHIMEDES AND FLOATATION

ARCHIMEDE'S PRINCIPAL

Up thrust

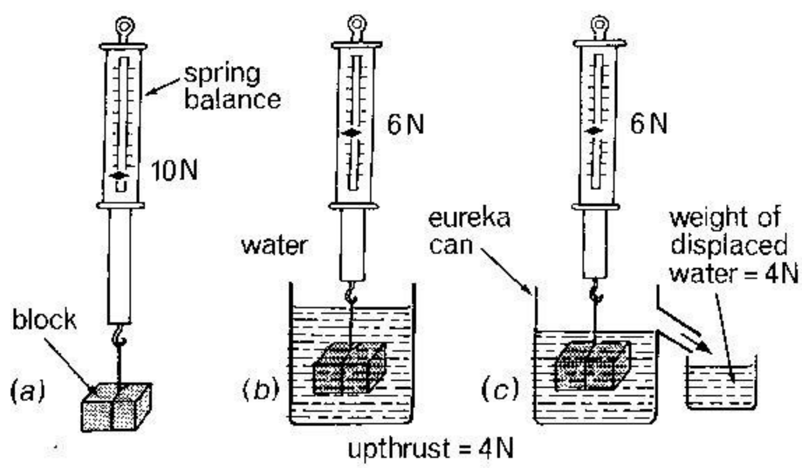
It is an upward force due to the fluid resisting being compressed. When any object is immersed or submerged into a fluid, its weight appears to have been reduced because it experiences an up thrust from the fluid.

Statement of Archimedes's principal

It states that when a body is wholly or partially immersed in a fluid, it experiences an up thrust equal to the weight of the fluid displaced

i.e up thrust = weight of fluid displaced

Experiment to verify Archimedes's principal



An object is weighed in air using a spring balance to obtain its weight w_1

The eureka can is completely filled with the liquid and a beaker is put under its spout

The body is then immersed in the liquid

The new weight w_2 is also read from the spring balance

The liquid collected in the small beaker is weighed to determine its weight w_3.

It is found that $w_3 = w_1 - w_2$

The weight of the body when completely immersed or submerged is called the apparent weight. The apparent weight is less than the weight of the body because when the body is immersed it experiences an up thrust

Example

1. A glass block weighs 25N. When wholly immersed in water, the block appears to weigh 15N, calculate the up thrust.

   Upthrust = weight in air – weight in a fluid (apparent weight)

   $= W_a - W_f$

   $= 25 - 15$

   $= 10N$

2. A body weighs 1N in air and 0.3N when wholly immersed in water. Calculate the weight of water displaced

   Up thrust $= W_b - W_f$

   $= 1 - 2.8$

   $= 0.2N.$

For a body completely immersed

Volume of the body immersed = volume of displaced fluid

$M = \rho \times v$

where ρ – density of displaced fluid

Volume of body, V = volume of displaced fluid

But

Up thrust = weight of fluid displaced

$= mg$

$U = \rho vg$

Example

A metal weights 20N in air and 15N when fully immersed in water. Calculate

a) Up thrust.
b) Weight of displaced water
c) Volume of displaced water (density = $1000kg/m^2$)

d) Volume of metal

e) Density of metal.

a) Up thrust = weight in air – weight in water

= 20N – 15N

= 5N

b) Weight of displaced water = up thrust

= 5N

c) Volume of displaced water

Upthrust = weight of displaced water

$5 = \rho v g$

$S = 1000 \times V \times 10$

V =

$V = 0.0005\ m^3$

d) Volume of metal = volume of displaced water

$= 0.0005m^3$

e) Density of metal =

=

$= 4000kgm^{-3}$

Application of Archimedes's principal

1. Measurement of relative density of solids
2. Measurement of relative density of a liquid

Measurement of relative density of a solid

- Weigh the object in air and note it to be W_a

- Weigh the object in water and note it to be W_w
- Determine the upthrust $U = W_a - W_w$
- Relative density of solid

EXAMPLE

1. An object weighs 5.6 N in air and 4.8N in water, find its relative density

=

= 7

2. An object of relative density 7 and weight 70N in air. What is its weight in water?

$W_w = 60N$

3. An object of relative density 9 weighs 40N in water find its weight in air.

$W_a = 45N$

Determination of RD of a liquid

- Weigh the object to find its weight in air W_a using a spring balance
- Weigh the object in the liquid whose RD is to be determined, label it W_l
- Weigh the object in water, call it W_w
- Find the up thrust in liquid $= W_a - W_l$
- Find the up thrust in water $= W_a - W_w$
- Obtain RD of a liquid from RD =

RD =

Example

1. An object weighs 5.6N in air, 4.8N in water and 4.6N when immersed in a liquid. Find the R.D of the liquid

=

=

2. An object weighs 100N in air and 20N in a liquid of RD 0.8. Find its weight in water.

$W_w = 0N$

FLOATING OBJECTS

There are two vertical forces which act on an object when immersed in water, Weight W and up thrust U

If W is less than U, the object rises

If W is equal to up thrust U object floats

If W is greater than up thrust U object sinks

Therefore floating objects weigh equal to up thrust. From Archimedes principal, up thrust is equal to weight of a fluid displaced. Therefore for floating objects, weight of objects should be equal to weight of fluid displaced.

Law of floatation

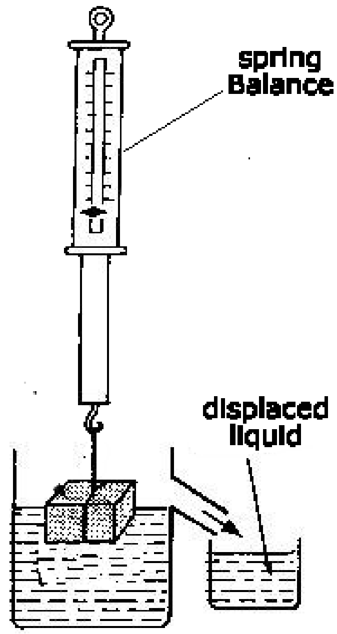
It states that a floating object displaces its own weight of the fluid in which it floats

Experiment to verify law of floatation

Method

- Weigh the object in air and note its weight W_a
- Fill the overflow can until water just overflows from the spout
- Place an empty measuring cylinder under the spout after dripping of water has stopped
- Gently lower the object into the overflow can and collect the displaced water

- Weigh the displaced water



- It is found out that weight of water displaced = weight of object W_a

Application of law of floatation

1. Ship

   A ship floats when the up thrust of the water it displaces equals its weight

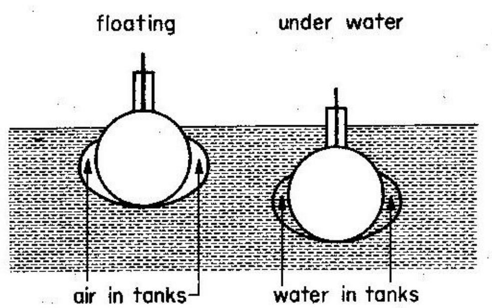
   i.e. Weight of floating ship =weight of water displaced

   While a ship is being loaded, it sinks lower and displaces more water to balance the extra load

   While steel does not float, steel ship floats. This is because steel ship is hollow and most of its parts contain air, hence its average density is less than the density of water. Therefore hollow steel displaces many times its volume of water

2. Submarines

   A submarine has ballast tanks which can be filled with water or air. When full of water, the average density of the submarine is slightly greater than the density of sea water and it sinks



When air is pumped into the tanks, the average density of the submarine falls until it's the same or slightly less than that of water around it. The submarine therefore stays at one depth or rises to the surface

Balloons and airships

A balloon is an airtight, light bag with hydrogen or helium. These gases are less dense than air. An airship is a large balloon with a motor to move it and fins to steer it.

The down ward force on the balloon equals to the weight of the bag plus the weight of gas in it.

The balloon rises if the up thrust is greater than the downward force

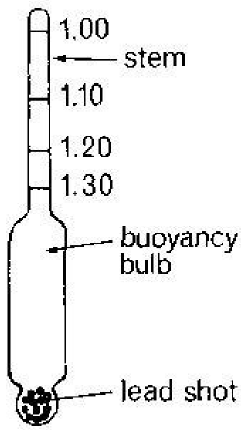
The lifting force= up thrust –total weight

= weight of air displaced –weight of bag + weight of gas

Balloons that carry passengers control their weight by dropping ballast to make them rise and by letting gas out of the gas bag to make them fall. As the balloon rises, the atmospheric pressure on it becomes less. The gas in the balloon tends to expand. Therefore the gas bag must not be filled completely when the balloon is on the ground.

4. Hydrometers

A hydrometer is a floating object used to find the density of liquids by noting how far it sinks in them.



No weighing is necessary. It consists of a longer glass tube with a bulb at the bottom. Mercury or lead is in the bulb so that the hydrometer floats up right. The stem is long and thin and is graduated. The thin stem means that the hydrometer is sensitive i.e. it sinks to different levels even in two liquids whose densities are almost the same.

Uses of a hydrometer

It is used for measuring the densities of milk (lactometer), beer, wines, acids in car batteries(the acid in a fully charged accumulator should have a density of $1.25g/cm^3$, if it falls below 1.18, the accumulator needs recharging).

Experiment to measure density of a liquid using the hydrometer

Mark a simple hydrometer in cm beginning at the end that sinks

Place it in a tall jar of water

Mark the level to which it sinks

Measure the length that was in the water

Remove the hydrometer, dry it and place it in a jar of another liquid. A gain measure the depth to which it sinks

Obtain density of liquid =

Worked out examples

1. The mass of a piece of cork ($0.25g/cm^3$) is 20g. What fraction of the cork is immersed when it floats in water?

Solution

Mass of cork = Mass of water displaced

= ρ v

20 = 1 × v   volume of water displaced =$20cm^3$ =volume of cork immersed

But volume of cork = = = 80 cm^3

Fraction of cork immersed = = ¼

2. A solid of volume 1 $x10^{-4}m^3$ floats on water of density 1 $x10^3$ kgm^{-3} with of its volume submerged. Find
   i) The mass of solid
   ii) The density of solid

   Solution

i) Mass of the solid = mass of liquid displaced

= v x ρ

= $x10^{-4}$x $1x10^3$

= 0.06kg

ii) Fraction of the body immersed=

=

Density of the body =

= $600kgm^3$

3. A rubber balloon of mass 5 x 10^{-3}kg is inflated with hydrogen and held stationary by means of a string. If the volume of the inflated balloon is 5 $x10^{-3}$, calculate the tension in the string (density of hydrogen = $0.8m^3$) (density of air=$1.15kgm^3$)

Solution

Up thrust U = weight of fluid displaced

$= \rho_a vg$

$=1.15 \times 5\times10^{-3} \times 10$

$= 0.0575N$

Weight of balloon fabric = mg

$= 5 \times10^{-3} \times10$

$= 0.05N$

Weight of hydrogen = ρ_h v g = $0.08 \times 5 \times10^{-3} \times 10= 0.004N$

Total weight of balloon W =0.05 + 0.004

$= 0.54N$

Tension T = U – W

$= 0.0575 – 0.054$

$= 0.0035N$

4. A body of mass 2kg is suspended from a spring which reads 17N when is completely submerged in water;
   i) What is the up thrust of the water in the body
   ii) What is the mass of water displaced by the body
   iii) If the density of water is $1000kg/m^3$, what is the volume of water displaced?
   iv) Calculate the density of the material of which the body is made.

$W_a = mg$

$= 2 \times 10$ and $U = W_a – W_w = 20 - 17$

$= 20N$ $= 3N$

i) Up thrust = weight of fluid displaced

$= 3N$

$W = mg$

$3 = m \times10$ hence m = = 0.3 kg

ii) Up thrust = weight of fluid displaced

$U = \rho v g$

$3 = 1000 \times v \times 10$

$V =$

$= 3.0 \times 10^{-4} m^3$

iii) Density =

=

$= 6.7 \times 10^3 \, kg/m^3$

5. When a metal is completely immersed in liquid A its apparent weight is 5N. When immersed in another liquid B the apparent weight is 16N. If the density of B is times that of A calculate the mass of the metal.

Solution

(i) Up thrust in A — Up thrust in B

$U_1 = W_a - W_A$ — $U_2 = W_a - W_B$

$U_1 = (W_a - 20)$ — $= (W_a - 16)$

Up thrust = weight of fluid displaced — U = weight of fluid displaced

$W_a - 20 = \rho_A Vg$ …….. (i) — $W_a - 16 = \rho_A Vg$………..(ii)

Divide (i) by (ii)

=

$8(w_a - 16) = 9(w_a - 20)$

$w_a = 52N$

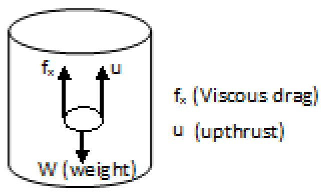
Mass of solid = =

$= 5.2kg$

Motion of a body through fluids

When a body falls through a fluid, it is acted on by forces namely

a) Weight of the body
b) Viscous force
c) Up thrust



The weight of the body acts downwards towards the earth. Up thrust acts upwards and viscous force acts in the direction opposite to body's motion

As the body falls, it accelerates first with net resultant force

$F = w - (f_x + u)$

As the body continues to fall, it attains a uniform velocity called terminal velocity, when the weight of the body $w = f_x + u$

At this stage, the resultant force or net force on the body is zero

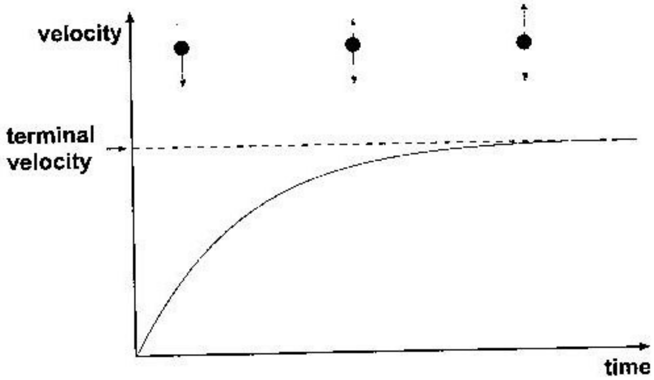
Terminal velocity

This is a constant or uniform velocity with which a body falling through a fluid moves such that the upward forces acting on it are equal to its weight

OR

Is the uniform velocity attained by a body falling through a fluid when the net force on the body is zero.

Incase of a balloon or a rain drop falling, the resisting force or retarding force on the body is called air resistance



LIGHT

Light is a form of energy that enables us to see

Sources of light

a) Luminous source of energy
Is that which produces its own light e.g. star, sun, bulb, candle etc.

b) Non luminous source of light is that which doesn't produce its own light but can reflect from luminous object e.g. mirrors, moon, car reflectors etc.

Transparent objects

These are objects which can allow light to pass through them. E.g. driving windscreen of a car, ordinary glass, pure water etc

Translucent objects

These are objects which allow little light to pass through them e.g. bathroom glass, tinted glass, tracing paper e.t.c

Opaque objects

These are objects which don't allow light to pass through them e.g. wood, concrete etc.

PROPERTIES OF LIGHT

- It undergoes reflection

- It undergoes refraction
- It undergoes diffraction.
- It undergoes interference.
- Can be plane polarized
- Travels in a straight line
- It has a velocity of 3.0×10^{8} ms^{-1} in vacuum
- Can travel through a vacuum

RAYS AND BEAMS

A ray

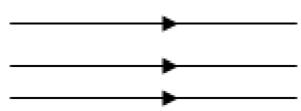
This is a path taken by light from an object (Source) to another. A ray is represented by a thin line with an arrow to indicate the direction of light

Beams of light

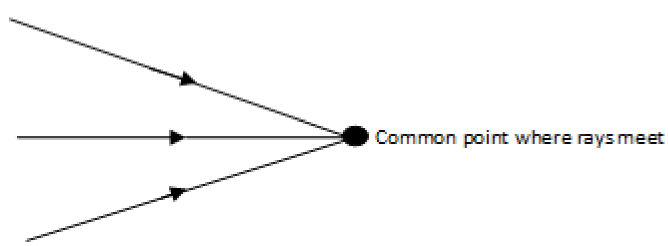
A beam is a collection of light rays moving in the same direction.

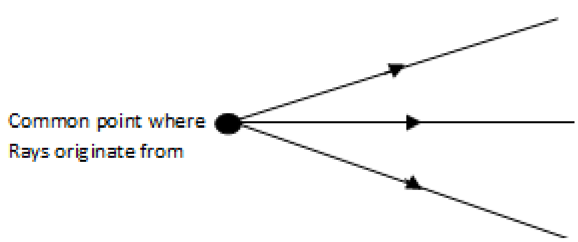
TYPES OF BEAMS

i) Parallel beam



ii) Convergent beam.





RECTLINEAR PROPAGATION OF LIGHT

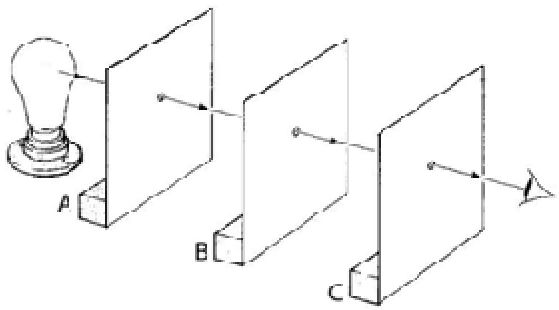
This is the phenomenon where by light travels in a straight line

EFFECTS OF RECTLINEAR PROPAGATION

i) Formation of shadows

ii) Occurrence of eclipses

EXPERIMENT TO SHOW THAT LIGHT TRAVELS IN A STRAIGHT LINE



PROCEDURE

Three (3) identical cardboards A, B and C each with a hole in its centre are arranged with the holes in a straight line as shown above

A source of light is placed behind cardboard A and an observer in front of C.

The observer is able to see the light from the source because light travels in a straight line

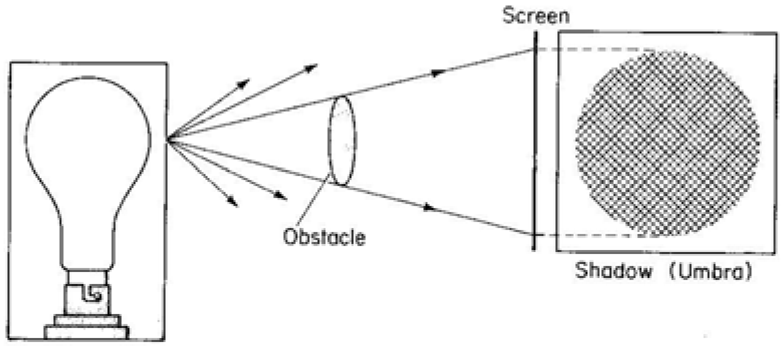
If one of the cardboards is displaced such that the holes are not in the straight line, no light will be seen by the observer

This shows that light travels in a straight line

SHADOWS

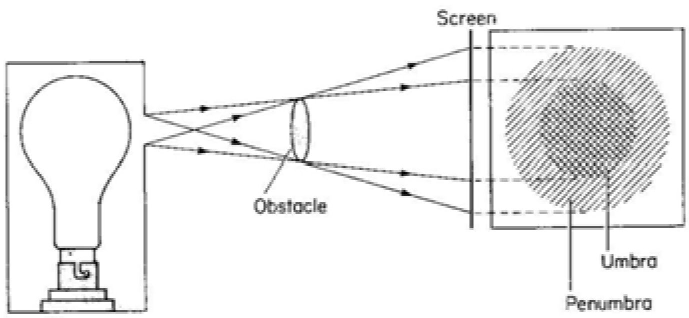
Shadows are formed when light rays are obstructed by an opaque object

FORMATION OF A SHADOW BY LIGHT FROM A POINT SOURCE



The shadow formed is completely dark with sharp edges and is called umbra

Formation of a shadow by light from an extended source



The shadow has two parts

(i) **umbra**

It is the central part of the shadow. It is dark and receives no light.

(ii) **Penumbra**

It is the outer part of the shadow. It is fairly dark. It receives some light from the source

ECLIPSE

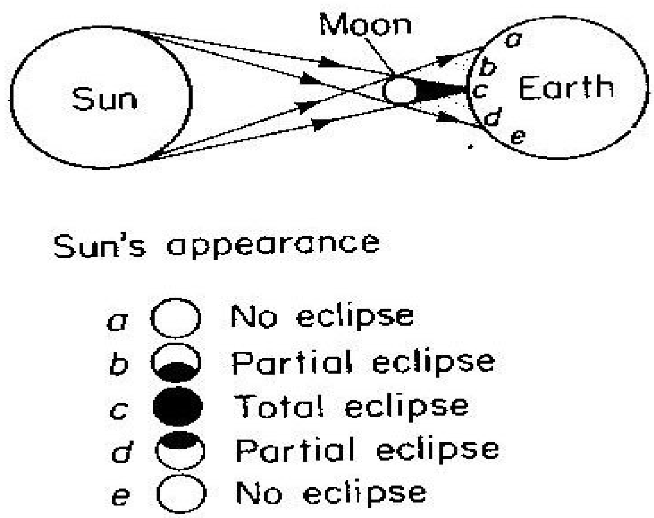
An eclipse occurs when the sun, moon and earth are in a straight line. It is a natural effect of the rectilinear propagation of light

TYPES OF ECLIPSE

1. **SOLAR ECLIPSE**

It occurs when the moon is between the sun and the earth. It is also called eclipse of the sun. In this eclipse there is total eclipse i.e. total darkness on the earth and partial eclipse where there is little light on earth

ILLUSTRATION



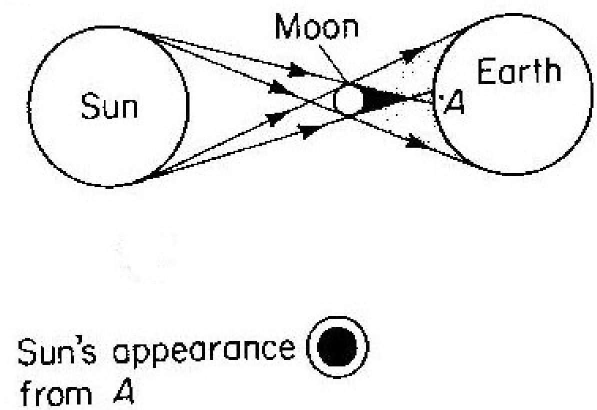
Region **c** represent total eclipse i.e. no light from the sun reaches the earth and the sun is not visible.

Regions **b** and **d** represent partial eclipse i.e. some light reaches the earth and part of the sun is visible There is partial darkness

In Regions **a** and **e** no eclipse occurs

A NNULAR ECLIPSE

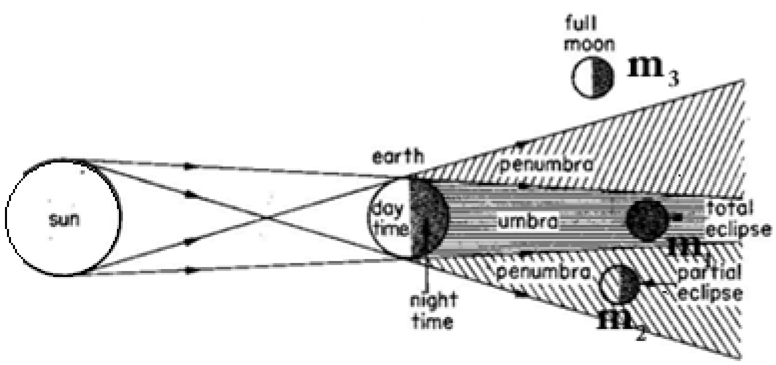
This is a solar eclipse when the shadow of the moon fails to reach the earth. The sun appears as an annulus.



LUNAR ECLIPSE (ECLIPSE OF THE MOON)

This occurs when the earth is between the sun and the moon. It takes place at night, as the moon revolves about the earth, along its orbit. If m_1, m_2 and m_3 are different positions of the moon, then during lunar eclipse, no eclipse occurs in position m_3, i.e moon is fully visible. In position m_2 partial eclipse occurs. i.e. only part of the moon is visible.

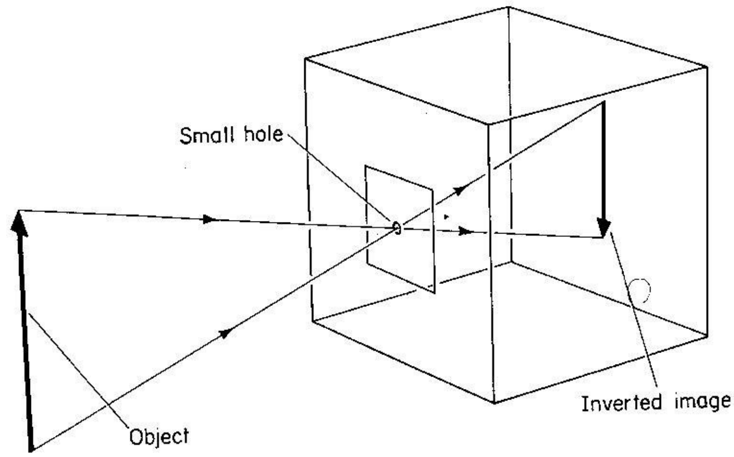
But the moon is visible with a copper like colour due to some light refracted by the earth at position m_1



THE PIN – HOLE CAMERA

This is a box or tin with a black and roughened internal surface and a screen opposite the face with a small hole. It works on the principle of rectilinear propagation of light.

N.B: the internal surface is made black by painting it and roughened so as to prevent reflection of stray light in box.



Light from object enters the pinhole camera through a small hole forming an inverted image.

Nature of the image formed in the pin-hole camera

1. It is real
2. It is inverted

FACTORS AFFECTING THE SIZE OF THE IMAGE

i) Distance between the object and the hole or camera

The image size increases as the distance from the pinhole decreases

ii) Distance between the hole and screen

The image size increases i.e. magnified as the distance increases or the image size diminishes as the distance decreases.

EFFECTS OF SEVERAL HOLES OR ENLARGING THE PINHOLE

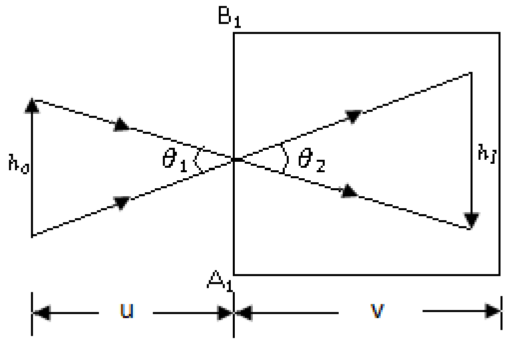
The image becomes blurred (not sharp) and brighter because more light is admitted into the pinhole camera. It has no effect on the size of the image

MAGINIFICATION

This is the ratio of image size to object size

M = =

Note



For $_1 = _2$ (vertically opposite)

By Proportionality

= = m

Where V – Image distance from pinhole to screen

Object distance from pinhole to object

Example

An object 2cm high forms an image on a screen of the pinhole camera. If the distance between the object and screen is 24cm and the distance between the object and the pinhole is 6cm find

i) The magnification of the image

ii) The size of the image.

i) h_I = 2cm , u = 6cm v = 24cm

Magnification M = = = 4

ii) M = = 4 = = h_1 = (4 x2) = 8 cm

REFLECTION OF LIGHT

It is the bouncing of light from a shiny surface

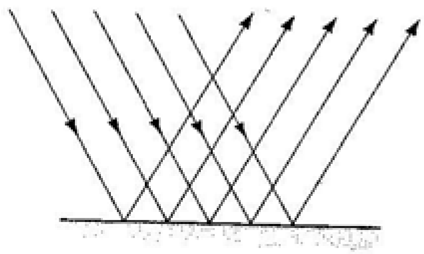
TYPES OF REFLECTION

There are two types of reflection

i) Regular reflection

ii) Diffuse / irregular reflection

Regular reflection



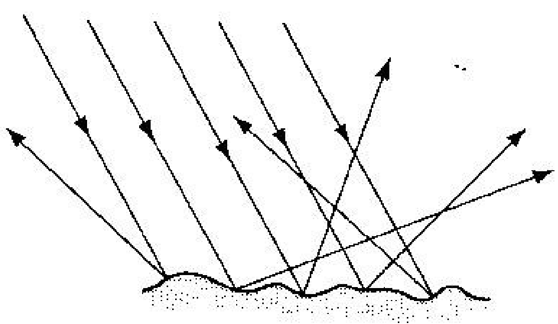
Regular reflection

Regular reflection is the type of reflection in which a parallel beam of light is incident on a smooth surface is reflected as a parallel beam

The angles of incidence are equal to the angles of reflection

Diffuse reflection

This is a type of reflection in which a parallel beam of light incident on a rough surface is reflected as a scattered beam. Angles of incidence and reflection keep varying with the points of incidence

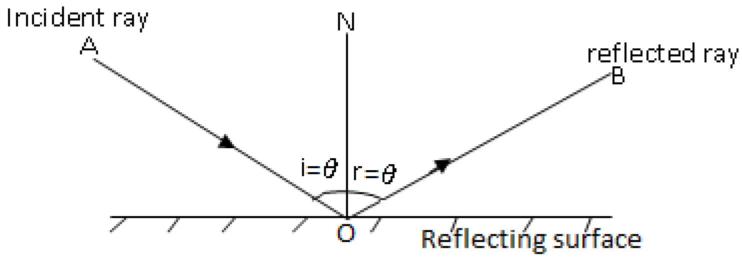


Diffuse reflection

Application of diffuse reflection

- Ability to see many objects at the same time
- Ability to read a book

TERMS USED IN REFLCTION OF LIGHT



i) Point O (point of incidence)

This is the point on the reflecting surface where the incident ray is directed

ii) Normal (ON)

This is a line drawn from point O and perpendicular to the reflecting surface

iii) Incident ray (AO)

This is the path along which light is directed on to the reflecting surface

iv) Angle of incidence (i)

This is the angle that the incident ray makes with the normal at the point of incidence

v) Reflected ray (OB)

Is the path along which light incident on a surface is reflected

vi) Angle of reflection Ɵ

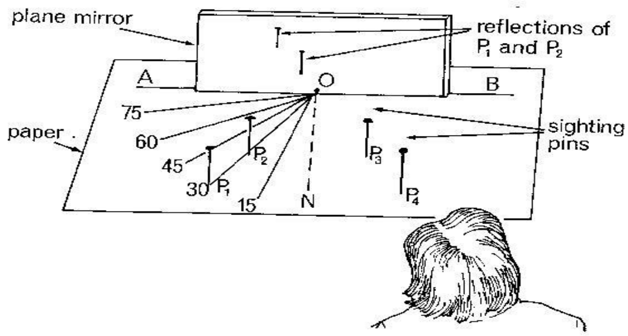
This is an angle between the reflected ray and the normal at the point of incidence

LAW OF REFLECTION OF LIGHT

There are two laws

1. The incident ray, the normal and reflected ray at the point of incidence all lie in the plane.
2. The angle of incidence is equal to the angle of reflection

EXPERIMENT TO VERIFY LAWS OF REFLECTION



Draw lines AB and ON perpendicular to each other on white sheet of paper

Measure angle I = 30^0 and draw line IO

Put the white piece of paper on the soft board. Fix pins p_1 and p_2 vertically

Insert a plain mirror along AB with the reflecting surface facing you.

Looking through the plain mirror in the opposite side, fix pins p_3 and p_4 such that they appear to be in line with images of p_1 and p_2.

Measure angle i and r using a protractor

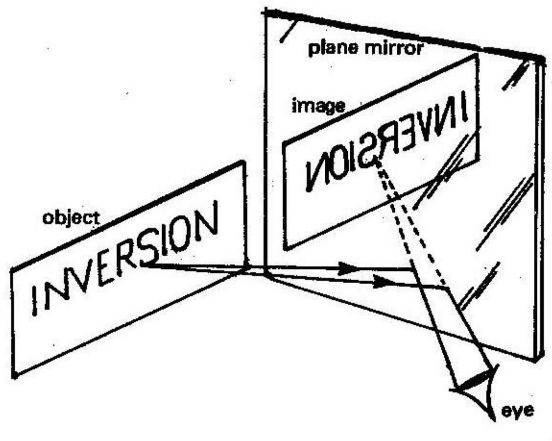
The procedure above are repeated for angle of incidence 45^0 and 40^0

It is observed that angle of incidence i is equal to angle of reflection and since IO, ON and OR are drawn on the same sheet of paper

The laws of reflection

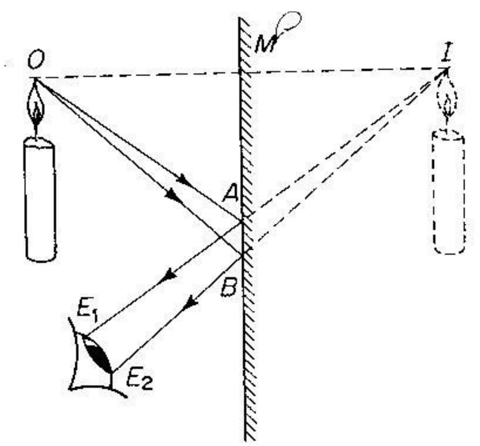
NATURE OF IMAGE FORMED BY A PLANE MIRROR

- The image formed is of the same size as the object
- The image distance from the mirror is equal to the object distance from the mirror
- The image is laterally inverted



- It is virtual i.e. can't be formed on the screen

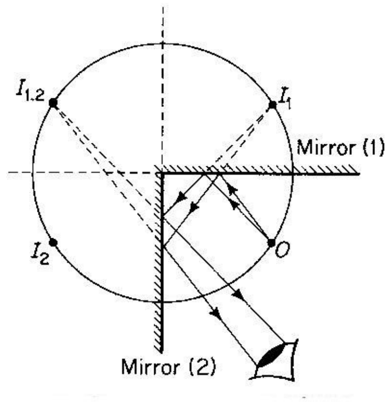
IMAGE FORMATION IN A PLANE MIRROR



Note: the line joining any point on the object to its corresponding point on the image cuts the mirror at 90^0

Distance OM = distance MI

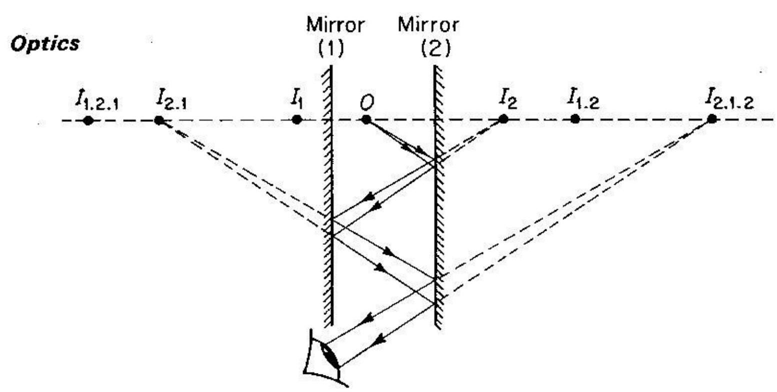
Images formed in two plane mirrors inclined at 90^0



When two mirrors are inclined at 90^0 to each other, images are formed by a single reflection in addition to two extra images formed by 2 reflections

Image formed in parallel mirrors

An infinite number of image is formed when an object placed between two parallel mirrors. Each image seen in one mirror will act as virtual object to the next mirror



The object O gives rise to image I_1 in mirror m_1 and I_2 on m_2 .I_1 acts as virtual object to give an image $I_{(1,2)}$ in mirror m_2 just as I_2 gives an image $I_{(2,1)}$ in mirror $m_{2.}$ $I_{(1,2)}$ in mirror m_2 gives $I_{(1,2,1)}$ after reflection in m_1 while I $_{(2,1,2)}$ after reflecting in Mirror $m_{2.}$

Image formed by an inclined mirror at an angle θ

The table below summarizes how one can obtain the number of image formed by 2 mirrors inclined at an angle

Angle between mirrors θ (°C)		**n = 1**
90	4	3
60	6	6
45	8	7
30	12	11
15	24	23

Where n = number of images formed

When two mirrors are parallel, the angle θ between them is zero and the number of images formed between them is

n = (1) = (1)= ∞ (infinite)

This shows infinite number of images when two plane mirrors are parallel. The image lies in a straight line through the object and perpendicular to the mirrors

Questions

1. Two plane mirrors are inclined at an angle 50^0 to one another. Find the number of images formed by these mirrors
2. Two plane mirrors are inclined at an angle θ to each other. If the number of image formed between them is 79, find the angle of inclination θ.

1. n = (1)

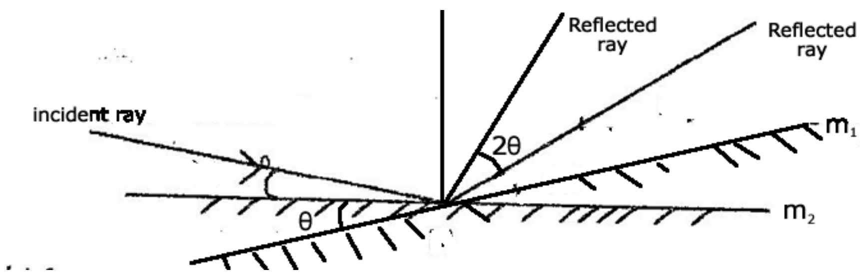
   n = ( ) = 7.2 -1= 6.2 images.

2. n =

   79 =

   θ = 4.5°

ROTATION OF REFLECTED RAY



When a mirror is rotated through any angle, the reflected ray will rotate through an angle 2θ provided the direction of the incident ray remains the same

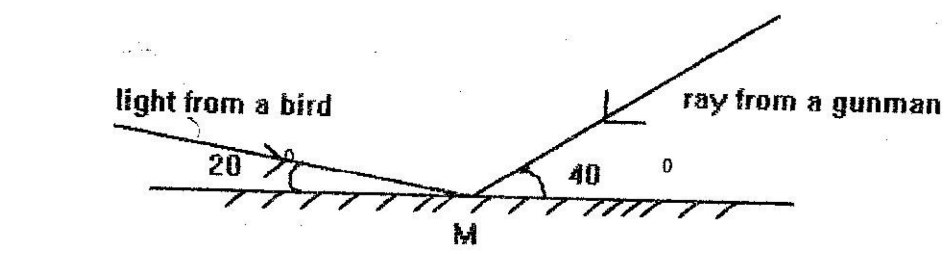
Example

The angle between the incident ray of light and a mirror is 25^0, if the mirror rotates through 20^o. Find by how many degrees do a reflected ray rotates.

Required angle = 2θ = 2 x 20 = 40^0

N.B. the angle through which the reflected ray is rotated does not depend on the angle of incidence but depends on the angle of rotation of the reflecting surface.

Questions



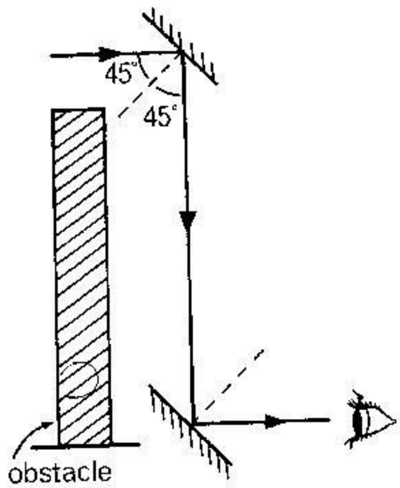
An incident ray makes an angle of 20^0 with the plane mirror in position m_1 as shown in the diagram

a) What will the angle of reflection be if the mirror is rotated through 6^0 to position m_2 while direction of incident ray remains the same?
b) An object is placed 6cm from a plane mirror. If the object is moved further, find the distance between the object and its image

Application of reflections

- Periscope

This is the instrument used for looking over top obstacles. It is made of 2 plane mirrors inclined at each other at 45^0. It is mainly used in submarines.



- Used in pointers to prevent errors due to parallax.
- Used in optical lever instruments to magnify angle of rotation.
- Used in kaleidoscope
- Used in small shops and supermarkets, takeaway and saloons to give a false magnification as a result of multiple reflections

REFLECTION BY CURVED MIRRORS

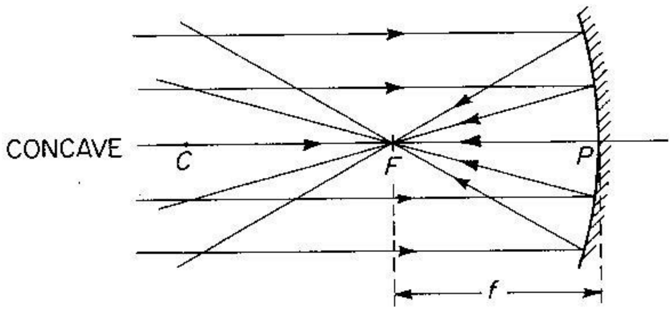
For some purposes, curved mirrors are more useful than plane mirrors. There are two types of curved mirrors

i) Concave / converging mirror (curve inwards)

ii) Convex /diverging mirror (curve outwards)

CONCAVE MIRRORS

A concave mirror converges parallel rays to a point called principal focus



P- Pole of mirror

F- Principal focus

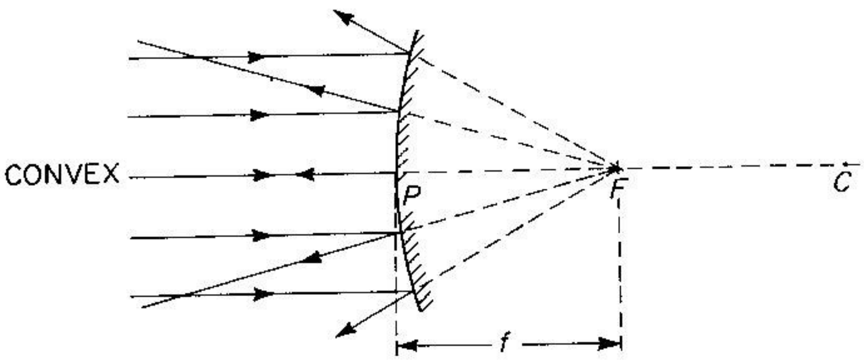
C- Center of curvature

r- Radius of curvature

f- Focal length

CONVEX MIRRORS

A convex mirror diverges (spreads out) parallel rays so that they never meet but appear to come from a point called virtual focal point



Terms used

- **The point (P):** the point P is the center of reflecting surface
- **Center of curvature(C):** it is the center of sphere of which the mirror is part
- **Principal axis:** is the line joining the pole of the curved mirror to the center of curvature
- **Radius of curvature:** this is the radius the of sphere of which the mirror is part
  OR: it is the distance between the pole of the mirror and its center curvature

- **Focal length (f):** this is the distance from the pole of the mirror to the principal focus i.e. (r = 2f or f = r/2)
- **Principal focus / focal point(f):**
  a) *For a concave mirror.*

     Focal point is a point on the principal axis through which all rays parallel and close to the principal axis converge after reflection

  b) *For a convex mirror.*

     Principal focus is a point on the principal axis from which all rays parallel and close to the principal axis appear to diverge from after reflection

     Note: F is real for a concave mirror and virtual for a convex mirror. It is mid way between c and p.
- **Aperture:** this is the width of the mirror

a) **Real image:** is one which can be formed on the screen? It is formed by actual intersection of rays

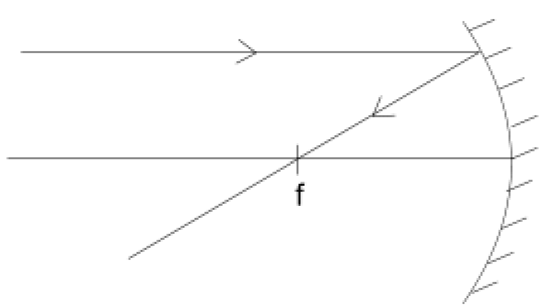
b) **Virtual image**: it is one which cannot be formed on the screen. It is formed by apparent intersection of rays.

CONSTRUCTION OF RAY DIAGRAMS

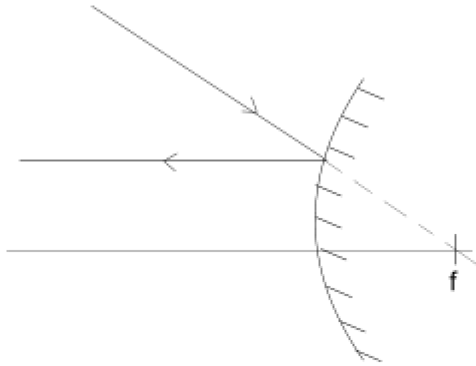
Ray diagrams can be used to explain how and where a curved mirror forms images. The rays are drawn using any two of the following 3 principal.

1. A ray parallel to the principal axis is reflected through the principal focus

   a) For a concave mirror

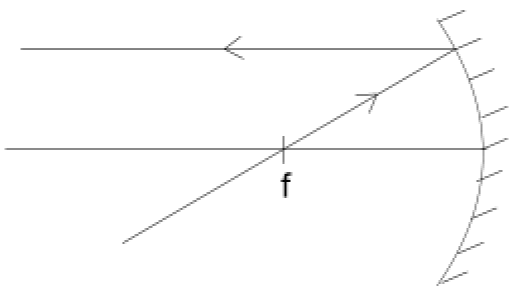


   b) For a convex mirror

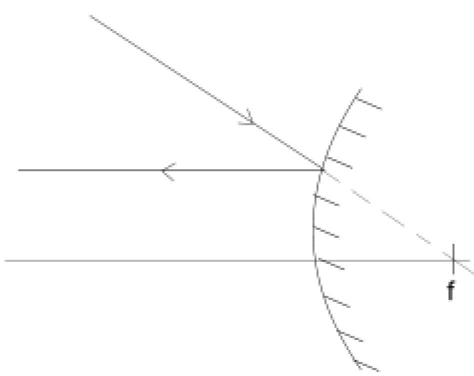


2. A ray through the principal focus is reflected parallel to the principal axis

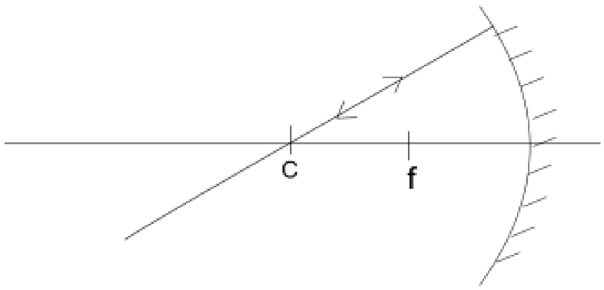
a) For a concave mirror



b) For a convex mirror



3. A ray through the center of curvature is reflected along the same path
   a) For a concave mirror



b) For a convex mirror

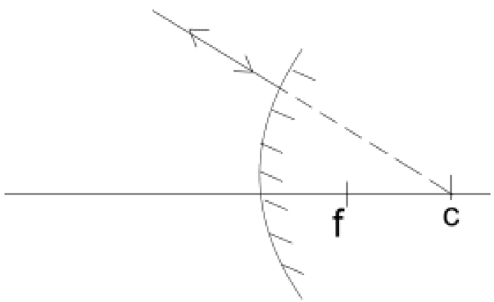
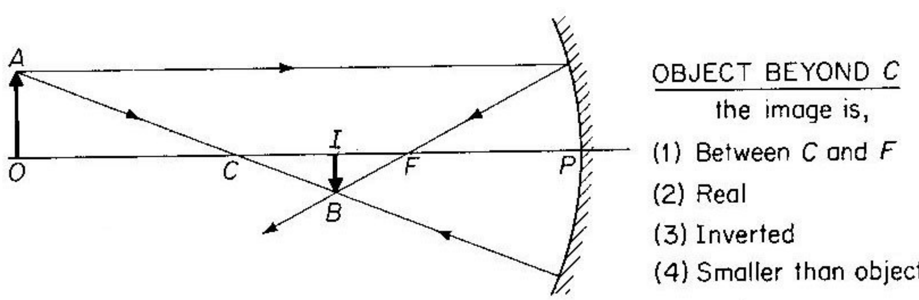


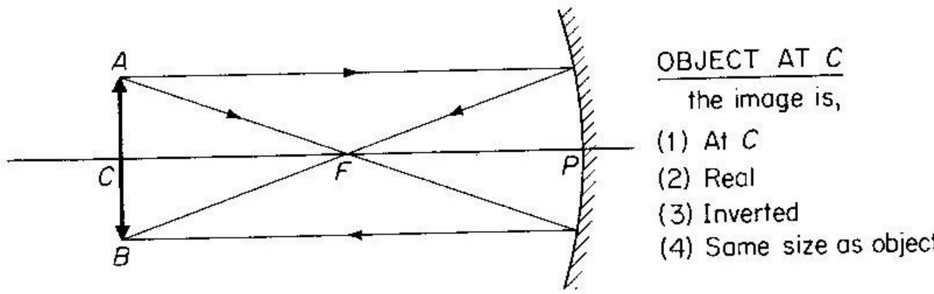
Image formation by concave mirror

The type, size and position of the image formed by a concave mirror depends centrally on the distance of the object from the mirror

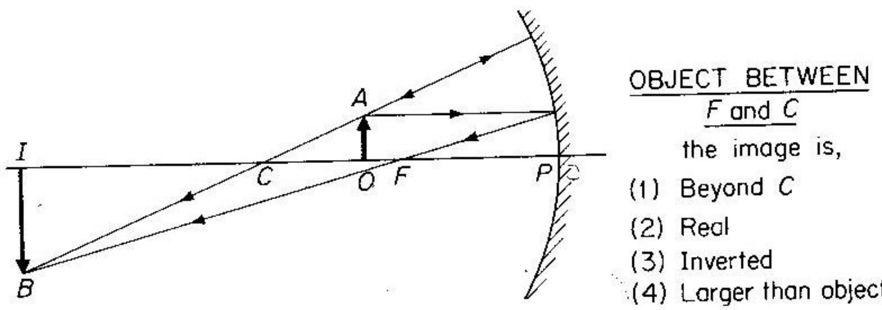
1. Object O beyond C



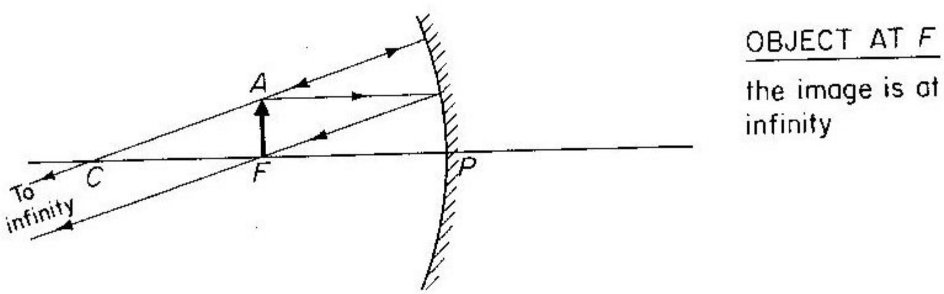
2. Objects O at C



3. Object O between C and F



4. Object O at F



5. Object O between F and P

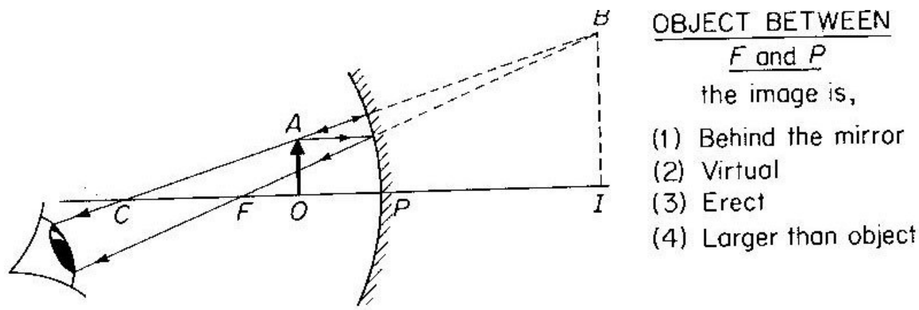


Image formation by convex mirror

No matter the position of the object from the convex mirror, the image formed is always virtual, diminished and upright.

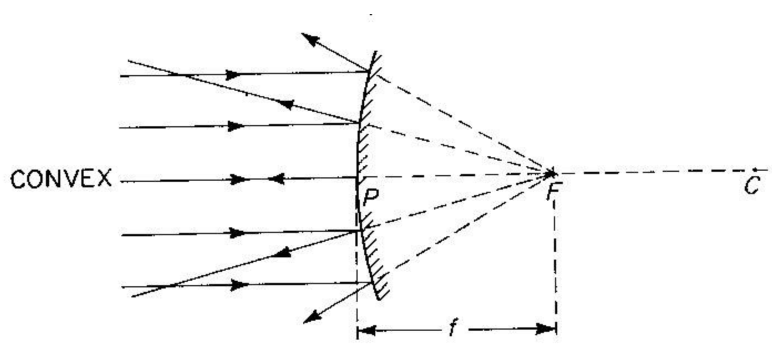


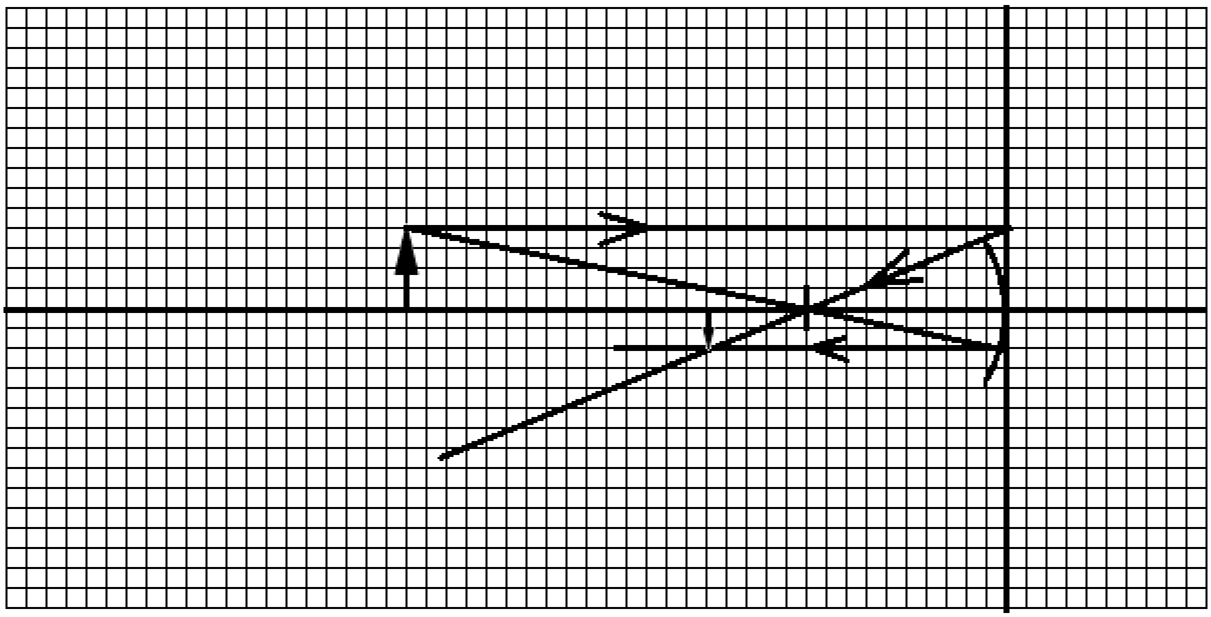
Image formed is virtual, diminished, upright (erect) and formed between F and P

Construction of ray diagrams to scale.

Example

An object 4cm high is placed 30cm from a concave mirror of focal length 10cm. by construction, find the position, nature and size of the image (scale, 1:5)

Graph



Questions

1. An object 4cm high is placed 2.4cm from concave mirror of focal length 8cm. draw a ray diagram to find the position size and nature of image. Scale 1cm = 2cm
2. An object of height 10cm is placed at a distance 60cm from a convex mirror of focal length 20cm. By scale find the image position, height, nature and magnification (scale 1cm: 5cm)

MAGNIFICATION

This is the ratio of image height to the object height

M = where h_I – image height, h_o – object height

OR

This is the ratio of image distance from distance from the mirror to the object distance from the mirror

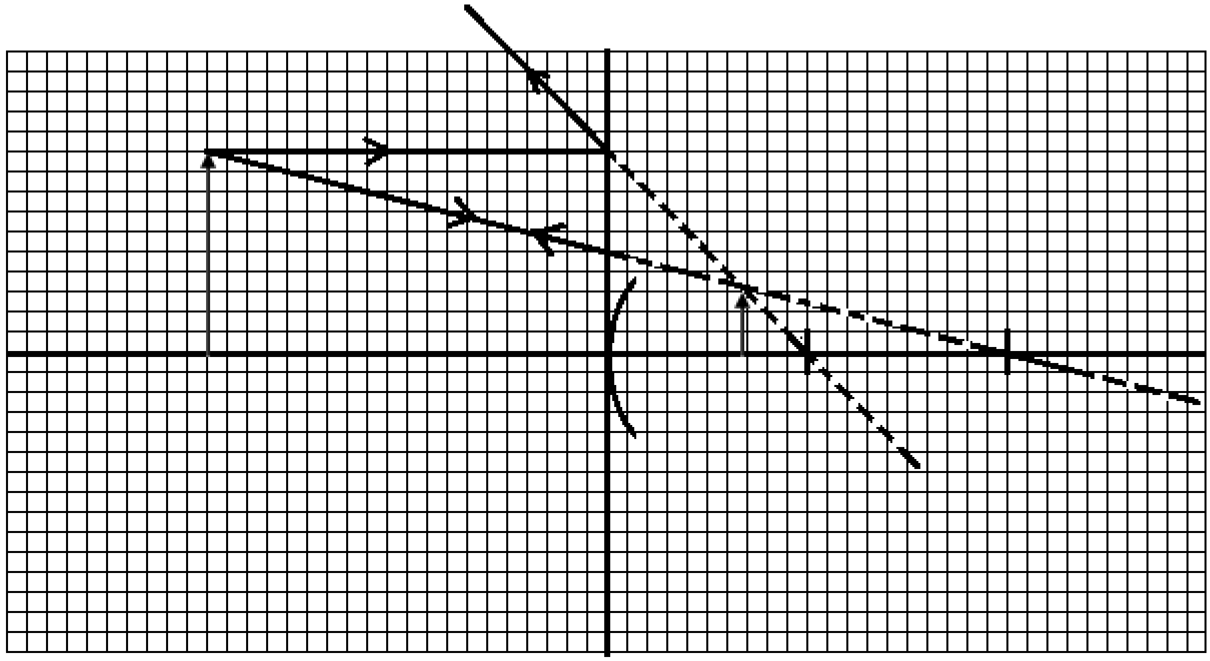
M= where v – image distance, u – object distance

Example 1

An object 10cm high is placed at distance of 20cm from a convex mirror of focal length 10cm

i) Draw a ray diagram, locate the position of the image

ii) Calculate the magnification (1cm :5cm)



M = =

USES OF CURVED MIRRORS

a) Convex mirrors

They are used as driving mirrors because

i) They give a wide field of view

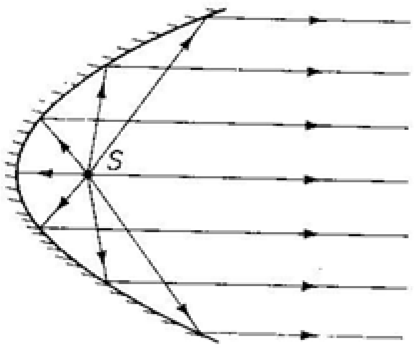
ii) They give upright images of the object

Disadvantages

- It gives a false impression of the distance of an object
- The object is diminished.

b) Concave mirror

- Used in head lamps , torches , parabolic mirrors



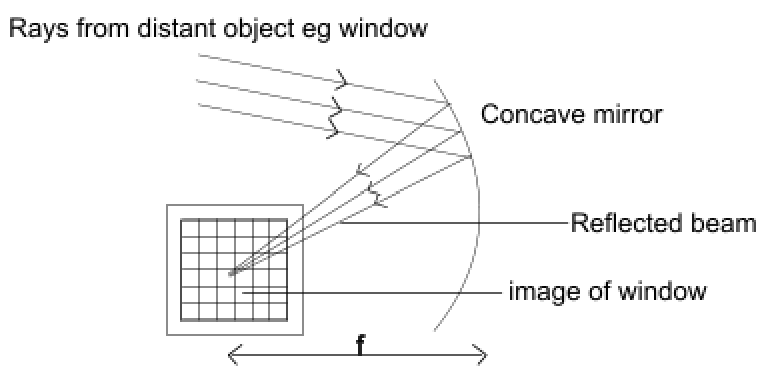
- It can be used as shaving mirror
- Used by dentists for magnification
- Can be used in astronomical telescope (reflecting type)
- Can be used as solar concentrators

MEASURING FOCAL LENGTH OF A CONCAVE MIRROR

METHOD 1:

Distant object method (rough method)

- Hold a concave mirror at one end focusing t he distant object.
- Hold a white screen in front of the mirror so that it receives rays reflected from it to reach the mirror from the object.



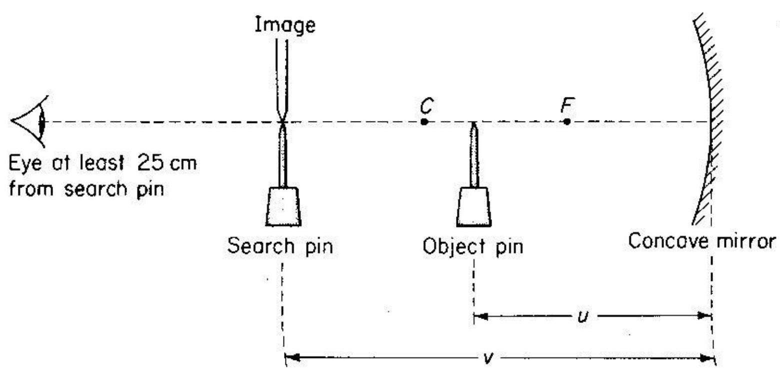
- Move the screen at different distances from the mirror until a sharp image is formed on the screen
- Measure the distance from the screen to the mirror with a metre rule.
- Repeat the experiment several times and find the average value of the distance between the screen and the mirror. This is the focal length (f) of the mirror

METHOD 2:

Using illuminated object at c

- With the mirror facing illuminated object, adjust the distance between them until a sharp image is formed on the screen alongside the object.
- Measure the distance between the object and the mirror
- Repeat the experiment for several attempts and find the average value. This is the radius of curvature so the focal length (f) is obtained from r =2f.

MIRROR FOMULA METHOD



- Two pins are required, one acts as an object pin and the other as a search pin.
- The object pin is placed in front of the mirror between F and C so that a magnified real image is formed beyond C.
- The search pin is then placed so that there is no parallax between it and the real image as shown in figure above
- The distance of the object pin from the mirror, u and that of the search pin, v is measured
- Several pairs of object and image distances are obtained in this way and the results recorded in a suitable table including , , and
- A mean value for focal length f is obtained from the mirror formula

f =

Sign convention

All distances are measured from the pole of the mirror

Distances of real objects and images are positive

Distance of virtual objects and images are negative

A concave mirror has a real focus therefore focal length is positive

A convex mirror has a virtual focus therefore focal length is negative

Examples

1. Calculate the focal length of a concave mirror from the following results
    a) Object distance u = 30cm
       Image distance v = 20cm

    b) Object distance u = 8cm
       Image distance v = 24cm

    Solution (a)

    Using = +

    = + = =

    f = 12cm

    Solution to (b)

    = + = + f = 6cm

2. Find the image distance when an object is placed
    a) 12cm from the concave mirror of focal length 8cm
    b) 10cm from a convex mirror of focal length 10cm.

Solution (a)

For concave = + = = +

v = 24cm

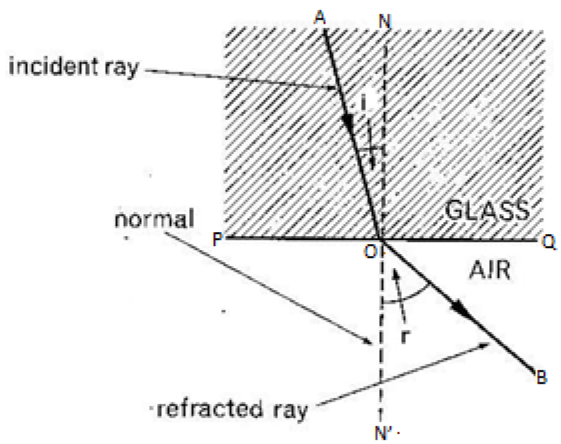
Solution to (b)

For convex = + = = +

$V = -5cm$

REFRACTION

This is the bending of light rays when it passes from one medium to another of different optical densities



PQ – Interface

O – Point of incidence

OB – Refracted ray

AO – Incident ray

i-Angle of incidence

r- Angle of refraction

NN' – Normal

Refraction can also be defined as the change in speed of light when it moves from one medium to another of different optical densities

N.B

When a ray of light enters an optically denser medium, it is bent towards the normal and when it enters a less dense medium it is bent away from the normal

LAWS OF REFRACTION OF LIGHT

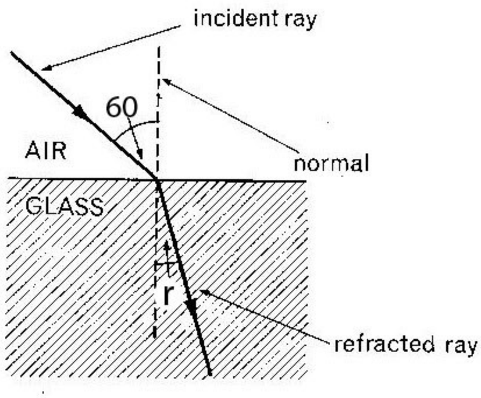
1. The incident ray, the refracted ray and the normal at the point of incidence all lie in the same plane
2. The ratio sine of angle of incidence to the sine of angle of refraction is constant for any given pair of media (Snell's law)
   i.e. = = constant (n) where n – refractive index of the medium containing the refracted ray

Refractive index

It is the ratio of sine of angle of incidence to the sine of angle of refraction for a ray of light moving from one medium to another of different optical densities

Example

1. A glass material has a refractive index n= 1.5. Find the angle of refraction, if the ray of light moves from air to glass as shown below



Refractive index n =

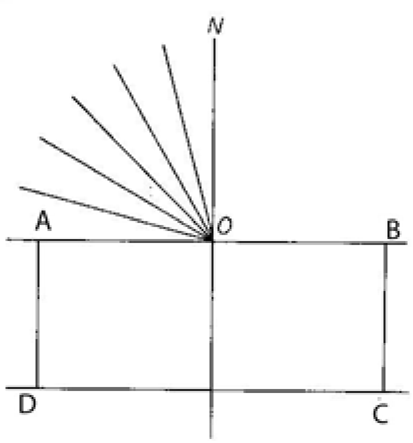
1.50 =

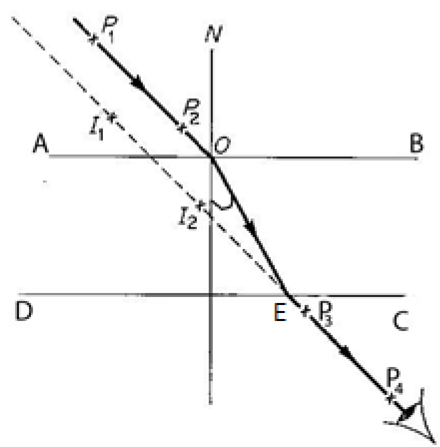
Sin r =

r = $\sin^{-1}$[=

EXPERIMENT TO VERIFY SNELL'S LAW

A glass block is placed on a white sheet of paper and its outline ABCD drawn as shown below





The glass block is then removed

Using a protractor, the normal is drawn at a point to O along AB and an angle of incidence I = 10^0 measured.

Pins P_1 and P_2 are fixed on the line making an angle of I to the normal and the glass block replaced on its outline ABCD

While looking through side CD, two other pins p_3 and p_4 are fixed so as to appear in line with images of p_1 and p_2.

The glass block, pins p_3 and p_4 are removed and a line drawn through points where p_3 and p_4 were fixed. This line is called the emergent ray. It is drawn through O to meet CD at E

Point O is joined to E. The line is called the refracted ray.

The angle of refraction r is measured.

The experiment is repeated using other angles of incident 20^0, 30^0, 40^0, and 50^0.

The values of i, r, sini and sinr are tabulated as shown.

$i(^0)$	$r(^0)$	Sin i	Sin r
10			
20			
30			
40			
50			

A graph of sin i against sin r is plotted.

A straight line graph through the origin verifies Snell's law

NB: The slope of the graph gives the refractive index of the glass

Slope n =

Absolute refractive index

This is the ratio of sine of angle of incidence to the sine of angle of refraction for a ray of light moving from air (vacuum) to another medium of different optical density.

n =   the angle incident i should be in air or vacuum.

REFRACTION ON PLANE PARALLEL BOUNDARIES

The refractive index n of the medium is denoted by $_1n_2$ for a ray of light moving from medium 1 to medium 2.The refractive index of a ray of light moving from glass to water is written as gw = where n_g and n_w are absolute refractive indices of glass and water respectively. So $_1n_2$ = =

$n_1 \sin i = n_2 \sin r$

Principal of reversibility of light

It states that when the direction of ray of light is reversed, it follows exactly the same path as before.

a∩g .....(i)

g∩a = ... (ii)

a∩g = or g∩a =

Question

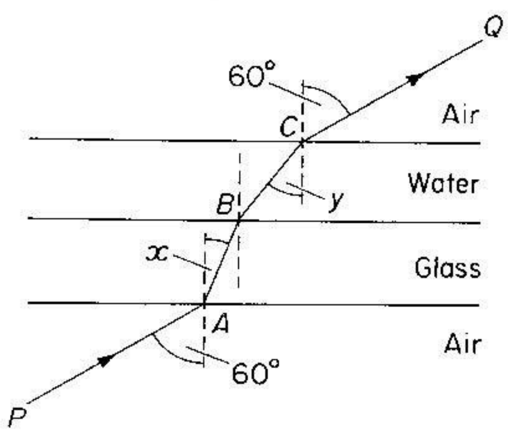


Figure above shows a glass slab of uniform thickness, lying horizontally. Above it is a layer of water. A ray of light PQ is incident upwards on a lower surface of the glass and is refracted successively at A, B and C, the points where it crosses the interfaces. Calculate

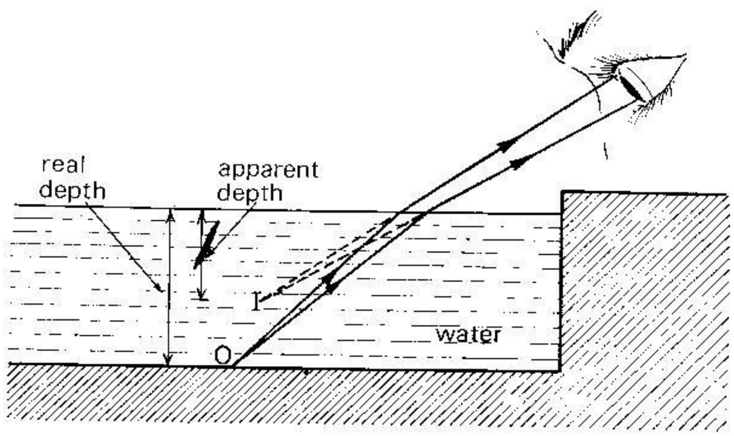
i. Angle x
ii. Angle y

iii. The refractive index for light passing from the water to glass. (Refractive indices of glass and water are 3/2 and 4/3 respectively)

EFFECTS OF REFRACTION ON PLANE SURFACES

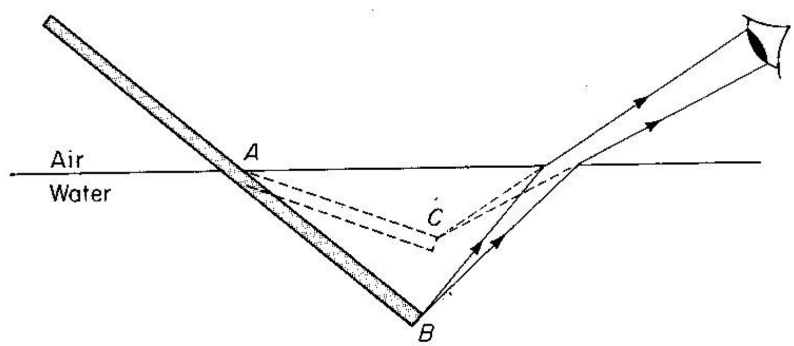
Refraction on plane surface causes

- A partially immersed stick in water at an angle to appear bent at the boundary between air and water.
- A stick placed upright in water appears shorter
- A swimming pool or well or pond appears shallower than its actual size



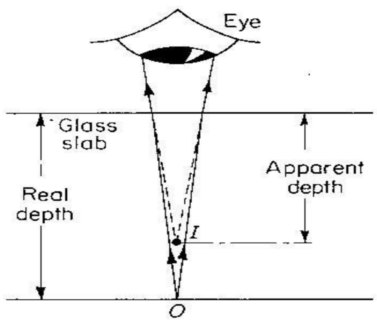
- An object placed under the glass block appears nearer

Explanation of the effects of refraction



Rays of light from point B on the stick move from water to air i.e. from a dense medium to a less dense medium. On reaching the surface of water, they are bent away from the normal. On entering the eye of the observer, rays appear to come from point C which is the image of B on the object.

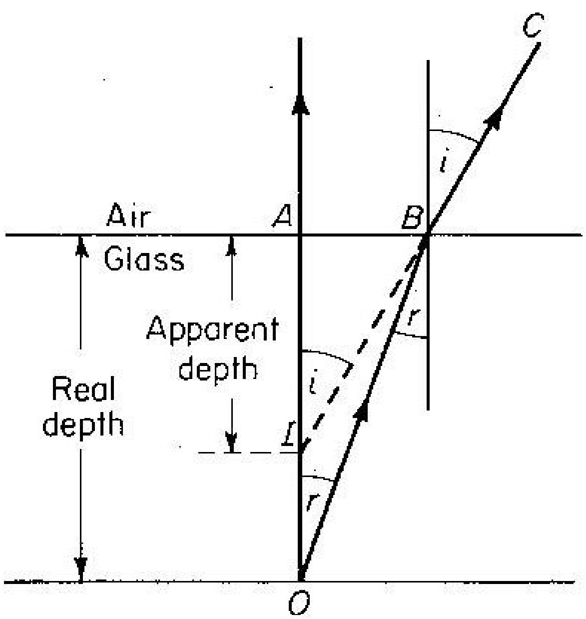
REAL AND APPARENT DEPTH



An object O placed below a water surface appears to be nearer to the top when viewed from above. The depth corresponding to apparent depth

The actual depth of an object, below the liquid surface is called the real depth.

Relationship between real apparent depth and refractive index



Refractive index n =

Using the principal of reversibility of light sin i = , sin r =

n=

= X n=

If B is close to A, BO =AO and BI = AI

n = but AO is the real depth

AI is the apparent depth

Hence n =

Examples

1. A swimming pool appears to be only 1.5m deep. If the refractive index of water is $^4/_3$ calculate the real depth of water in the pool.

   n =

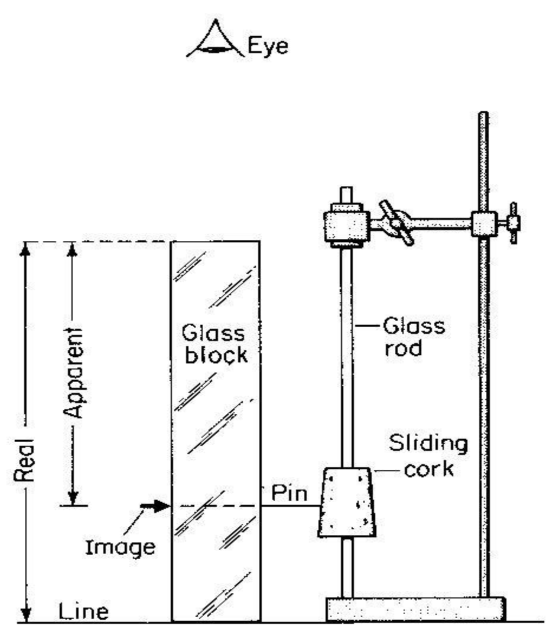
   $^4/_3$ = → r = = 2.0m

2. A coin is placed at the bottom of the beaker which contains water at a depth of 8cm. how much does the coin viewed from above appears to be raised (take n to be $^4/_3$)

Question

1. A pin at the bottom of the beaker containing a transparent liquid at a depth of 24cm is apparently displaced by 6cm. Calculate the refractive index of the liquid.

Determination of refractive index by real and apparent depth method



A glass block placed vertically over a cross (x) drawn on a white sheet of paper as shown above

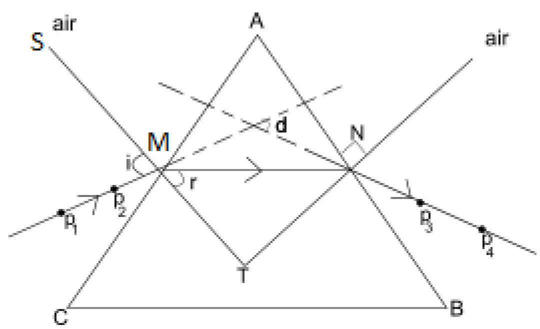
A pin is clamped on a sliding cork adjacent the block, it is moved up and down until there is no parallax between it and the image of the cross (x) seen through the block.

The real depth and apparent depths are measured and the refractive index is then calculated from

n =

Determination of refractive index using a triangular prism

A prism is placed on a white sheet of paper and its outline drawn as shown below



Two object pins $p_1$and p_2 are fixed upright on side AC and while looking through the prism from side AB, two other pins p_3 and p_4 are fixed such that they appear to be in line with images of P_1 and P_2

The prism is removed and a line drawn through P_1 and P_2 and another drawn through P_3 and P_4.

Points M and N are joined by a straight line and normal ST drawn at a point M as shown

Angle i and r are measured

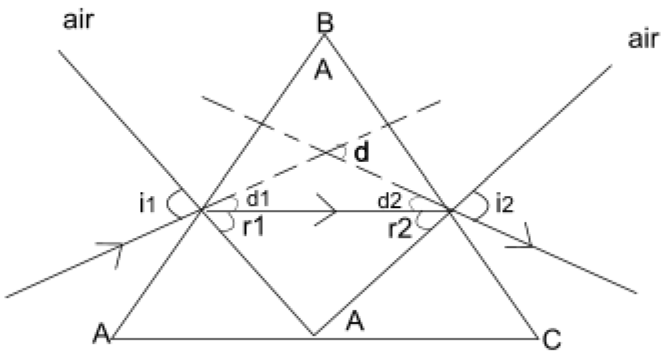
The procedure is repeated to obtain different values of i and r and the results tabulated as shown

i(°)	r(°)	Sin i	Sin r
	-	-	-
	-	-	-
	-	-	-

A graph of sin i against sin r is plotted. The slope of the graph is the refractive index of the prism

DEVIATION THROUGH PRISMS

A monochromatic light incident on a prism changes its direction (deviates) as it enters the prism as shown



Deviation on face AB, $d_1 = i_1 - r_1$

Deviation on BC, $d_2 = i_2 - r_2$

Total deviation $d = d_1 + d_2 = i_1 - r_1 + (i_2 - r_2)$

$$= (i, +i_2) - (r_1 + r_2)$$

But $A = r_1 + r_2$

Hence deviation $d = (i_1 + i_2) + A$

EXAMPLE 1

A prism of refractive index 1.5 and refracting angle $A = 60^0$ has an angle of refraction of 28^0 on the 1st face. Determine

a) angle of incidence i
b) angle of refraction on 2nd face r_2
c) angle of emergency i_2
d) angle of deviation d

Solutions

a) = sin i = sin r

$1 \times \sin i = 1.5 \sin 28$

$i = \sin^{-1}(1.5 \sin 28) = 44.7^0$

b) $A = r_1 + r_2$

$60 = 28 + r_2$

$r_2 = 60 - 28$

$r_2 = 32^0$

c) Applying Snell's law on face 2

sin r = sin i_2

$1.5 \sin 32 = 1 \times \sin i_2$

$i_2 = \sin^{-1}(1.5 \sin 32)$

$i_2 = 52.64^0$

d) $d = d_1 + d_2$

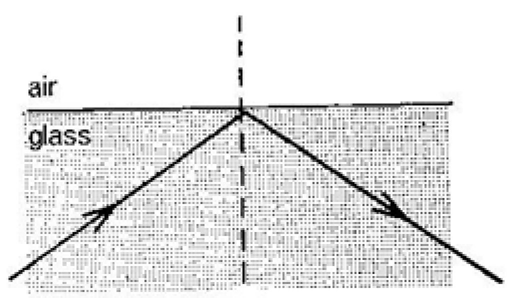
$= (i_1 + i_2) - A$

$= (44.7 + 52.64) - 60$

$= 37.34^0$

TOTAL INTERNAL REFLECTION

This is the phenomenon by which all light travelling from an optically dense medium to a less dense medium is reflected back in the dense medium, when the angle of incidence in the dense medium is greater than the critical angle.



Conditions for total internal reflection to occur

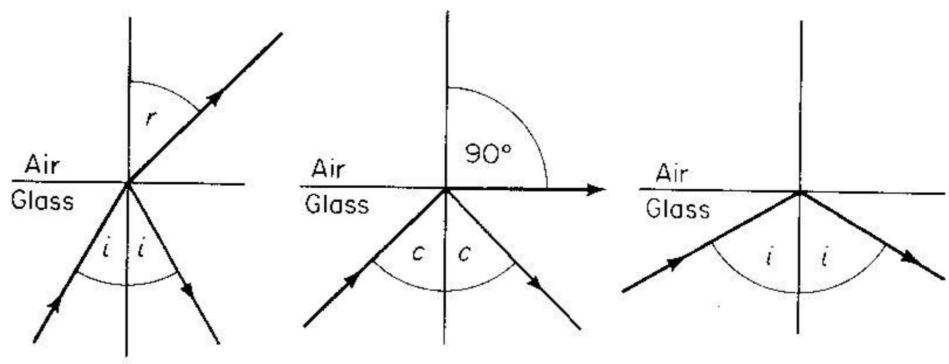
Light should travel from an optically dense medium to a less dense medium

The angle of incidence in the dense medium should be greater than the critical angle

How does total internal reflection arise?

Consider a ray of light in the dense medium for which the angle of incidence is less than the critical angle

The ray produces a weak reflected ray and a strong refracted ray as shown in (a)



(a) Refraction and internal reflection $i < c$ (b) Critical internal reflection $i = c$ (c) Total internal reflection $i > c$

When the angle of incidence is increased to a critical angle, the angle of refraction is 90^0 (fig. b.)

Critical angle c: this is the angle of incidence in a more optically dense medium for which the angle of refraction is 90^0

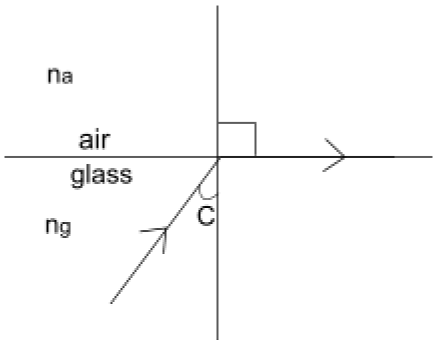
When the angle of incidence is increased beyond the critical angle, total internal reflection occurs as shown below in (c)

Relationship between Refractive index and critical angle

Applying Snell's law at the interface

$n_g \sin c = n_a \sin 90 = 1$

$n_g =$



Example:

1. Find the critical angle of a medium of reflective index 1.5

   Sin c =   c = sin^{-1}( ) = sin^{-1}(= 41.8^0

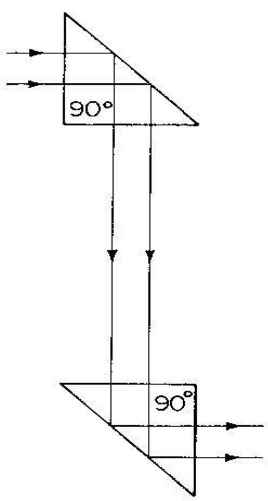
APPLICATION OF TOTAL INTERNAL REFLECTION

In refracting prisms which are in binoculars, periscopes and cameras

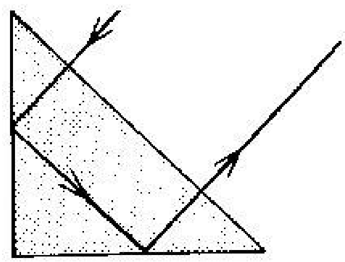
Examples

1. Turning a ray through 90^0

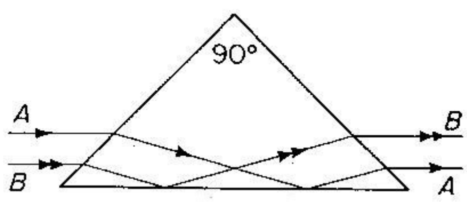
Prism periscope



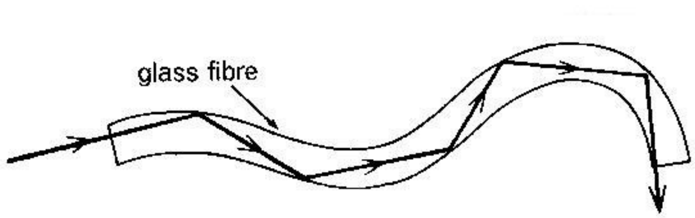
2. Turning a ray through 180^0



3. Turning a ray through 360^0



Optical light pipes



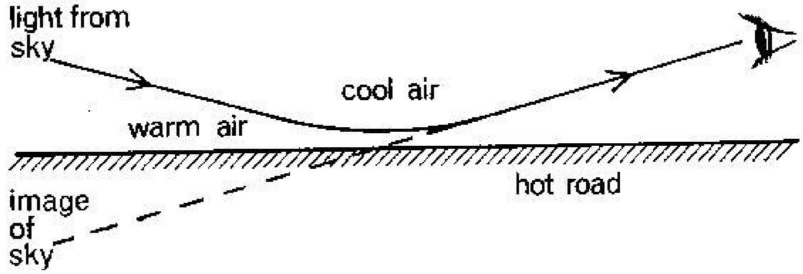
The inner surface has slightly higher refractive index than the outer surface making it slightly denser medium. Light can be trapped by total internal reflection inside a bent glass rod and piped along a curved path as shown above

Optical fibres can be used by doctors and engineers to light up some awkward spot for inspection Modern telephone cables are optical fibres using laser light

EFFECTS OF TOTAL INTERNAL REFLECTION

The mirage

This can happen when the air nearer the surface of the ground is less dense than that above. Cool air is dense than warm air.

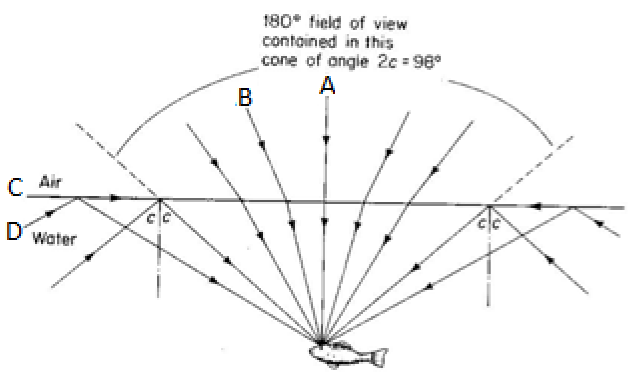


Light from the sky is gradually refracted away from the normal as it passes from denser layer of air to less dense layers

When light meets a layer at angles of incidences greater than the critical angle, it suffers total internal reflection.

The reflection of the sky forms an image which appears as a pool of water on the road

Fish's eye view



- A fish in water can have a wide field of view as it can see an object normally at A
- If angle i is less than the critical angle, it can see an object B by refraction.
- It can also see an object at the bank C of lake if the angle of incidence is equal to the critical angle.
- If i is greater than the critical angle an object at D can be seen by total internal reflection.

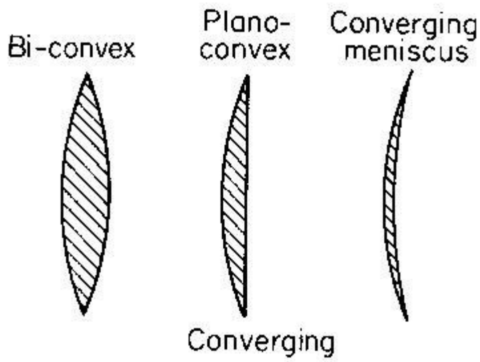
LENSES

These are two types:

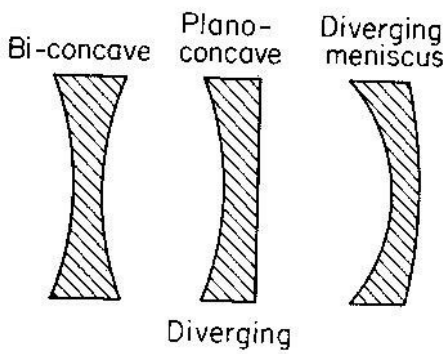
(i) Convex/converging lenses

(ii) Concave/diverging lenses

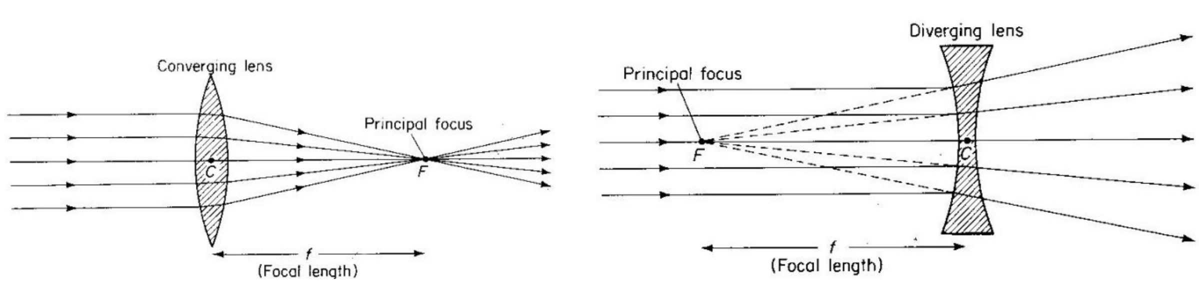
Convex lens



Concave lens



Terms used:



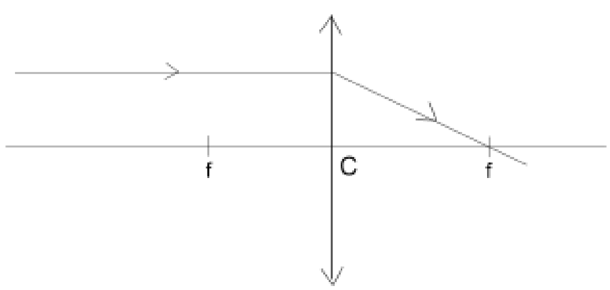
1. **Principal axis:** is a line joining the principal focus and the optical Centre

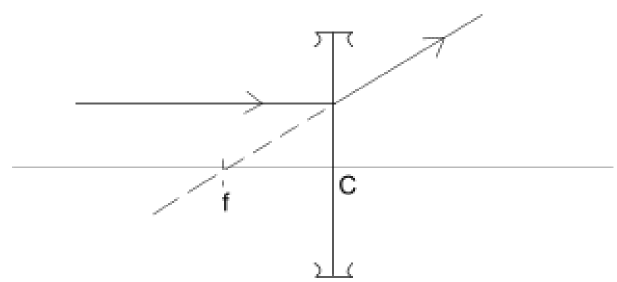
2. **Principal focus of a convex lens**: is a point on the principal axis to which all rays originally parallel and close to the principal axis converge after refraction by the lens
3. **Principal focus of a concave lens:** this is a point on the principal axis to which all rays originally parallel and close to the principal axis appear to diverge after refraction by the lens
4. **Focal length:** this is the distance between the principal focus and the optical centre
5. **Optical centre:** this is the centre of the lens at which rays pass undeviated.

CONSTRUCTION OF RAY DIAGRAM

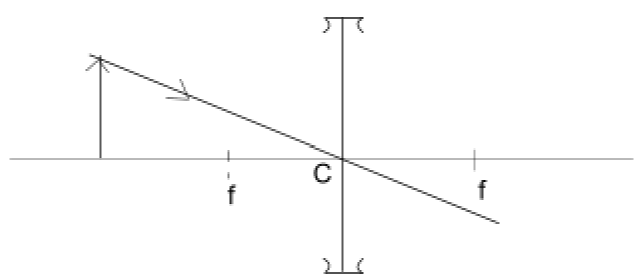
In constructing ray diagrams, 2 of the 3 principal rules are used.

1. A ray parallel to the principal axis is refracted through the focal point

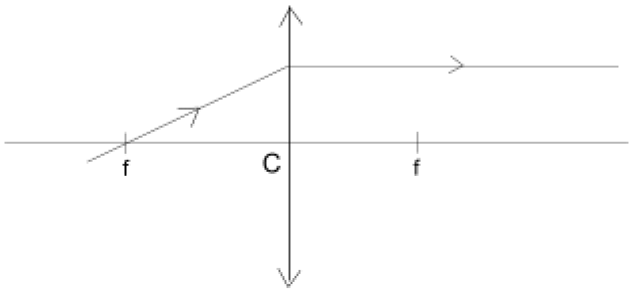




2. A ray through the optical centre passes through undeviated i.e. is not refracted



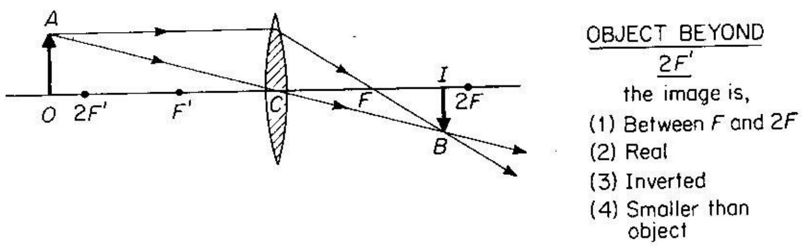
3. A ray through the principal focus emerge parallel to the principal axis after refraction



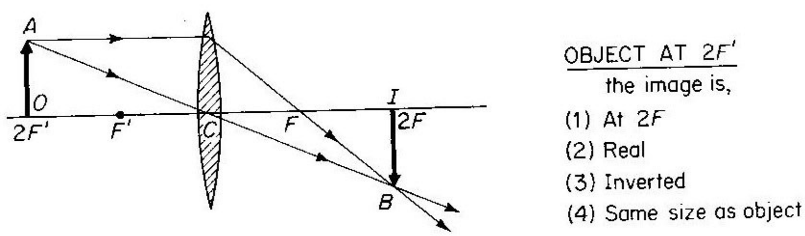
Images formed by convex lenses

The nature of the image formed in a convex lens depends on the position of the object from the lens

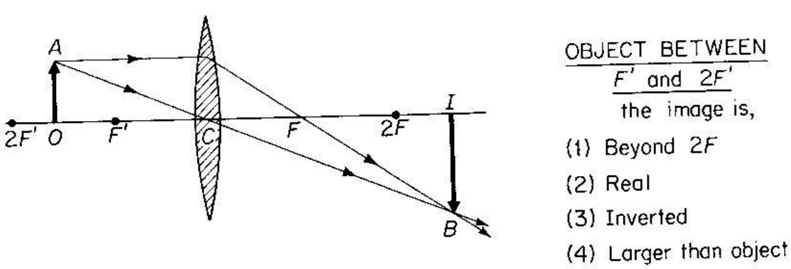
a. Object beyond 2f



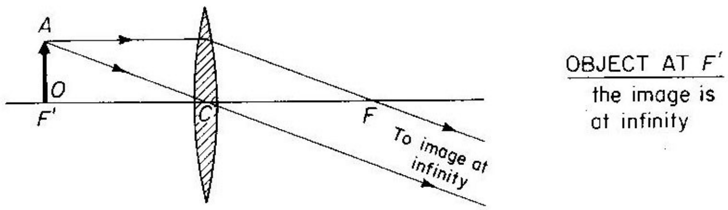
b. Object at 2f



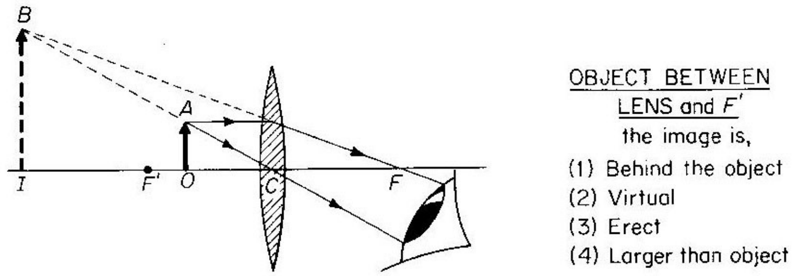
c. Object between f and 2f



d. Object at f

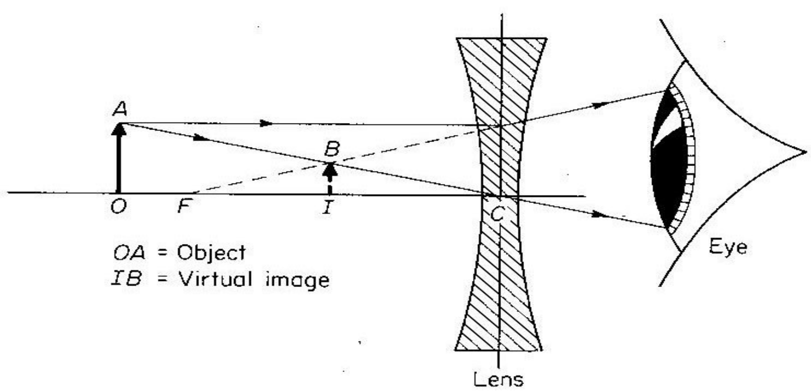


e. Object between F and C



When the object is placed between f and c, the image is magnified and this is why the convex lens is known as a magnifying glass

Image Formation in a Concave Lens



Power of a lens

It is defined as the reciprocal of focal length in metres

Power of lens = where f is focal length of the lens in metres

S.I units of power of the lens is dioptres (D)

Example

1. Calculate the power of the focal length 10cm.

P = =

= 10D

2. Find the power of the lens whose focal length is 20cm

P = =

= 50D

Magnification of the lens

It is defined as the ratio of the image height to object height

M =

OR

It is the ratio of image distance to object distance from the lens

M = where v – image distance

U – Object distance

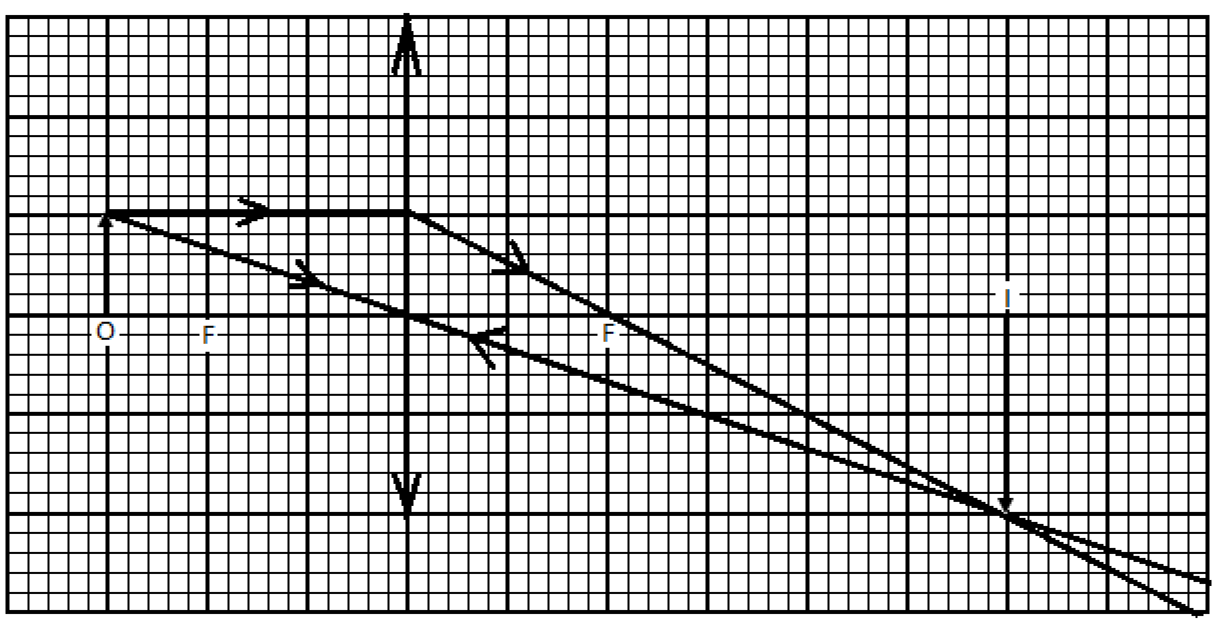
Determination of image position by graphical method

Same rules are used

A lens is represented by a line on a graph paper. Scale must be used.

Example

Object 5cm tall is placed 15cm away from a lens of focal length 10cm. By construction;



Determine the position, size and nature of the final image (use a scale 1cm: 5cm)

Question

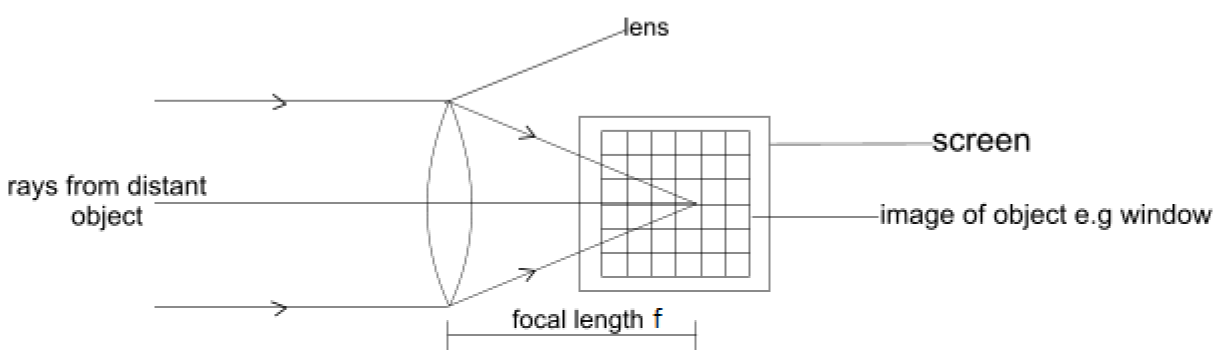
1. A simple magnifying glass of focal length 5cm forms an erect image of the object 25cm from the lens. By graphical method
   a. Find the distance between the object and image
   b. Calculate the magnification
2. An erect object 5cm high is placed at a point 25cm from a convex lens. A real image of the object is formed 25 cm high. Construct a ray diagram and use it to find the focal length of the lens
3. An object is placed at right angle to the principal axis of a thin covering lens of focal length 10cm. A real image of height 5cm is formed at 30cm from the lens. By construction, find the position and height of the object (use 1cm: 5cm)

Determination of focal lens of a convex lens

a) Method 1: Rough method

Procedure

A converging lens with a screen on one side is placed some distance from the distant object e.g. a window as shown.

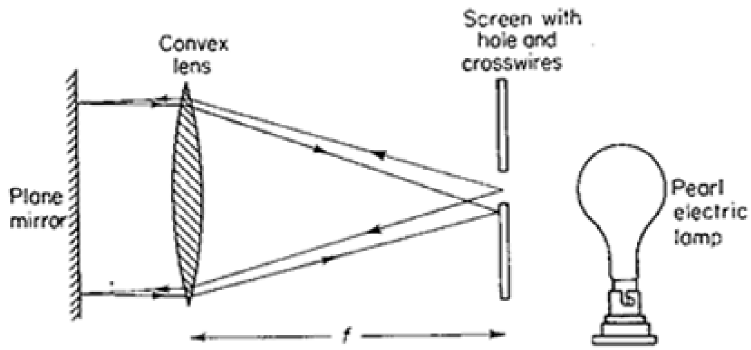


The screen is moved away or towards the lens until a clear image of the window is formed on the screen

The distance between the lens and the screen is measured and this is its focal length f

N.B – the value of f obtained by the above method is not very accurate because rays of light from the window are assumed to be parallel but may not be perfectly parallel.

b) **Determination of focal length using on illuminated object**

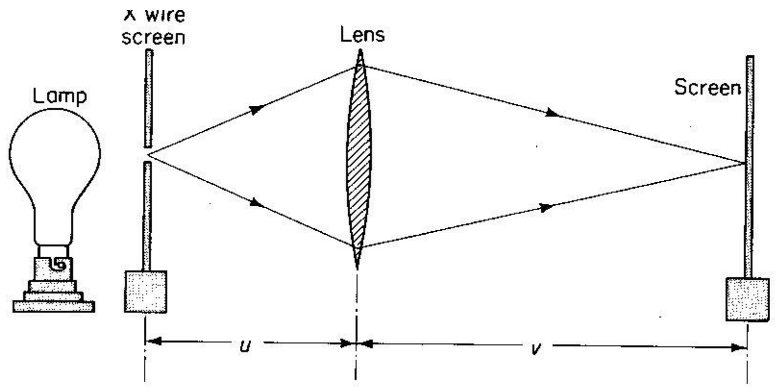


Procedure

- A lens is set up in a suitable holder with a plane mirror behind it so that light passing through the lens is reflected back as shown above
- Across wire is used as the object in a hole of a white screen. It is illuminated by the bulb
- The position of the lens is adjusted until a sharp image of the object is formed on the screen alongside the object
- The distance between the lens and the screen is measured, this gives the focal length of the lens

c) **Using lens formula method**

- The lens is set up in front of an illuminated object so that a real image is formed on a white screen placed on the opposite side.
- The lens is then adjusted so that the image is sharply in focus.
- The object distance u and image distance v from the lens is measured



- Several pairs of values of u and v are found and the results entered in a suitable table, including values of and the mean value of = + determined.
- Focal length is calculated from: f =

Application of lenses

Lenses are used in

- Lens camera
- Slide projectors
- Spectacles (used by people with eye defects)
- Microscopes and telescopes.

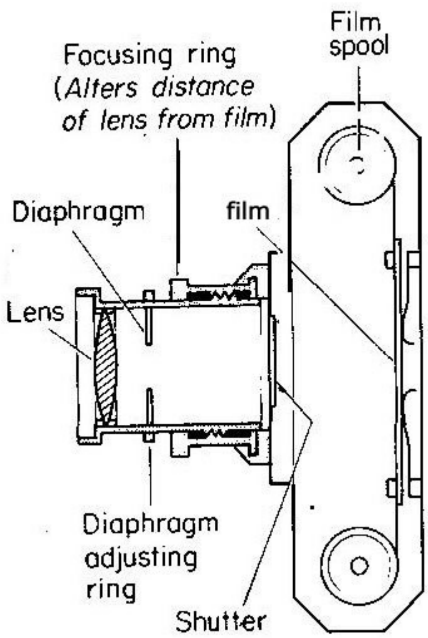
OPTICAL INSTRUMENTS

1. **The lens camera**

This is an optical instrument like the eye; light enters the camera through the convex lens which focuses light onto the film

The film contains a chemical that changes behavior on exposure to light.

It is developed to give a negative from which a photograph is made by printing.



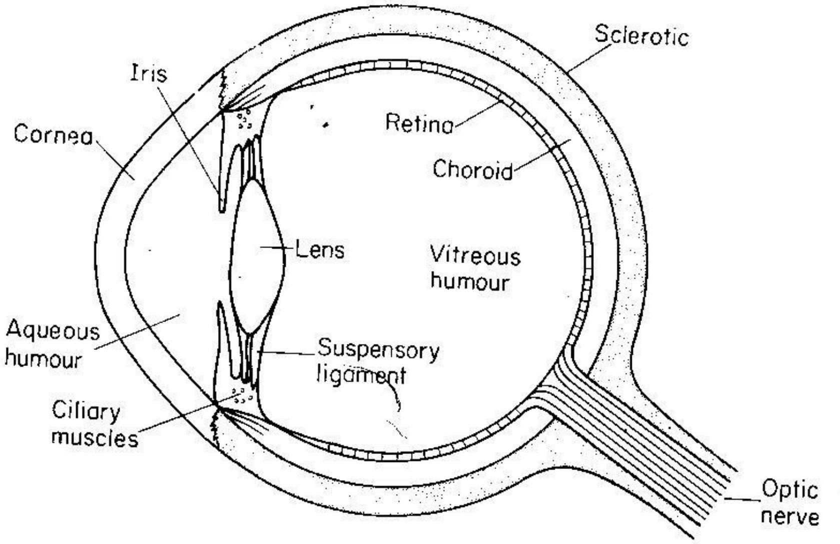
The camera is focused by varying the distance between the lens and the film. The lens is mounted on a screw thread so that it can be moved in and out

For near objects, the lens is moved away from the film.

The amount of light entering the camera is controlled by the

1. Shutter, which opens for a certain length of time to expose the film to the light
2. Aperture (hole) through which light enters the camera by varying its size
3. Diaphragm, this changes the size of the aperture. a stope is made of a sense of metal plates which can be moved to increase the aperture size

THE EYE



Functions of the parts of the eye

1. Lens

The lens inside the eye is convex. It changes in order to focus light

2. Ciliary muscle

These alter the focal length of lens by changing its shape so that the eye can focus the image on the retina.

3. **The iris**

This is the coloured position of the eye. It controls the amount of light entering the eye by regulating the size of the pupil

4. **The retina**

This is a light sensitive layer at the back of the eye where the image is formed

5. **The optic nerve**

It is the nerve that transmits the image on the retina to the brain for interpretation

6. **The cornea:** It is the protective layer and it also partly focuses light entering the eye

Accommodation

This is the process by which the human eye changes its size so as to focus the image on the retina. This process makes the eye to see both near and far objects.

EYE DEFECTS AND THEIR CORRECTIONS

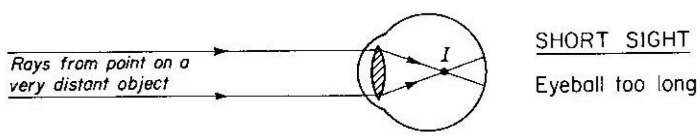
The normal eye can see objects clearly placed at infinity (far point) to see objects in greater details the eye sees it at the near point i.e. 25cm

TYPES OF EYE DEFECTS

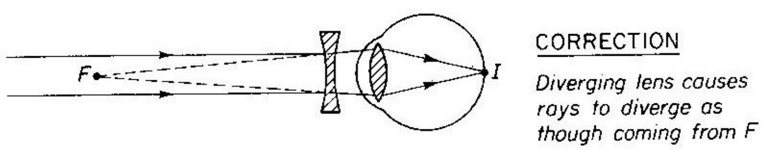
a) Short sightedness
b) Long sightedness

SHORT SIGHTEDNESS

A person with short sightedness can see near objects clearly but distant objects are blurred. The furthest point at which one can see the objects clearly is the far point. An object which is further than the far point is focused in front of the retina.



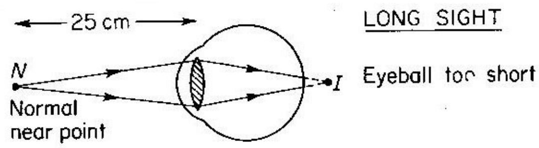
Correction of shortsightedness



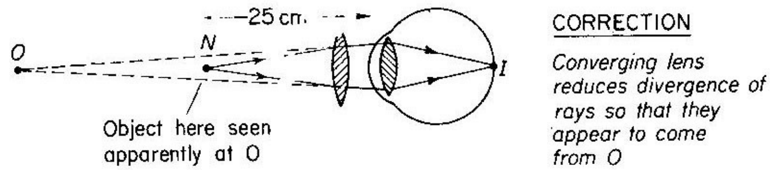
A concave lens is placed in front of the eye to make the light diverge so that it appears to come from the near point when it is actually coming far away as shown above

LONG SIGHTEDNESS

A long sighted person can see distant objects clearly but those that are near are blurred. The nearest point at which the person can see an object clearly is called near point. An object placed nearer than the near point is focused behind the retina as shown below



Correction of long sightedness



A convex lens is placed in front of the eye to make the light parallel, so that it appears to come from a distant object as shown above.

Similarities and differences between the eye and camera

a) **Similarities**

The camera consists of a light proof box painted black. Inside the eye it is fitted with a black pigment in to it to prevent stray reflection of light

Both have converging lenses that focus light from the external objects

Both have light sensitive parts, the camera has a film while the eye has a retina

Both have a system that controls the amount of light entering them, in the eye, iris is responsible and diaphragm does the same function in the camera.

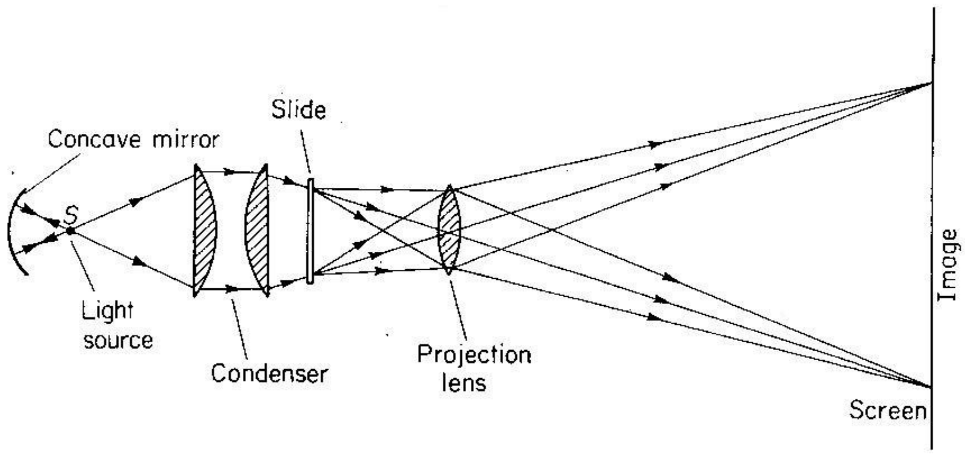
Differences

The eye lens is a biological organ while that of a camera is made out of glass

The distance between the eye lens and the retina is fixed while that between the camera lens and the film can be varied

The eye focuses image by changing the shape of the lens, in a camera the image is focused by changing the distance between the lens and the film

THE SLIDE PROJECTOR

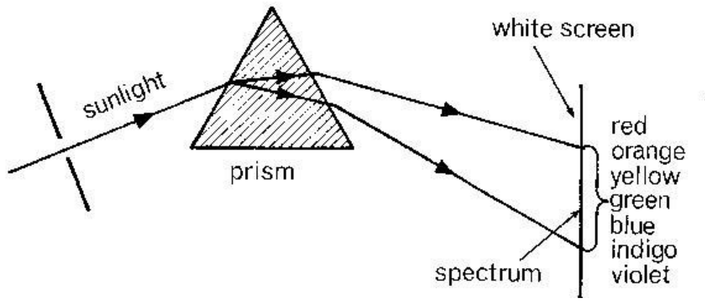


Functions of the parts of the slide projection

1. Lamp – it gives small but very high intensity source of light. It is suitable at the center of curvature of a convex mirror
2. Concave mirror- it is placed behind the light source. It reflects all lights forward
3. Condenser lens – it converges light through the slide on to the projector lens
4. Convex projector lens – it focuses the image of the slide on the screen
5. The fan- cools the light source once a lot of heat is produced
6. Heat shield – it shield the slide from heat produced by the light source
7. The slide – this is where the object is placed
8. Screen – this is where the object is formed. The size of the image on the screen increases as the projector is moved back from it. The image is focused by altering the distance between the slide and the lens. The projector lens is mounted on the screw thread so that it can be moved in and out to focus the image.

DISPERSION OF LIGHT

This is the separation of white light into various colours listed in order. The colours are red, orange, yellow, green, blue, indigo, and violet. The bundle of colours formed is called a spectrum. Visible light spectrum can be made by passing a beam of white light through a glass prism

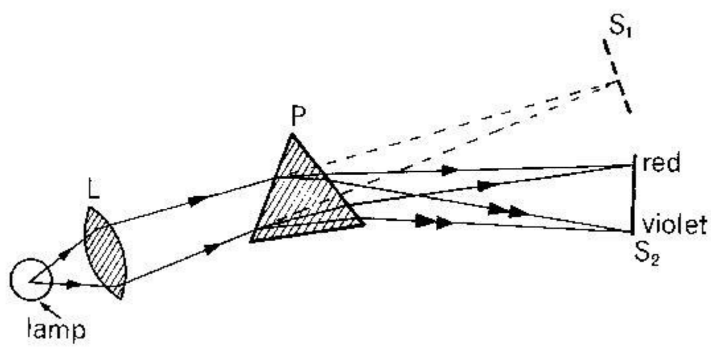


Dispersion occurs because each colour is refracted in glass by different amount i.e. each colour has different refractive index. So red is refracted least and violet is refracted most.

HOW TO OBTAIN A PURE SPECTRUM

The spectrum obtained above is impure i.e. the colours of the spectrum overlap one another

Apure spectrum is one in which light of one colour only forms each part of the image on the screen without overlap. This can be achieved by placing a convex lens in front of the prism to increase on the deviation of the colours as they pass through the prism



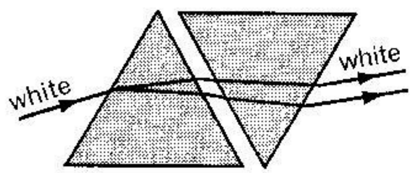
Lens L produces parallel beam of white light. The light is then dispersed and deviated at the prism sprinting up into various colours.

Lens B collects the different coloured lines so that the parallel beam of each separate colour is focused on the screen.

RECOMBINATION OF THE SPECTRUM:

The colours of the spectrum can be recombined by;

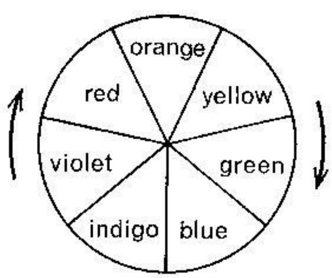
(i) Arranging a second prism so that the light is deviated in the opposite



(a)

direction.

(ii) Using an electric motor to rotate at high speed, a disc with spectral colours from its sectors as shown below.



The white light is slightly grey because paints are not pure colours.

Colours of objects:

The colour of an object depends on;

- The colour of light falling on it.
- The colour it transmits or reflects e.g. an object appears blue because it reflects blue light into the eyes and absorbs the other colours of the spectrum. Similarly, an object appears red because it reflects red light into the eyes and absorbs all other colours.

- A white object reflects all the colours of the spectrum into the eyes and absorbs none.

Types of colours:

a. Primary colours

These are colours that can't be obtained by adding two different colours of light. They include red , blue and green

b. Secondary colours

These are colours which are obtained by adding 2 primary colours together. They include yellow, peacock blue and magenta.

NB:- peacock blue is at times called cyan or tachois.

c. Complementally colours

These are two different colours which when added produce white light. One of them is a secondary colour and the other must be a primary colour. The pairs are

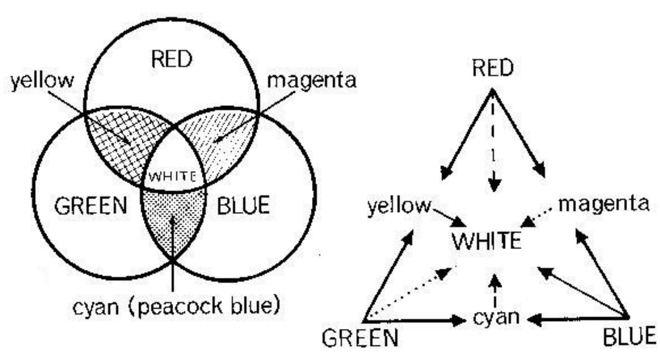
Red + peacock blue → white light

Green + magenta → white light

Blue + yellow → white light

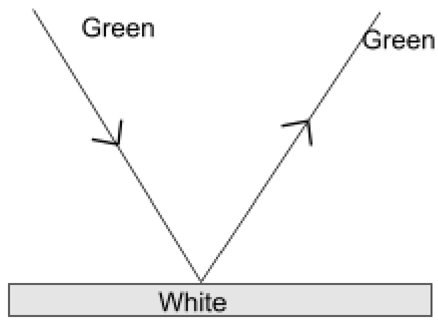
From the complementally colours it is noted that when the three primary colours are joined, they produce white light.

SUMMARY OF COLOURED LIGHTS

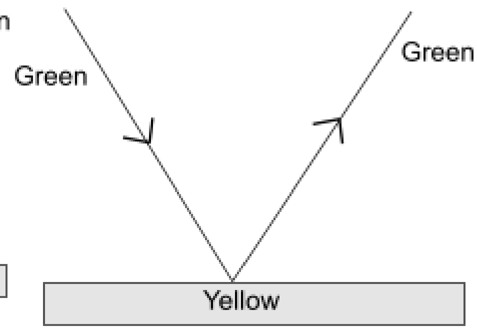


Coloured objects in white light

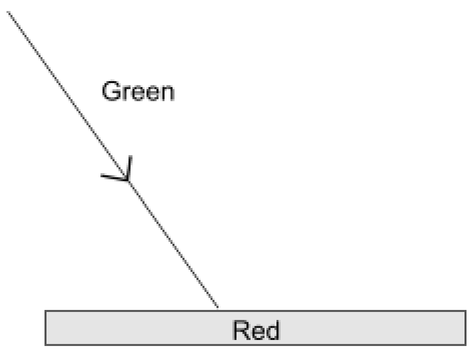
A coloured object reflects and transmits its own colour and absorbs other colour incident on it. **Examples:**



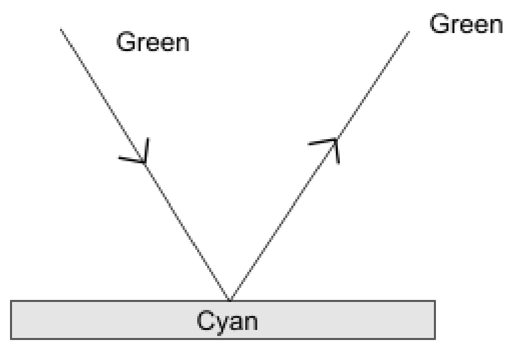
Body appears green



Body appears green



None is reflected, body appears black



Body appears green

N.B:- primary colour +primary colour = black

Primary colour + secondary colour = primary

Secondary colour + secondary colour = common primary colour.

Question 1

Describe and explain the appearance of a red tie with blue spots when observed in;

a. Red light
b. green light

Solution

a) **Green light** – the red tie appears black because both colours are primary colours and non is reflected

b) **Red light** – in the red light the tie appears red and blue spots appear black.This is because the red reflects the red colour and observes blue colour.

Question 2

A plant with green leaves and red flowers is placed in

a) green
b) blue
c) Yellow

What colour will the leaves and flowers appear in each case . Assume all colours are pure

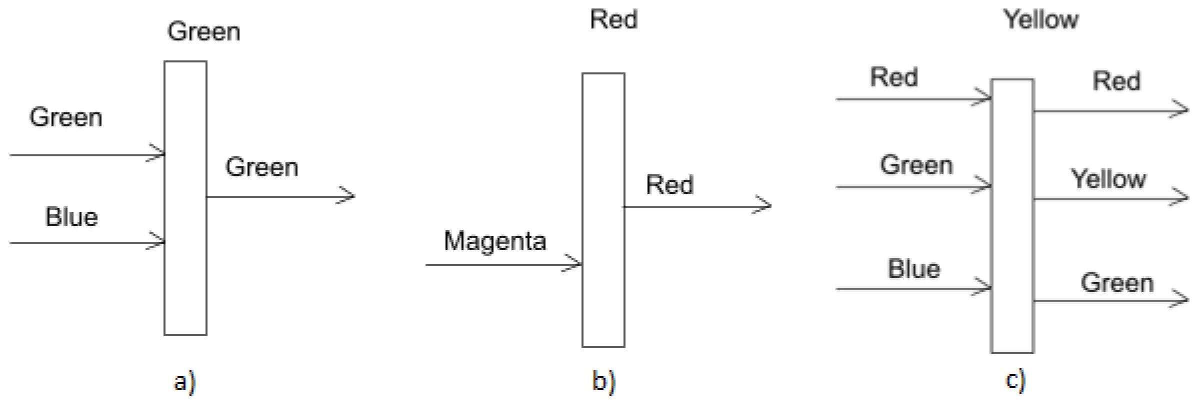
a. **green** -: the leaves remain green but the flowers black

b. **blue** -: the leaves will appear black and flowers black

c. **Yellow** -: the leaves appear green and flowers appear red

FILTERS (COLOUR)

A filter is a coloured sheet of plastic or glass material which allows light of its own type to pass through it and absorbs the rest of the coloured lights i.e. a green filter transmits only green, a blue transmits only blue, a yellow filter transmits red, green and yellow lights.



MIXING OF COLOURED PIGMENTS

A pigment is a substance which gives its colour to another substance .A pigment absorbs all the colours except its own which it reflects. When pigments are mixed, the colour reflected is the common to all e.g. blue + yellow → green

Yellow + orange →black

Green + indigo → blue

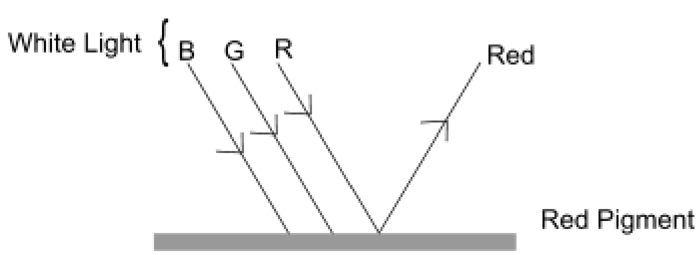
The blue reflects indigo and green, its neighbour in the spectrum as well as blue

Yellow reflects green, yellow and orange, only green is reflected by both

Mixing coloured pigments is called colour mixing by subtraction

Pigments appear black because none of the colours are reflected

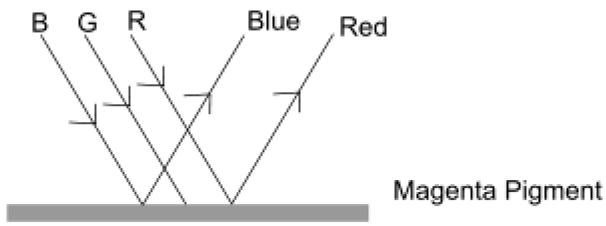
APPEARANCE OF COLOUR PIGMENT IN THE WHITE LIGHT



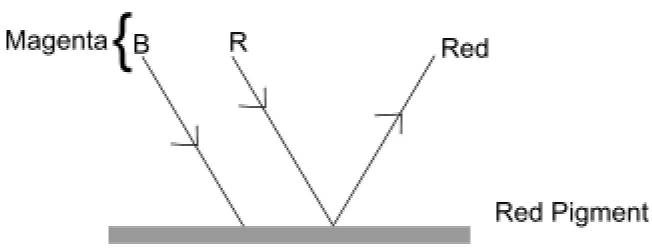
A colour pigment reflects only one colour

APPEARANCE A COLOUR PIGMENT IN COLOURED LIGHT

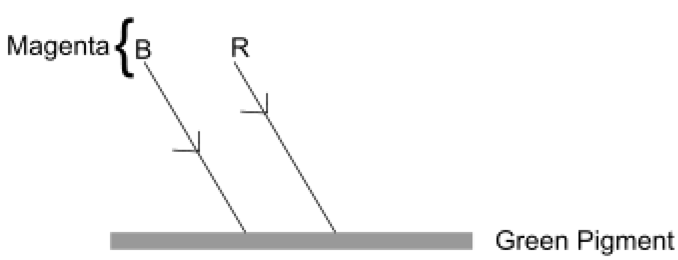
a. Magenta pigment reflects two colours of light i.e. blue and red when white light is incident on it



b. Red pigment reflects only the red colour when magenta light is incident on it



c. The pigment appears black because none of the colours in the magenta light is reflected



WAVES

A wave is a disturbance which travels through a medium and transfer energy from one point to another without causing any permanent displacement of the medium itself e.g. water waves, sound waves, waves formed when a string is plucked.

Many waves are invisible but have visible effects. In this chapter, you will study the properties and characteristics of waves and their effects on matter.

Types of waves:

We can classify all waves into two categories:

1. Mechanical waves

This is a type of waves produced by physical disturbance and requires a material medium for its propagation. Examples of mechanical waves include water ripples, sound waves, waves on strings and ultrasonic waves.

2. Electromagnetic waves

This type of waves does not require any medium for propagation and are caused by electrons undergoing any energy change. Examples of electromagnetic waves include light waves, infra-red rays and ultra-violet rays

Note: All waves are as a result of vibrations caused in the medium.

WAVE MOTION

When a wave is set up on the medium, the particles of the medium vibrate from about a mean position as the wave passes. The vibrations are passed from one particle to the next until the final destination is reached

FORMS OF WAVES

There basically two broad forms -:

a) progressive waves
b) stationary waves

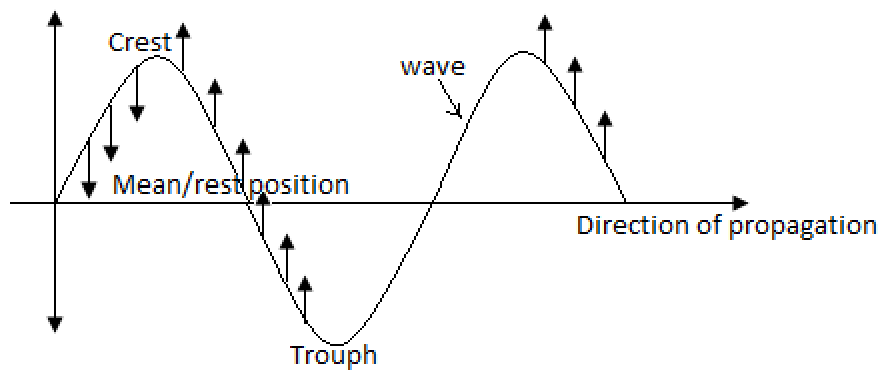
PROGRESSIVE WAVES

This is a wave which moves away from its source through a medium and spreads out continuously. There are two kinds of progressive waves namely:

- Transverse waves
- Longitudinal waves

i. TRANSVERSE WAVES

These are waves in which particles vibrate perpendicular to the direction of propagation of the wave e.g. water waves, light waves, waves formed when a rope is moved up and down.



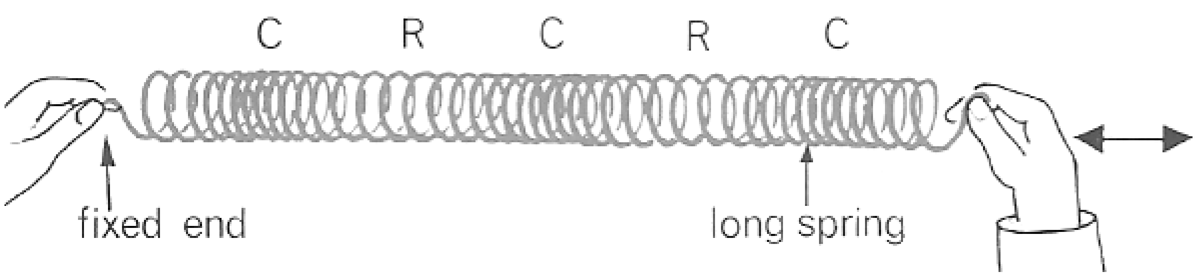
ii. LONGITUDINAL WAVES

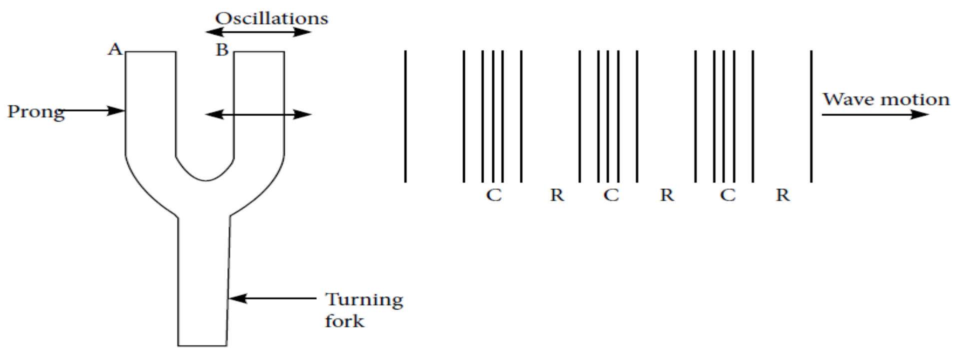
These are waves in which the particles of the media vibrate in the same direction as the wave

OR

These are waves in which the particles of the media vibrate parallel to wave motion e.g. sound waves, waves from a slinky spring.

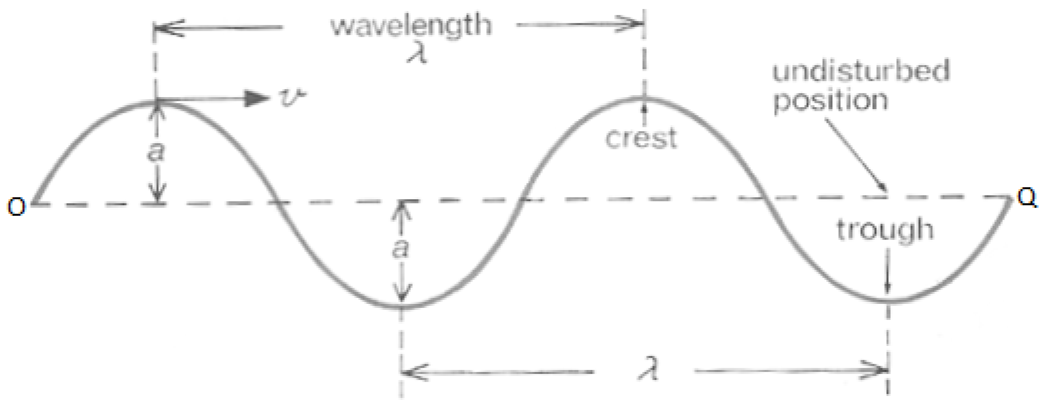
Longitudinal waves travel by formation of compressions and rare factions. Regions where particles crowd together are called compressions and regions where particles are further apart are called rare factions.





C = Compression R = Rarefaction

General representation of a wave



TERMS USED IN DESCRIBING WAVES

1. Rest position (Mean position)

This is the line OQ where particles are stationary or displacement of a particle is zero (0)

2. Amplitude (a)

This is the maximum displacement of a particle from the rest position.

Displacement is the distance the object or particle is displaced from the undisturbed position or rest position.

3. Cycle

This is one complete oscillation of the wave.

4. Wave length (λ)

- ✓ This is the distance between two successive crests or two successive troughs.
- ✓ This is the distance covered by one complete cycle of a wave.
- ✓ This is the distance between two particles of a wave vibrating in phase

- ✓ This is the distance between two successive compressions or rare factions.

5. Period

Is the time taken by a wave to perform one complete cycle, i.e. T= where n is number of cycles.

6. Frequency

This is the number of cycles a wave completes in one second i.e. F=

S.I. unit = Hertz (Hz)

8. Crest

It is the maximum displaced point above the line of 0 (zero) disturbance.

9. Trough

It is the maximum displaced point below line of zero disturbance.

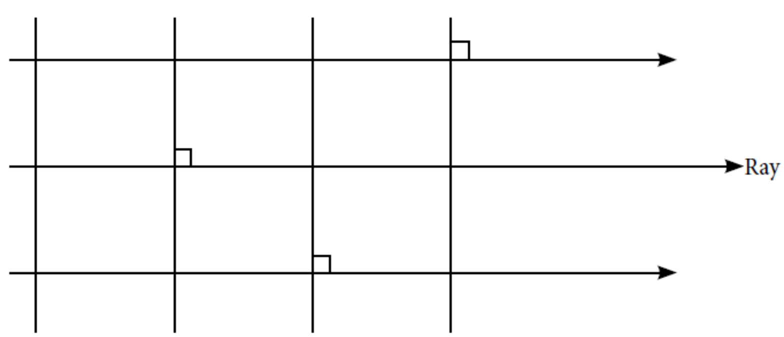
Ray: A ray is a direction or a path taken by a wave. It is represented by a line with an arrow pointing in the direction of the wave.

Phase: This is the state of vibration of a particle in a wave. Two particles are said to be vibrating in phase if their state of vibration is the same.

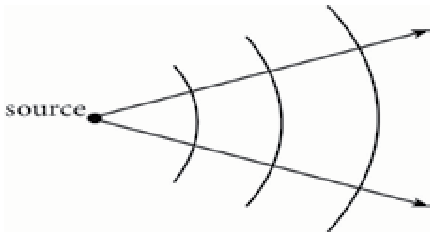
Wavefront: This is a line or a section through an advancing wave in which all the particles in that line are vibrating in the same phase

Example

Straight wavefronts



Circular wavefronts



10. Wave velocity

It is the distance which the wave travels in one second in a given direction. S.I unit is m/s.

THE WAVE EQUATION

From the wave speed v = …..(i)

If the wave describes n cycles in time t

Then the distance covered d= $n\lambda$ …. (ii)

Substituting for d in … (i) → v =

But f = hence v = fλ wave equation

Examples

1. A radio station produces waves of wave length 10m. If the wave speed is 3×10^8m/s, calculate

(i) Frequency of radio wave.

(ii) Period T

(iii) Number of cycles completed in 10s

(i) λ = 10m , v = 3×10^8m/s t = 10s

v = f λ → f = =

f = 3×10^7

(ii) Period T = = 3.3×10^{-8}Hz

(iii) Number of cycles → f = → n = f t

= $3\times10^7 \times 10$

= 3×10^8cycles

2. The distance between 10 consecutive crests is 36cm. Calculate the velocity of the wave if the frequency of the wave is 12Hz.

Since;

$d = (n - 1)\lambda$

$0.36 = (10 - 1)\lambda$

$0.36 = 9\lambda$

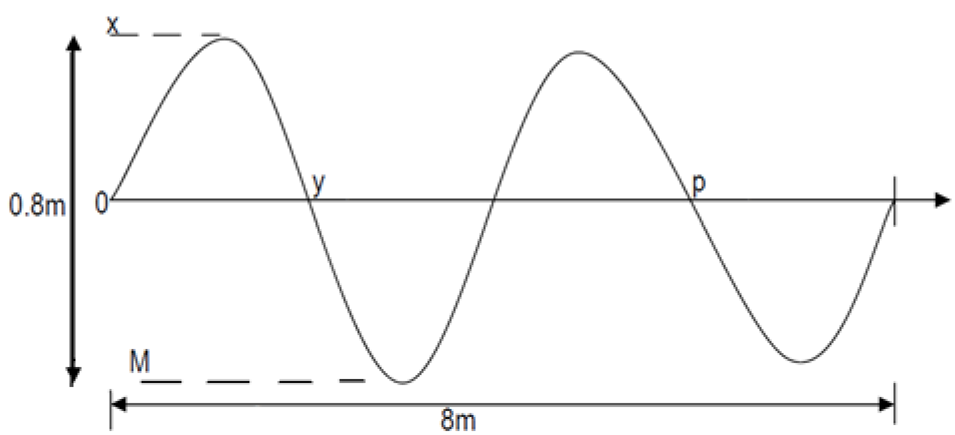
$\lambda = = 0.04m$

$V = f\lambda$

$= 12 \times 0.04$

$= 0.48m/s$

3. The diagram below shows a wave travelling in water.



(a) Name (i) Any two points on the wave which are in phase

(ii) Label M and x

(b) (i) Determine the amplitude of the wave.

(ii) If the speed of the wave is 80m/s, determine the frequency of the wave.

Questions

A vibrator produces waves which travel 35 m in 2 seconds. If the waves produced are 5cm from each other, calculate;

(i) the wave velocity

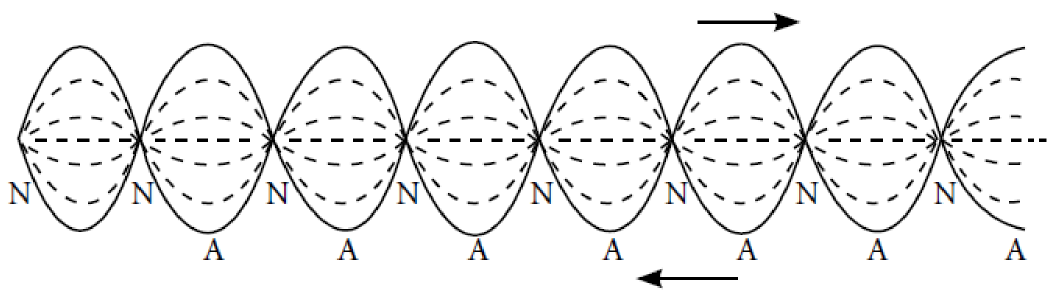
(ii) wave frequency

(i) $v = f\lambda \rightarrow =$

(ii)v = f→f =

Stationary waves

These are waves formed when two progressive waves of nearly the **same amplitude and frequency** moving in **opposite directions** meet e.g. when an incident wave meets its own reflection from a barrier. Stationary waves are formed in pipes and on stretched strings.

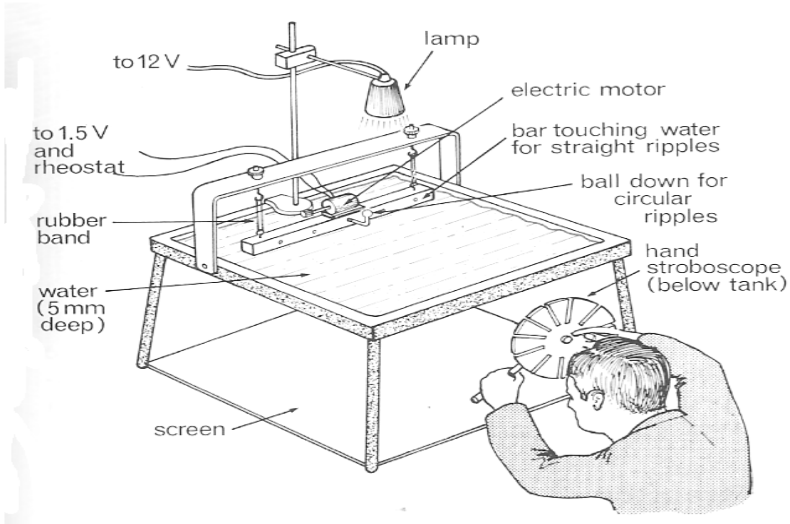


The distance between two neighbouring nodes is

Characteristics of stationary waves

- The stationary wave comprises of points where the displacement of particles is permanently zero. They are called nodes (N).
- Between the nodes, particles are vibrating in phase, but they do not attain the same amplitude.
- Particles half-way between the nodes attain maximum amplitude. They are called antinodes (A). (The broken lines show how the displacements of individual particles vary with time.)
- The peaks are always at the same position.

THE RIPPLE TANK



A ripple tank is an instrument used to study water wave properties. It is a shallow glass trough which is transparent. The images of the wave are projected on the screen which is placed below it.

The waves are produced by means of a dipper which is either a strip of a metal or a sphere. When the dipper is moved up and down by vibration of a small electric motor attached to it. The sphere produces circular wave fronts and the metal strip is used to produce plane waves.

A stroboscope helps to make the waves appear stationery and therefore allows the wave to be studied in detail.

N.B The speed of the wave in a ripple tank can be reduced by reducing the depth of water in the tank. The effect of reducing speed of waves is that wave length of water reduces but frequency does not. The frequency can only be changed by the source of wave.

WAVE PROPERTIES

The wave produced in a ripple tank can undergo.

(a) Refraction

(b) Reflection

(c) Diffraction

(d) Interference

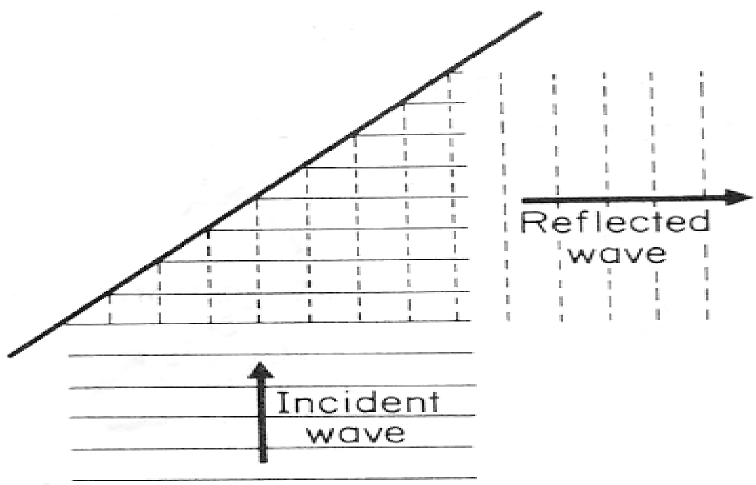
REFLECTION OF WAVES

A wave is reflected when a barrier is placed in its path. The shape of the reflected wave depends on the shape of the barrier.

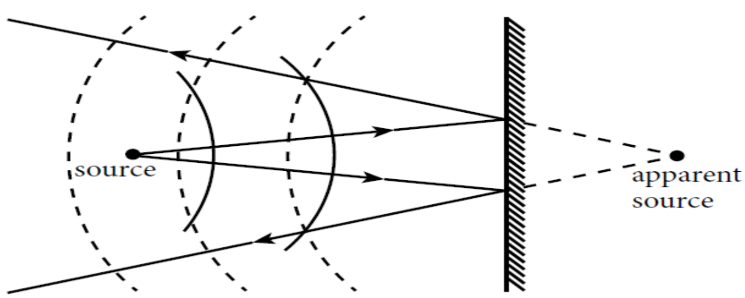
The laws of reflection of waves are similar to the laws of reflection of light.

(i) Reflection by plane reflectors

(a) Reflection of straight wave front.



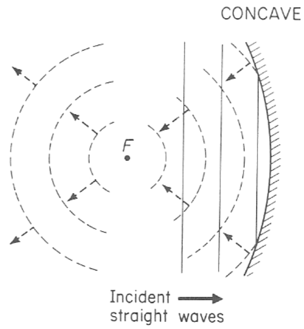
(b) Reflection of circular wave front



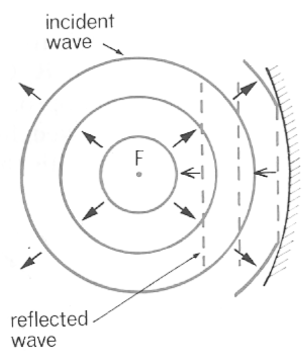
(ii) Reflection by curved reflectors

(a) By Concave reflector

i. Reflection of straight wave front

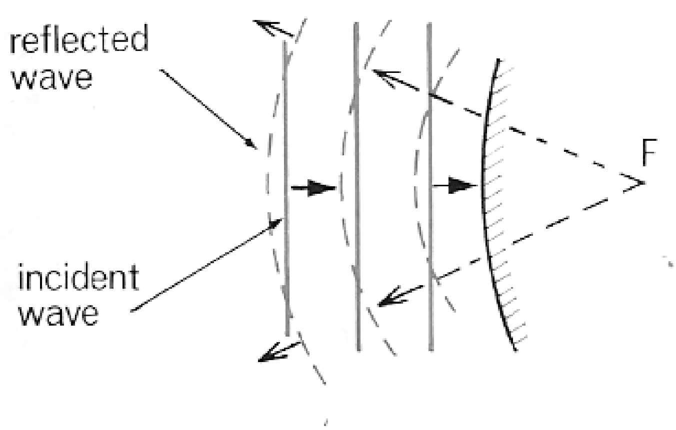


ii. Reflection of circular wave

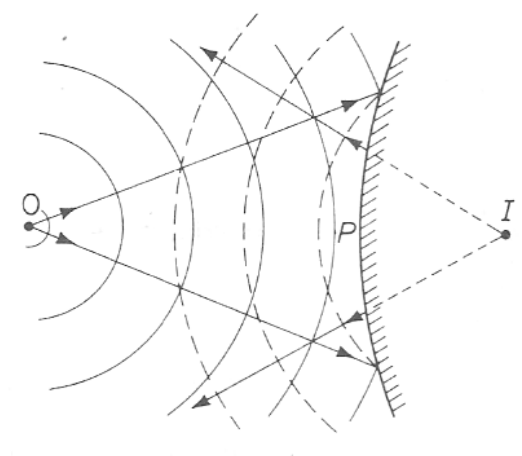


(b) By a Convex reflector

i. Reflection of plane wave



ii. Reflection of circular wave

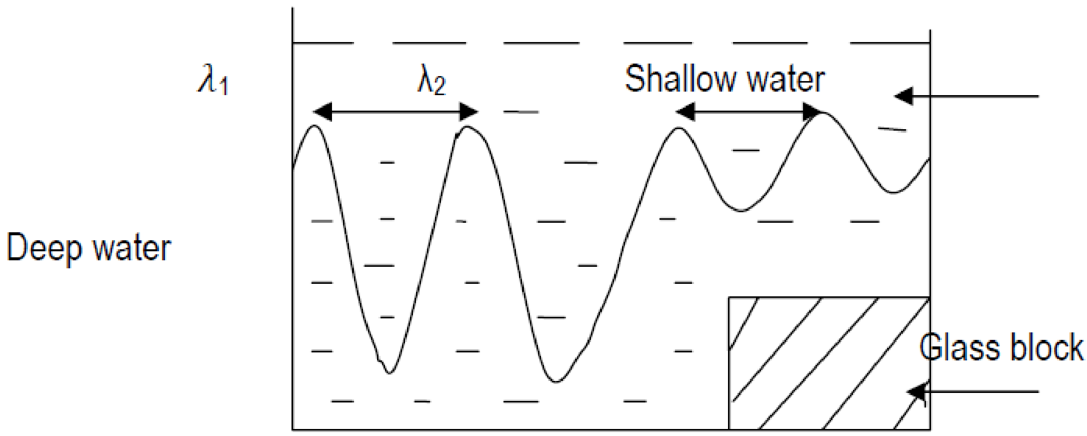


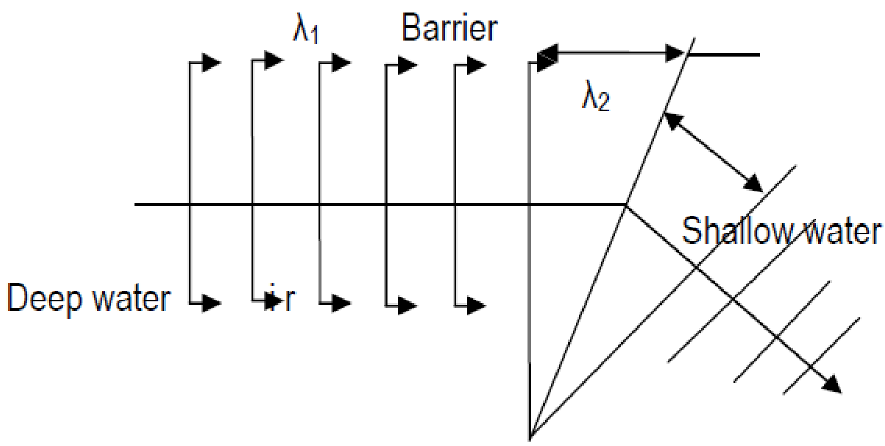
Note

During reflection of water waves, the frequency and velocity of the wave does not change.

REFRACTION OF WAVE

This is the change of in direction of wave travel as it moves from one medium to another of different depth. It causes change of wave length and velocity of the wave. However, the frequency and the period are not affected. In a ripple tank, the change in direction is brought about by the change in water depth.





λ_1 = wave length in deep water

λ_2 = wave length in shallow water

Note (i) $\lambda_1 > \lambda_2$

(ii) $v_1 = f\lambda$ and $v_2 = f\lambda_2$

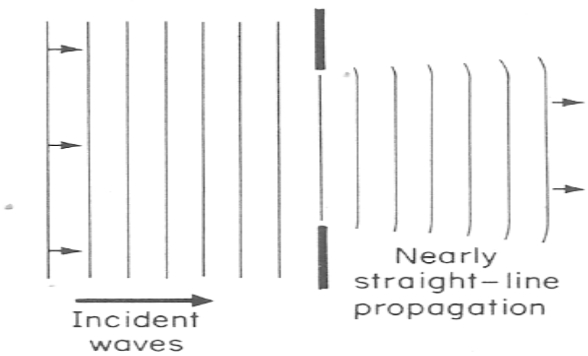
(iii) $v_1 > v_2$ When f – is constant.

Refractive index,

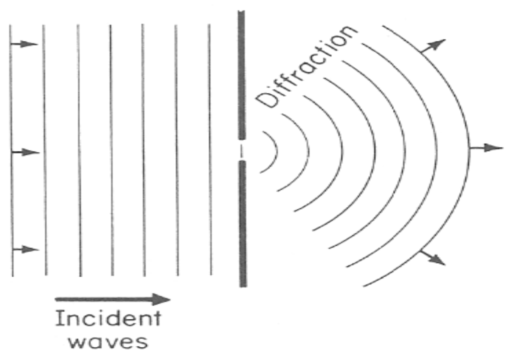
DEFRACTION OF WAVES

This is the spreading of waves as they pass through holes, round corners or edges of obstacle. It takes place when the diameter of the hole is in the order of wave length of the wave i.e. the smaller the gap the greater the degree of diffraction as shown below.

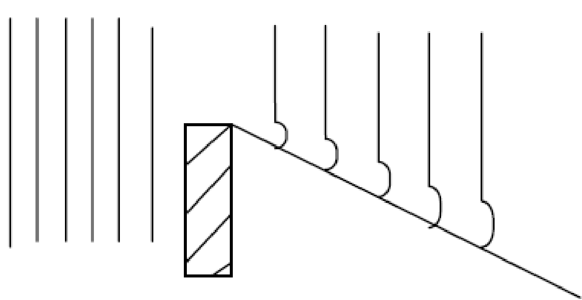
(a) Wide gap



(b) Narrow gap



(c) Edge of obstacle



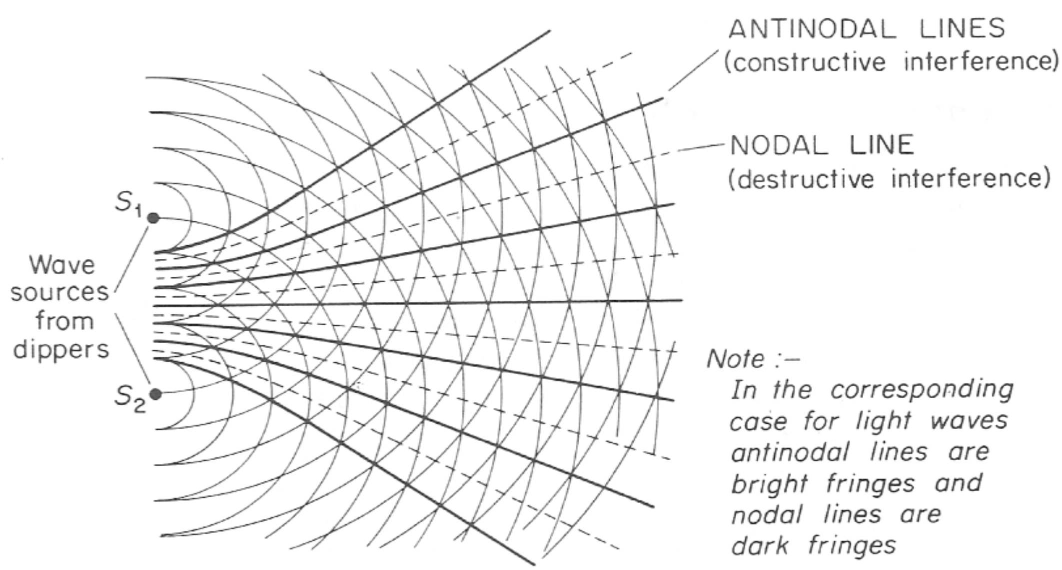
Sound waves are more diffracted than light waves because the wave length is greater than that of light.

Therefore sound can be heard in hidden corners.

N.B - When waves undergo diffraction, wave length and velocity remain constant.

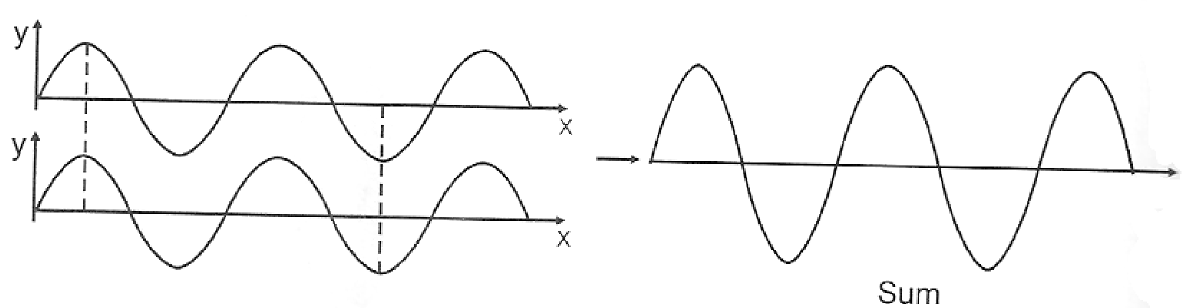
INTERFERENCE OF WAVES

This is the superposition of two identical waves travelling in the same direction to form a single wave with a larger amplitude or smaller amplitude. The two waves should be in phase (matching).



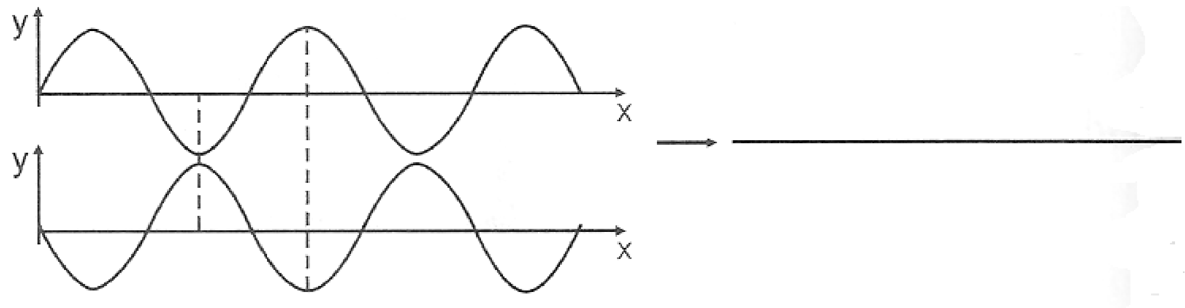
CONSTRUCTIVE INTERFERENCE

This constructive interference occurs when a crest from one wave source meets a crest from another source or a trough from one source causing reinforcement of the wave i.e. increased disturbance is obtained. The resulting amplitude is the sum of the individual amplitudes.



DESTRUCTIVE INTERFERENCE

This occurs when the crest of one wave meets a trough of another wave resulting in wave cancelling i.e.

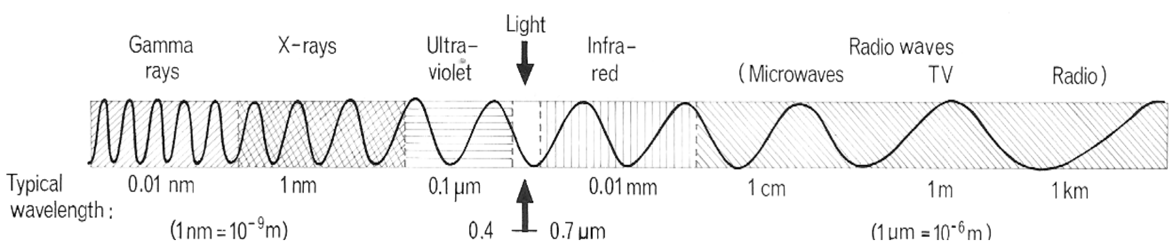


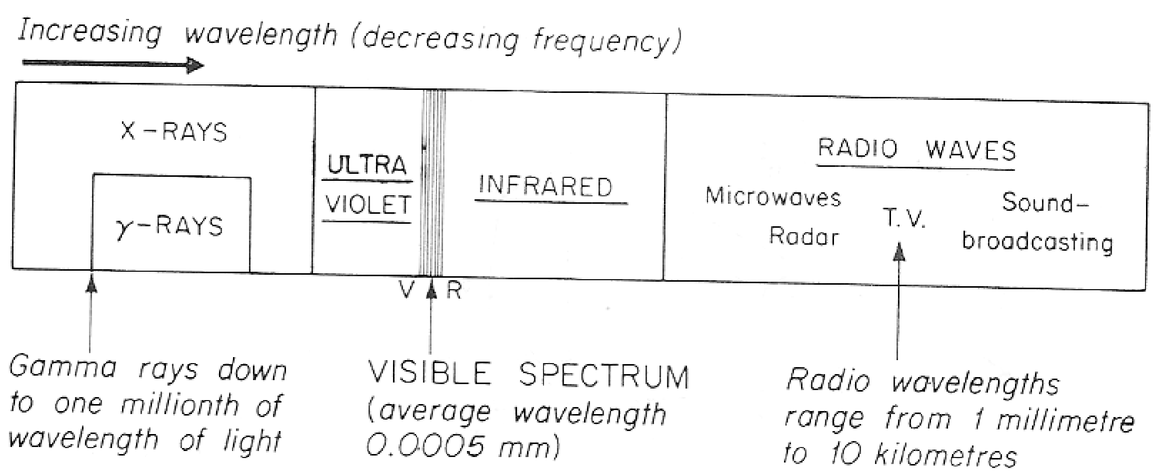
ELECTRO MAGNETIC WAVES

This is a family of waves which is made by electric and magnetic vibrations of very high frequency. Electromagnetic waves do not need a material medium for transformation i.e. they can pass through a vacuum.

SPECTRUM OF ELECTRO MAGNETIC WAVES

In decreasing frequency





PROPERTIES OF ELECTROMAGNETIC WAVES

- They are transverse waves.

- They can travel through vacuum.
- They travel at a speed of light (3.0×10^8 m/s).
- They can be reflected, refracted, diffracted and undergo interference.
- They possess energy.

EFFECTS OF ELECTROMAGNETIC WAVES ON MATTER

(a) Gamma rays.

- They destroy body tissues if exposed for a long time.
- They harden rubber solutions and lubricate oil to thickness.

(b) X- rays

- Causes barriers/curtains to give off electrons.
- Destroys body tissues if exposed for a long time.
- Used in industries to detect leakages in pipes and in hospitals to detect fractures of bones.

(c) Ultra violet

- Causes sun burn
- Causes metals to give off electrons by the process called photoelectric emission.
- Causes blindness.

(d) Visible light

- Enables us to see.
- Changes the apparent colour of an object.
- Makes objects appear bent to refraction.

(e) Infrared

- Causes the body temperature of an object to rise.
- It is a source of vitamin D.

(f) Radio waves

- Induces the voltage on a conductor and it enables its presence to be detected.

Wave band	Origin	Source
Gamma rays	Energy changes in modes of atoms	Radio active substance
X- rays	Electrons hitting a metal target	X – ray tube
Ultra- violet	Fairly high energy changes in atoms	Very hot bodies Electron discharge Through gases especially mercury Vapour
Visible light	Energy changes in electron structure of atoms	Lamps, flames etc
Infrared radiation	Low energy changes in electrons of atoms	All matter over a wide range of temperature from absolute zero onwards.
Radio waves	High frequency Oscillating electric current Very low energy changes in electronic structures of atoms.	Radio transmission aerials.

SOUNDS WAVES (LONGITUDINAL WAVES)

Is a form of energy which is produced by vibrating objects e.g. when a tuning fork is struck on a desk and dipped in water, the water is splashed showing that the prongs are vibrating or when a guitar string is struck.

SPECTRUM SOUND WAVES

Frequency	$0H_Z$	$20H_Z$	$20{,}000H_Z$
Type of sound	Subsonic sound	Audible sound waves	Ultra sonic sound wave.

SUBSONIC SOUND WAVES

These are not audible to human ear because of very low frequency of less than 20Hz

AUDIBLE SOUND WAVES

These are audible to human ear. This frequency ranges from
20Hz- 20 KHz.

ULTRASONIC SOUND WAVES

These are sound waves whose frequencies are above 20Hz. They are not audible to human ears.

They are audible to whales, Dolphins, bats etc.

APPLICATION OF ULTRASOUND WAVES

- They are used by bats to detect obstacles e.g. buildings a head.
- Used in spectacles of the blind to detect obstacles.
- Used in radiotherapy to detect cracks and faults on welded joints.
- Used in industries to detect rocks in seas using sonar.
- Used to measure the depth of seas and other bodies.

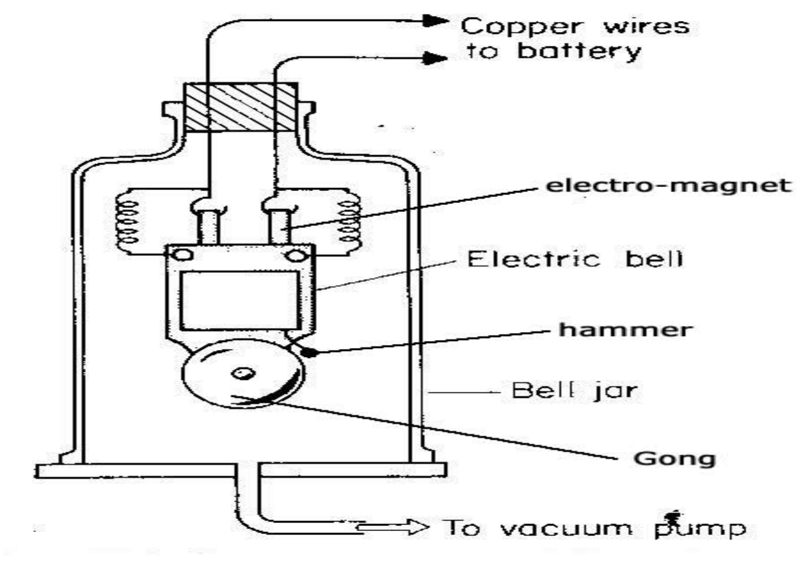
PROPERTIES OF SOUND WAVES

- Cannot travel in a vacuum because of lack of a material medium
- Can cause interference.
- Can be reflected, refracted, diffracted, planes polarized and undergo interference.
- Travels with a speed V = 330m/s in air.

TRANSMISSION OF SOUND

Sound requires a material medium for its transmission. It travels through liquid, solids and gases, travels better in solids and does not travel through vacuum.

EXPERIMENT TO SHOW THAT SOUNDS CANNOT PASS THROUGH A VACCUM.



- Arrange the apparatus as in the diagram with air in the jar.
- Switch on the electric bell, the hammer is seen striking the gong and sound is heard.
- Gently withdraw air from the jar by means of a vacuum pump to create a vacuum in the jar.
- The sound produced begins to fade until it is heard no more yet the hammer is seen striking the gong.
- Gently allow air back into the jar, as the air returns, the sound is once again heard showing that sound cannot travel through vacuum.

Note: The moon is sometimes referred to as a silent planet because no transmission of sound can occur due to lack of air (material medium).

The speed of sound depends on;

(i) Temperature

Increase in temperature increases the speed of sound i.e. sound travels faster in hot air than in cold air.

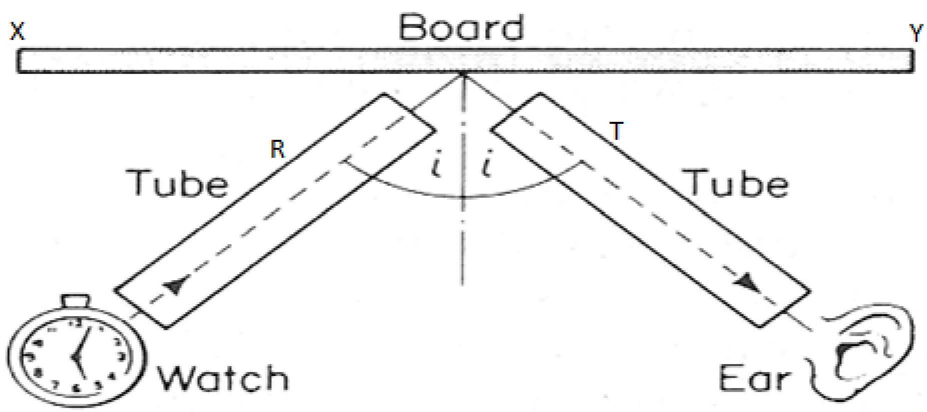
(ii) Wind

Speed of sound is increased if sound travels in the same direction as wind.

(iii) Density of medium.

Speed of sound is more in denser medium than in less dense. Change in pressure of air does not affect speed of sound because density is not affected by change in pressure.

EXPERIMENT TO VERIFY THE LAWS OF REFLECTION OF SOUND



R – Closed tube

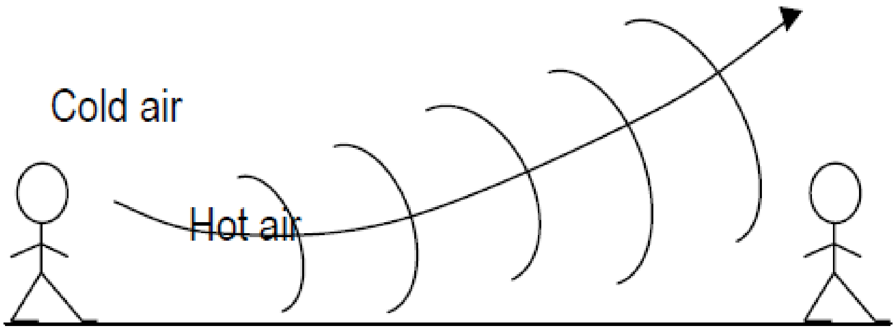
T – Open tube

- Put a ticking clock in tube R on a table and make it to face a hard plane surface e.g. a wall.
- Put tube T near your ear and move it on either sides until the ticking sound of the clock is heard loudly.
- Measure angle i and r which are the angles of incidence and reflection.
- From the experiment, sound is heard distinctly due to reflection.
- Angle of incidence (i) and angle of reflection (r) are equal and lie along XY in the same plane.
- This verifies the laws of reflection.

REFRACTION OF SOUND WAVES

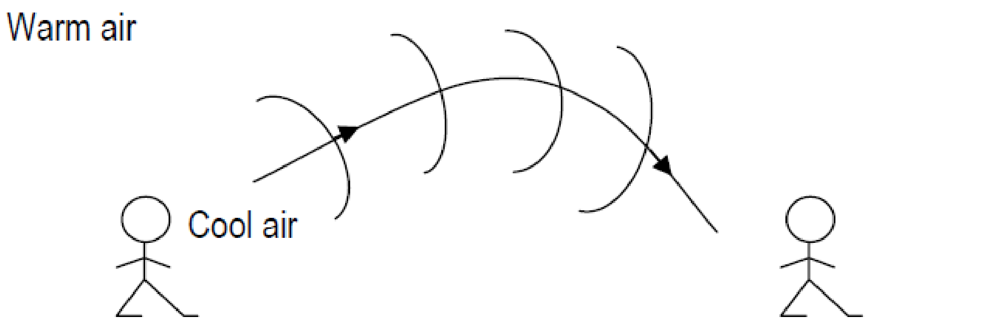
Refraction occurs when speed of sound waves changes. The speed of sound in air is affected by temperature. Sound waves are refracted when they are passed through areas of different temperature. This explains why it is easy to hear sound waves from distant sources at night than during day.

REFRACTION OF SOUND DURING DAY



During day, the ground is hot and this makes the layers of air near the ground to be hot while that above the ground is generally cool. The wave fronts from the source are refracted away from the ground.

REFRACTION OF SOUND DURING NIGHT



During night, the ground is cool and this makers layers of air near the ground to be cool while above to be warm. The wave fronts from the source are refracted towards the ground making it easier to hear sound waves over long distances.

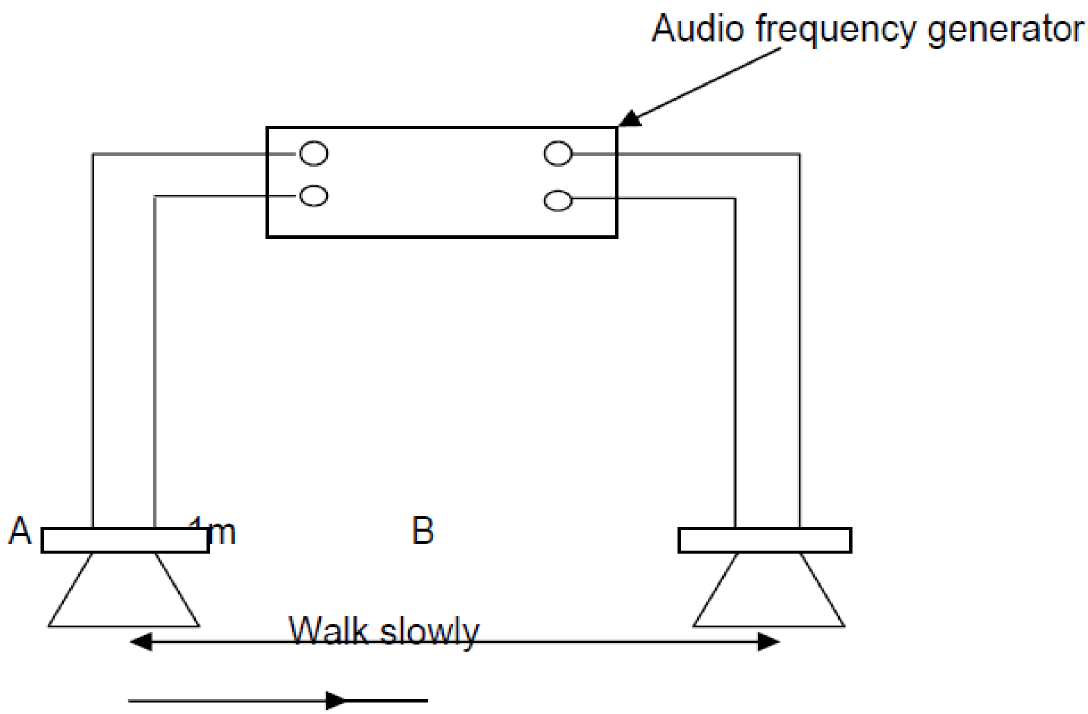
DEFRACTION OF SOUND

This refers to the spreading of sound waves around corners or in gaps when sound waves have wave length similar to the size of the gap. It is due to refraction that a person behind the house can hear sound from inside.

INTERFERENCE OF SOUND

When two sound waves from two different sources overlap, they produce regions of loud sound and regions of quiet sound. The regions of loud sound are said to undergo constructive interference while regions of quiet are said to undergo destructive interference.

EXPERIMENT TO SHOW INTERFERENCE OF SOUND



ECHOES

An echo is a reflected sound. Echoes are produced when sound moves to and fro from a reflecting surface e.g. a cliff wall. The time taken before an echo arrives depends on the distance away from the reflecting surface.

In order for a girl to hear the echo; sound travels a distance of 2d.

Velocity =

For an echo; velocity of sound,v =

Examples

1. A girl stands 34m away from a reflecting wall. She makes sound and hears an echo after 0.2 seconds. Find the velocity of sound.

v =

v =

= 340m/s

2. A person standing 99m from a tall building claps his hands and hears an echo after 0.6 seconds. Calculate the velocity of sound in air.

   v =

   v =

   = 330m/s

3. A gun was fired and an echo from a cliff was heard 8 seconds later. If the velocity of sound is 340m/s, how far was the gun from the cliff?

   v =

   340 =

   1360 = d

   d = 1360m

4. A student is standing between two walls. He hears the first echo after 2 seconds and then another after a further 3 seconds. If the velocity of sound is 330m/s, find the distance between the walls.

   V =

   V =

   Distance between the walls = $d_1 + d_2$

   d_1 =330m

   d_2 = 825m hence

Distance between the walls = $d_1 + d_2 = 330+825 = 1155$m

5. A man is standing midway between two cliffs. He claps his hands and hears an echo after 3 seconds. Find the distance between the two cliffs.

   (Velocity of sound = 330m/s)

   V=

   $3 \times 165 = 990$m

   d_1

   d_1=495m

   $d_1=d_2$

   d_1+d_2 = 495+495

MEASUREMENT OF VELOCITY OF SOUND USING AN ECHO METHOD

Method;

A person stands a certain distance d from the reflecting surface (tall wall), then measure that distance.

Make a sharp clapping sound by banging two blocks of wood together.

Repeat the sound at regular time intervals to coincide exactly with the echo.

Count the number of claps in a given time t

Find the time taken for one clap i.e.

Velocity =

Velocity =

Velocity =

Example

A student made 50 claps in one minute. If the velocity of sound is 330s, find the distance between the student and the wall.

Velocity =

d=198m

REVERBERATION

In a large hall where there are many reflecting walls, multiple reflections occur and cause or create an impression that sound lasts for a longer time such that when somebody makes a sound; it appears as if it is prolonged. This is called reverberation.

Definition of Reverberation

Reverberation is the effect of the original sound being prolonged due to multiple reflections.

ADVANTAGES OF REVERBERATION

In grammar, reverberation is used in producing sound. Complete absence of reverberation makes speeches inaudible.

DISADVANTAGES OF REVERNERATION

During speeches, there is a nuisance because the sound becomes unclear.

PREVENTION OF REVERBERATION

The internal surfaces of a hall should be covered with a sound absorbing material called acoustic material.

WHY ECHOES ARE NOT HEARD IN SMALL ROOMS?

This is because the distance between the source and reflected sound is so small such that the incident sound mixes up with the reflected sound making it harder for the ear to differentiate between the two.

Question

1. Outline four properties of electromagnetic waves.
2. Distinguish between
   i. sound waves and light waves.
   ii. sound waves and water waves
3. A man standing midway between two cliffs makes a sound. He hears the first echo after 3s. Calculate 'the distance between the two cliffs (Velocity of sound in air = 330m/s)

Musical notes

Music

This is an organized sound produced by regular vibrations.

Noise

This is a disorganized sound produced by irregular vibrations.

Musical note

This is a single sound of a certain pitch made by a musical instrument or voice.

Characteristics of musical notes

Pitch

This is the loudness or softness of sound. It depends on the frequency of sound produced, the higher the frequency the higher the pitch.

Timber

This is the quality of sound produced, it depends on the number of overtones produced, the more the number of overtones, the richer and the sweeter the music and therefore the better the quality.

Overtone

This is a sound whose frequency is a multiple of a fundamental frequency of the musical note.

Beat

This refers to the periodic rise and fall in the amplitude of the resultant note.

Loudness

This depends on the amplitude of sound waves and sensitivity of the ear.

Amplitude

This is the measure of energy transmitted by the wave. The bigger the amplitude, the more energy transmitted by the wave and the louder sounder sound produced.

Sensitivity of the ear

If the ear is sensitive, then soft sound will be loud enough to be detected and yet it will not be detected by the ear which is insensitive.

Pure and impure musical notes.

Pure refers to a note without overtones. It is very boring and only produced by a tuning fork.

Impure refers to a note with overtones. It is sweet to the ear and produced by all musical instruments.

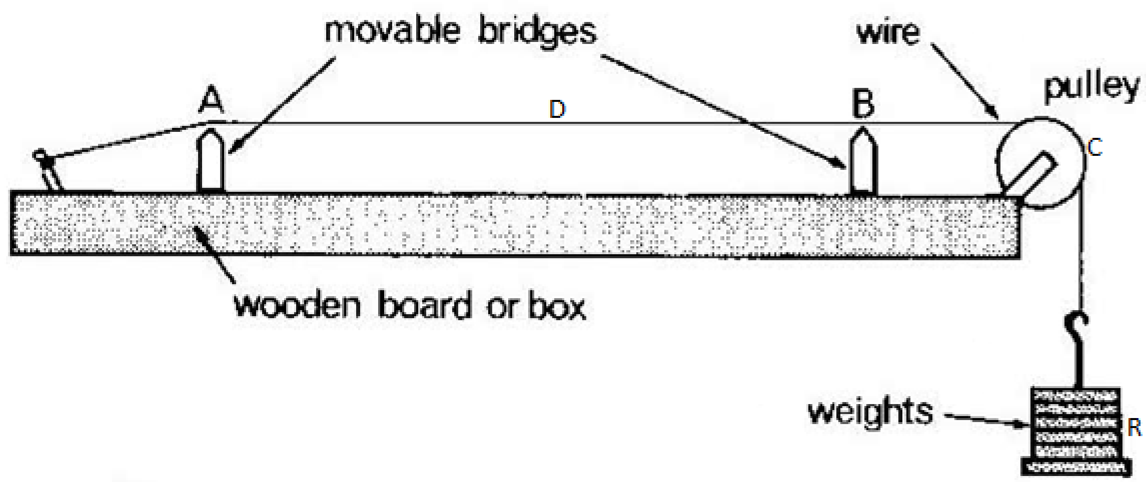
VIBRATION IN STRINGS

Many musical instruments use stretched strings to produce sound. A string can be made to vibrate by plucking it like in a guitar or in a harp in pianos. Different instruments produce sounds of different qualities even if they are of the same note.

Factors affecting the frequency of the stretched string

(a) Length

For a given tension of the string, the length of the string is inversely proportion to the frequency of sound produced. This can be demonstrated by an instrument called sonometer as shown below.



A- Fixed bridge

B- Movable bridge

C- Wheel

D- Stretched string

R-Load

By moving bridge B, higher frequency can be obtained for a short length AB and lower frequency for a long length AC. The relation can be expressed as f

(b) Tension

Adding weights or removing them from its ends at load R varies the tension of the sonometer wire. It will be noted that the higher the tension, the higher the frequency of the note produced.

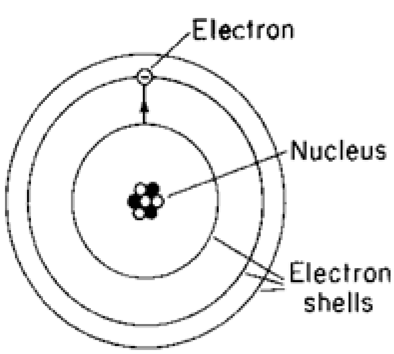
(c) Mass per unit length (m)

Keeping length (l) and tension (t) constant, the frequency of sound produced depends on the mass per unit length of the string. Heavy strings produce low frequency sounds. This is seen in instruments such as guitar, base strings are thicker than solo stings. If the tension and length are kept constant, the frequency of sound is inversely proportional to the mass per unit length of the strings thus a thin short and taut string produces high frequency sound. (f)

ELECTROSTATICS

This refers to the study of charge at rest. To understand the nature of charge, it is necessary to know the structure of an atom.

Structure of an atom



An atom consists of the nucleus containing protons and neutrons

Around and outside the nucleus resides the electrons in their respective orbits and in circular motion

The electrons are negatively charged while protons are positively charged. The two types of charges however are of the same magnitude in a neutral atom.

In a neutral atom, the number of negative charges is equal to the number of positive charges and the atom is said to be electrically neutral. Therefore, electrostatics is the study of static electricity because the charges which constitute it are stationary.

ELECTRIFICATION

This is the process of producing electric charges which are either positive or negative.

Methods of producing Electric charges

- By friction or rubbing (good for insulators and non conductors).
- By conduction/contact (good for conductors).
- By induction (conductors).

Electrification by friction

Two uncharged bodies (insulators) are rubbed together. Electrons are transferred from one body to the other. The body which loses electrons becomes positively charged and that which gains electrons becomes negatively charged.

Acquire positive charge	**Acquire negative charge**
Glass	silk
Fur	Ebonite (hard rubber)
Cellulose Acetate	Polythene

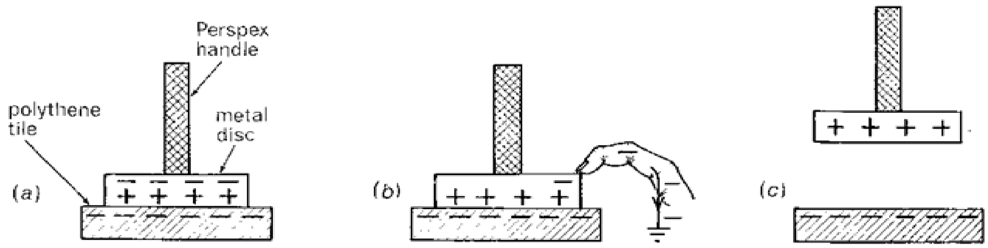
Explanation of charging by friction

When two bodies are rubbed together, work is done, transfer of electrons from one body to another occurs. This results into two bodies acquiring opposite charges.

Law of Electro statics

- Like charges repel each other.
- Unlike charges attract each other.

Electrification by conduction



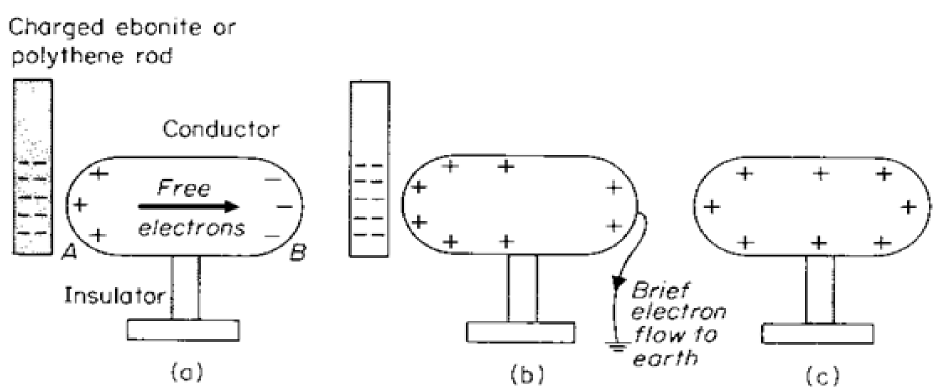
- Support the uncharged conductor on an insulated stand.
- Put a positively charged rod in contact with the conductor.
- Earth the conductor by touching
- Remove the earthing
- When the conductor is removed from the rod, it is found to be positively charged.

Note

The insulated stand prevents flow of charge away from the conductor. To charge the conductor negatively, a negative rod is produced.

Electrification by induction

(a) Charging the body positively.

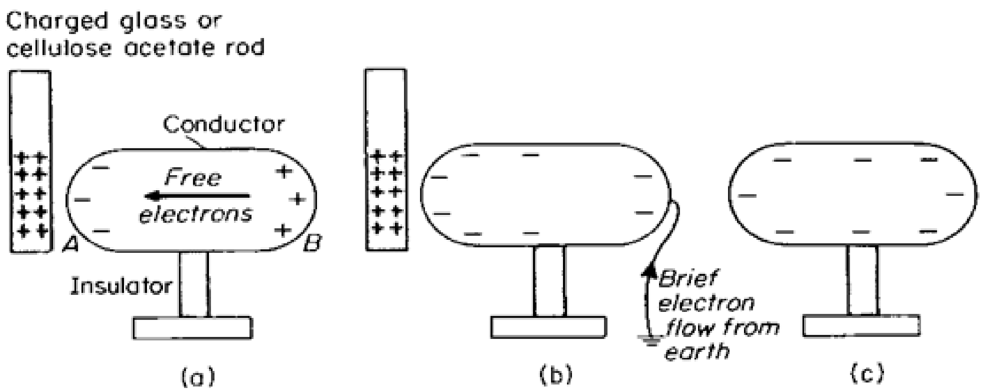


Procedure

- Put the conductor on an insulated stand as in (a)
- Bring a negatively charged rod near the conductor.
- The positive and negative charges separate as shown in (a)

- Earth the conductor by momentarily touching it with a finger and electrons flow from it to the earth as in (b) in presence of the charged rod.
- Remove the charged rod
- The conductor is found to be positively charged.

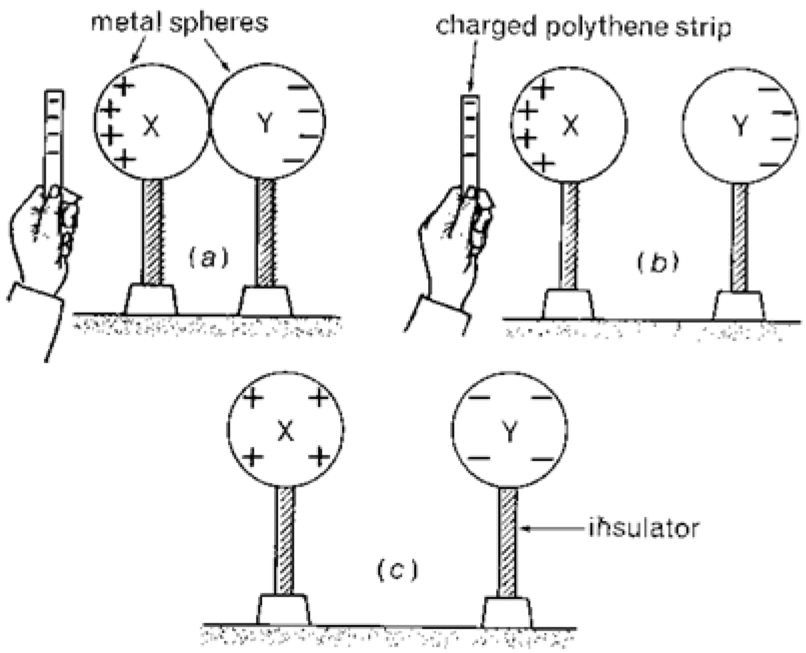
(b) Charging the body negatively by induction



Procedure

- Put the conductor on an insulated stand as in (a)
- Bring a positively charged rod near the conductor.
- The positive and negative charges separate as shown in (a)
- Earth the conductor by momentarily touching it with a finger and electrons flow from it to the earth as in (b) in presence of the charged rod.
- Remove the charged rod
- The conductor is found to be negatively charged.

(c) Charging two bodies simultaneously with opposite charges



- Support two uncharged bodies in contact on an insulated stand as shown in (a)
- Bring a positively charged rod near the two bodies
- Positive and negative charges separate as in (b).
- Separate (X) from (Y) in presence of the inducing charge.
- Remove the inducing charge
- Body (X) will be positively charged and (Y) will be negatively charged.

CONDUCTORS AND INSULATORS

A conductor is a material which allows charge to flow through it.

It has loosely bound electrons known as conduction electrons.

The flow of these electrons constitutes current flow

Examples of conductors

- All metals
- Graphite
- Acids
- Bases
- Salt solutions

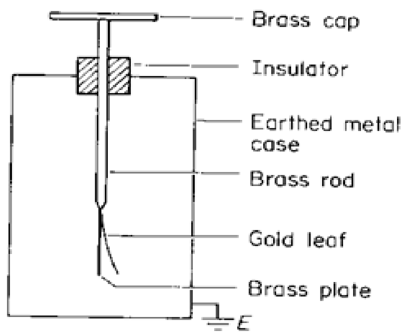
An insulator is a material which does not allow flow of charge through it.

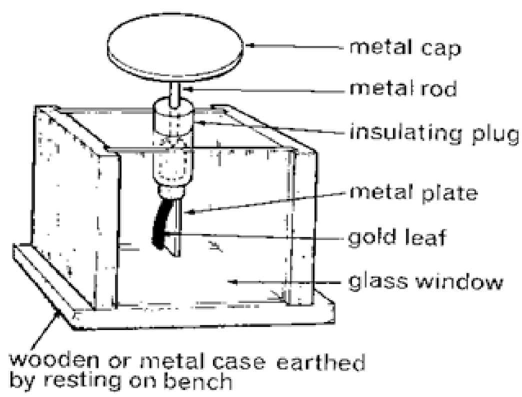
It has no conduction electrons because its electrons are strongly bound by the nuclear attractive forces

Examples of insulators

- Rubber
- Dry wood
- Glass
- Plastic
- Sugar solutions

The gold leaf electroscope

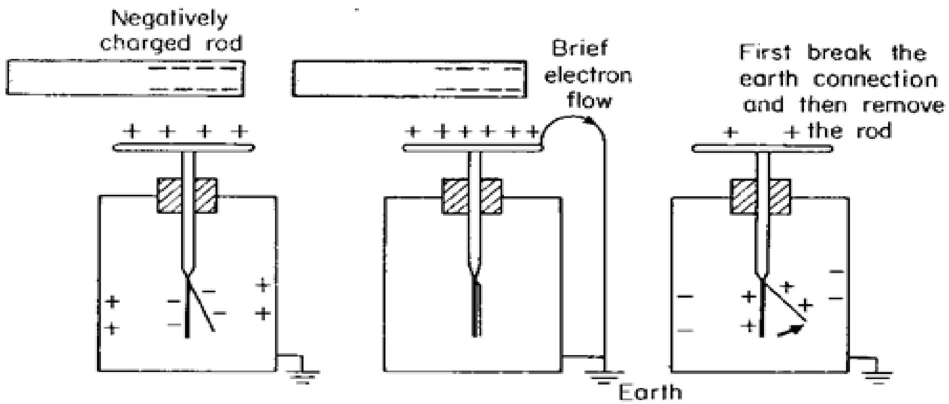




- It consists of a brass cap and brass plate connected by a brass rod.
- A gold leaf is fixed together with a brass plate
- The brass plate, gold leaf and part of brass rod are put inside a metallic box which is enclosed with glass windows.

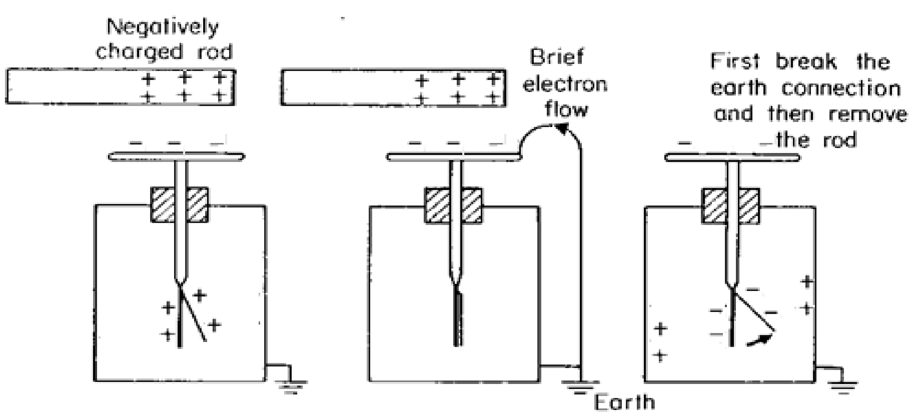
CHARGING A GOLD LEAF ELECTROSCOPE BY INDUCTION

(i) Charging it positively



- Bring a negatively charged rod near the cap of the gold leaf electroscope.
- Positive charges are attracted to the cap and negative charges are repelled to the plate and gold leaf.
- The leaf diverges due to repulsion of the same number of charges on the plates and the leaf.
- Earth the gold leaf electroscope in presence of a negatively charged rod.
- Electrons on the plate and leaf flow to the earth.
- The leaf collapses.
- Remove the negatively charged rod
- Positive charges on the cap spread out to the plate and leaf therefore the leaf diverges, hence the gold leaf is positively charged.

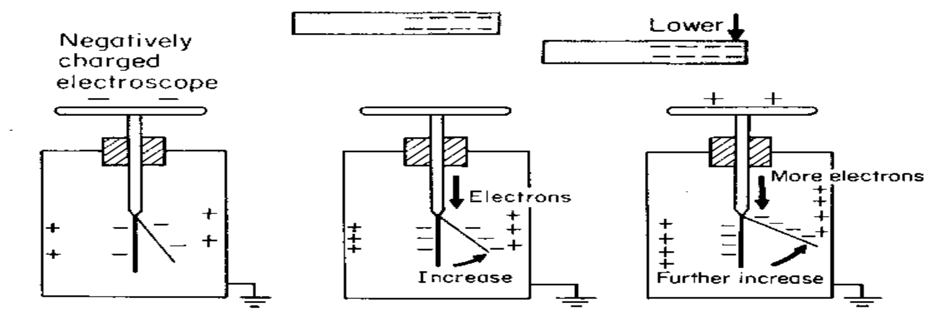
(ii) *Charging it negatively.*



- Get an uncharged gold leaf electroscope.
- Bring a positively charged rod near its cap.

- Negative charges are attracted to the cap and positive charges are repelled to leaf and brass plate.
- Earth the gold leaf electroscope in presence of a positively charged rod.
- Negative charges flow from the earth to neutralize positive charges on plate and leaf.
- The leaf collapses.
- Remove the positively charged rod, negative charges on the cap spread out on the leaf and plate, hence charged negatively

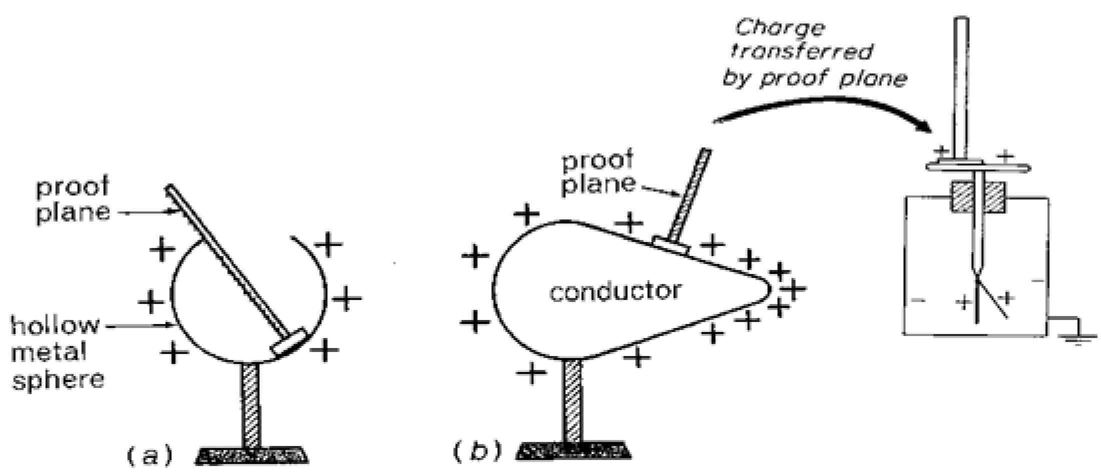
Testing for presence of charge



A negatively charged rod is brought near the cap of a negatively charged gold leaf electroscope, the leaf increases in divergence as the charged rod is lowered on to the cap

Distribution of charge on a conductor

(a) Hollow conductor



When the proof plane is placed on the outside surface of a charged hollow conductor (a) and charge is transferred to the uncharged G.L.E, the leaf diverges.

This proves that charge was present on the outside of the surface.

When the proof plane is placed on the inside of a charged hollow conductor and transferred to the uncharged G.L.E, the leaf does not diverge. Therefore, charge resides on the outside surface of the hollow charged conductor.

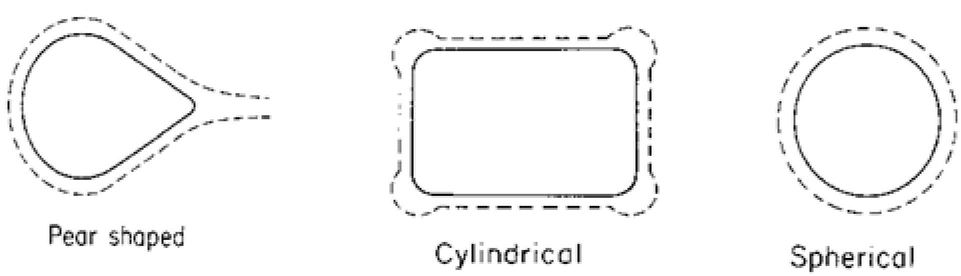
(b) Curved bodies

A curve with a big curvature has a small radius and a curve with small curvature has big radius therefore, curvature is inversely proportional to radius. A straight line has no curvature.

Surface charged density is directly proportional to the curvature. Therefore a small curvature has small charge density.

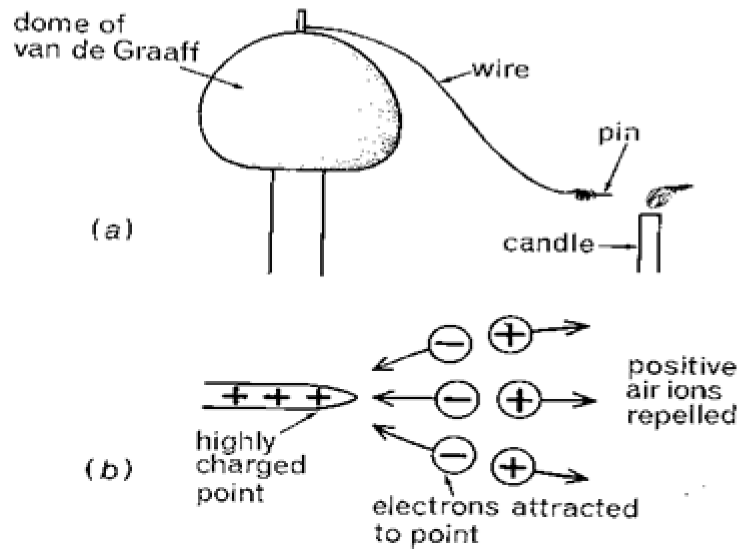
Note.

Surface charge density is the charge per unit area of the surface



Action of points

Charge concentrates at sharp points. This creates a very strong electrostatic field at charged points which ionizes the surrounding air molecules producing positive and negative ions. Ions which are of the same charge as that on the sharp points are repelled away forming an electric wind which may blow a candle flame as shown in the diagram below and ions of opposite charge are collected to the points



Therefore, a charged sharp point acts as;

(i) 'Spray off' of its own charge in form of electric wind.

(ii) Collector of unlike charges.

The spray off and collecting of charges by the sharp points is known as <u>**corona discharge**</u>

Application of action of points (corona discharge)

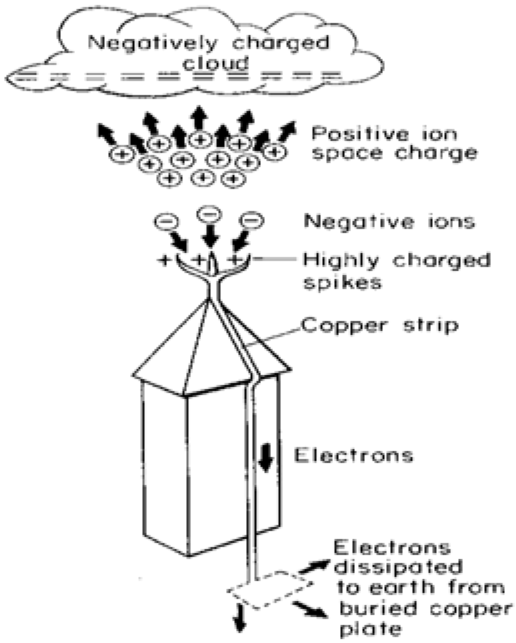
- Used in a lightening conductor.
- Used in electrostatics generators.
- Electrostatic photocopying machines.

Aircrafts are discharged after landing before passengers are allowed to board. Aircrafts get electrified but charge remains on the outer surface.

Lightening conductor

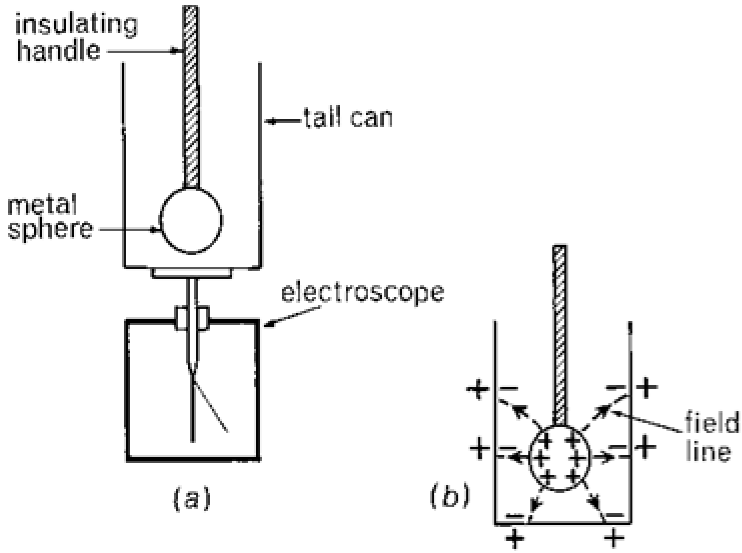
A lightening conductor is made up of a thick copper strip which is fixed to the ground and on the walls of the tall building, ending with several sharpened spikes. It is used to protect structures from damage once struck by lightening.

How it works



- A moving cloud becomes negatively charged by friction.
- Once it approaches the lightening conductor, it induces opposite charge on the conductor.
- A high charge density on a conductor ionizes the air molecules and sends a stream of positively charged ions which neutralize some of the negative charges of the cloud.
- The excess negatively charged ions are safely conducted to the earth through a copper strip.

Ice pail experiment



Electric fields

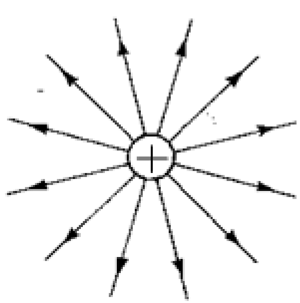
This is a region around a charged body where electric forces are experienced. Electric fields may be represented by field lines. Field lines are lines drawn in an electric field such that their directions at any point give a direction of electric field at that point. The direction of any field at any given point is the direction of the forces on a small positive charge placed at that point.

Properties of electric field lines

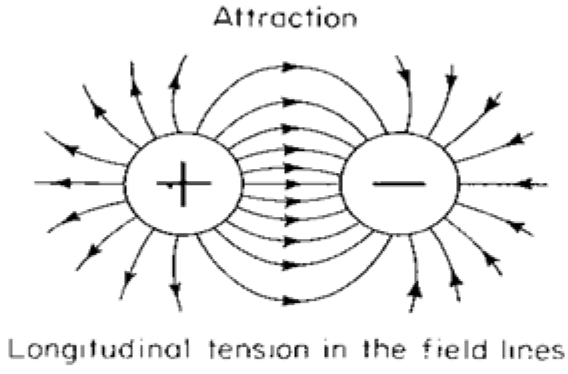
- They begin and end on equal quantities of charge.
- They are in a state of tension which causes them to shorten.
- They repel one another side ways.

Field patterns

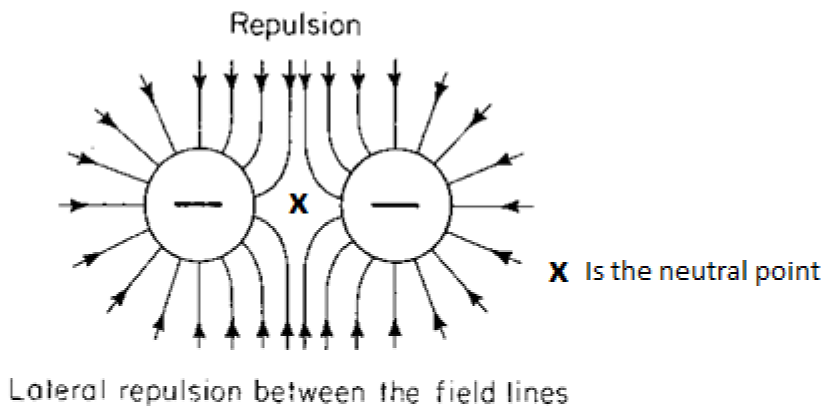
(a) Isolated charge



(b) Unlike charges close together



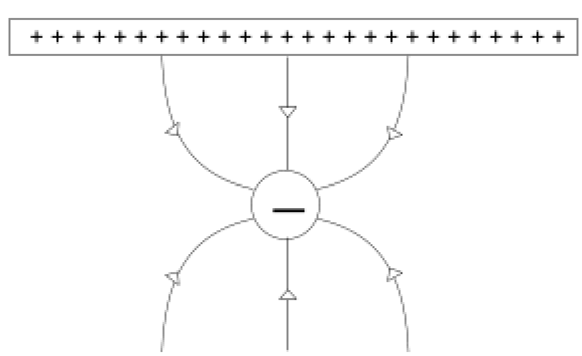
(c) Like charges close together



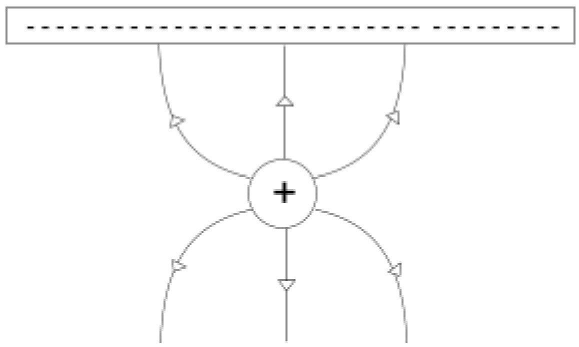
A neutral point is a region where the resultant electric field is zero i.e. field lines cancel each other and therefore no resultant electrostatic forces exists.

(d) Field between charged points and plates

(i) Negative charge close to a positively charged plate



(ii) *Positive charge near a negatively charged plate*



MODERN PHYSICS

STRUCTURE OF AN ATOM

An atom consists of three particles namely -:

- Protons
- Neutrons
- Electrons

It is made up of the central part called nucleus around which electrons rotate in orbits. The protons and neutrons lie within the nucleus and these particles are sometimes referred to as nuclear particles or nuclide

Name	Symbol	Sign of change
Protons	${}^{1}_{1}H$	Positive
Neutrons	${}^{1}_{0}n$	No change
Electrons	${}^{0}_{-1}e$	Negative

The nucleus is positively charged

ISOTOPES

These are atoms of the same element having the same atomic number but different mass numbers

ATOMIC NUMBER

This is the number of protons in the nucleus of an atom

MASS NUMBER

This is the sum of number of protons and neutrons in the nucleus of an atom. It is sometimes called atomic mass. It is expressed as;

$^{Z}_{A}X$ Where A- atomic number and Z – mass number

e.g. Given that $^{35}_{17}Cl$ determine:

a) Number of protons = 17

b) Number of neutrons = 18

PRODUCTION OF ELECTRONS

Electrons are ejected from a metal surface in two processes, namely;

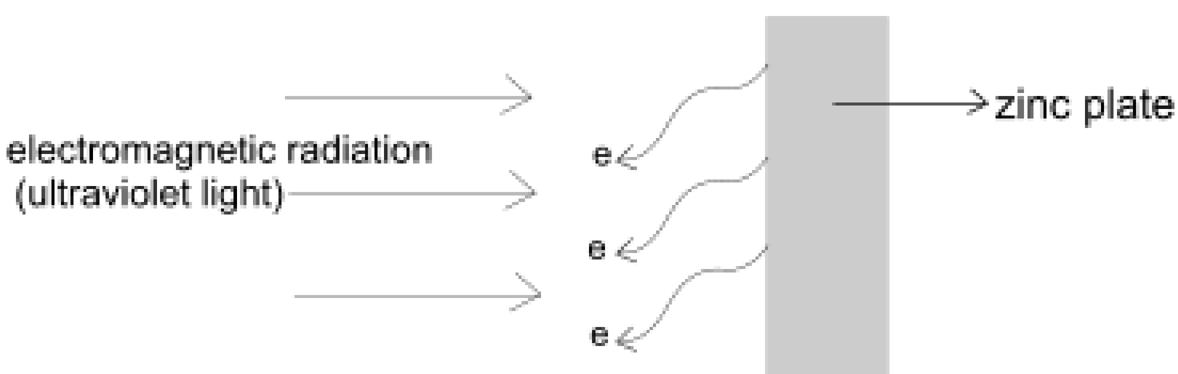
1. Thermionic emission
2. Photoelectric emission

1. **Thermionic emission**

   This is the process by which a metal surface gives off electrons due to heating it

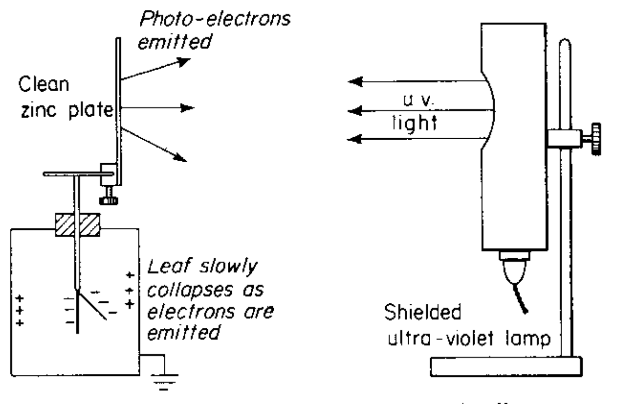
2. **Photoelectric emission**

   This is the process by which a metal surface gives off electrons due to an electromagnetic radiation of short wavelength falling on it



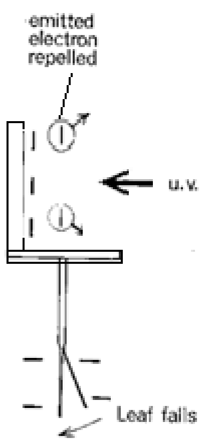
PHOTOELECTRIC EFFECT

When an ultraviolet radiation is shone on a zinc plate placed on the cap of a negatively charged gold leaf electroscope, the divergence of the leaf reduces



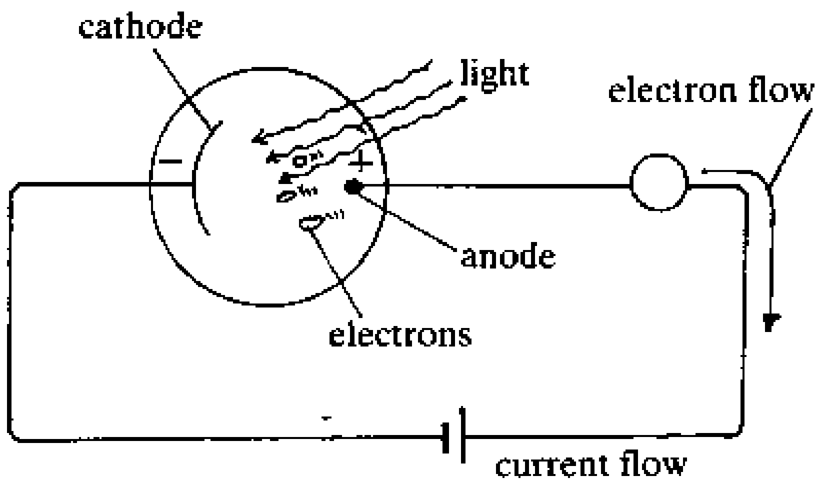
Explanation

The leaf divergence reduces because electrons are emitted from the zinc plane by photoelectric emission, so it is due to loss of charge



Application of photoelectric effect

Consider a zinc plate and an anode closed in vacuum in which an ammeter and a cell are connected in series as shown below.



Electrons are produced by zinc atoms photo electrically

These electrons are attracted by the anode and produce current in the circuit hence the ammeter deflects.

If gas is introduced, current increases slowly because gas particles collide with electrons and hence this reduces the number of electrons reaching the anode.

CONDITIONS FOR PHOTOELECTRIC EFFECT TO TAKE PLACE

- Depends on the nature of the metal.
- Light incident on the metal surface must have a certain minimum frequency known as threshold frequency.

Question

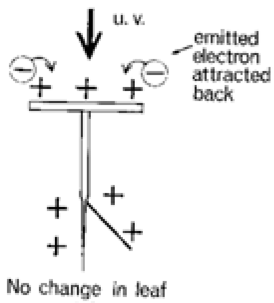
Ultraviolent radiation is incident on a clean zinc plate resting on the cap of a charged G.L.E. Explain what is observed is

i) The G.L.E is positively charged

ii) Radio wave is used instead of ultraviolent radiation.

ANSWER

i. No further divergent of the leaf is observed because the ultraviolent radiation eject electrons from the metal surface but the electrons are immediately attracted back hence no loss of charge.



ii. Radio waves have low energy thus are unable to eject electrons so there will be no effect on the leaf divergence of the electroscope.

RADIOCTIVITY

This is the spontaneous disintegration of heavy unstable nuclei to form stable nuclei accompanied by release of energetic particles like beta particles, gamma rays and alpha particles.

ALPHA PARTICLES

An alpha particle is a helium atom which has lost 2 electrons. An alpha particle has mass 4 and atomic number 2 which is positively charged.

PROPERTIES OF ALPHA PARTICLES

Ionize gases

Have a high ionizing power compared to gamma rays

They are deflected by magnetic fields

They are deflected by electric fields

They are positively charged

They penetrate matter

Have a low penetrating power compared to beta particles.

When un stable nuclei emits an alpha particle, the mass reduces by 4 and atomic number by 2 e.g. a radioactive substance $^{238}_{92}X$ Undergoes decay and emits an alpha particle to form Y.

Write an equation for the process

$$^{238}_{92}X \longrightarrow {}^{x}_{y}Y + {}^{4}_{2}He$$

238 =x + 4 x =234

92 = y + 2 y = 90

$$^{238}_{92}X \longrightarrow {}^{234}_{92}Y + {}^{4}_{2}He$$

BETA PARTICLES

These are fast moving electrons. When radioactive nuclei decay by emitting a beta particle, mass number is not affected but the atomic number increases by one.

PROPERTIES OF BETA PARTICLES

They carry negative charge

They cause ionization of gases

They are deflected by electric fields

They are deflected by magnetic fields

They can penetrate matter which is not too thick

E.g. unstable nuclei $^{226}_{88}X$ decays to form a stable nuclei Y by emitting a beta particle

$$^{226}_{88}X \longrightarrow {}^{n}_{m}Y + {}^{0}_{-1}e$$

226 = n + 0 n =226

88 = m + $^{-}$ 1 = 89

$$^{226}_{88}X \longrightarrow {}^{226}_{89}Y + {}^{0}_{-1}e$$

Write down an equation for the process

$$^{246}_{107}X \longrightarrow {}^{x}_{y}Y + {}^{0}_{-1}e$$

GAMMA RAYS

These are electromagnetic radiation with the shortest wave length. When unstable nuclei decay by emitting gamma rays, the mass and atomic number are not affected

PROPERTIES OF GAMMA RAYS

They have no charge

They ionize gases although they have the least ionizing power compared to beta and alpha particles

They are not deflected by electric fields

They are not deflected by magnetic fields

They penetrate matter

They have the greatest penetrating power compared to other particles

SIMILARITIES BETWEEN ALPHA AND BETA PATICLES

Both ionize gases

They both penetrate matter

They are both deflected by electric fields

They are both deflected by magnetic fields

DIFFERENCES BETWEEN ALPHA AND BETA PARTICLES

Alpha particles carry positive charges while beta particles carry negative charges

Alpha particles have lower penetrating power compared to beta particle

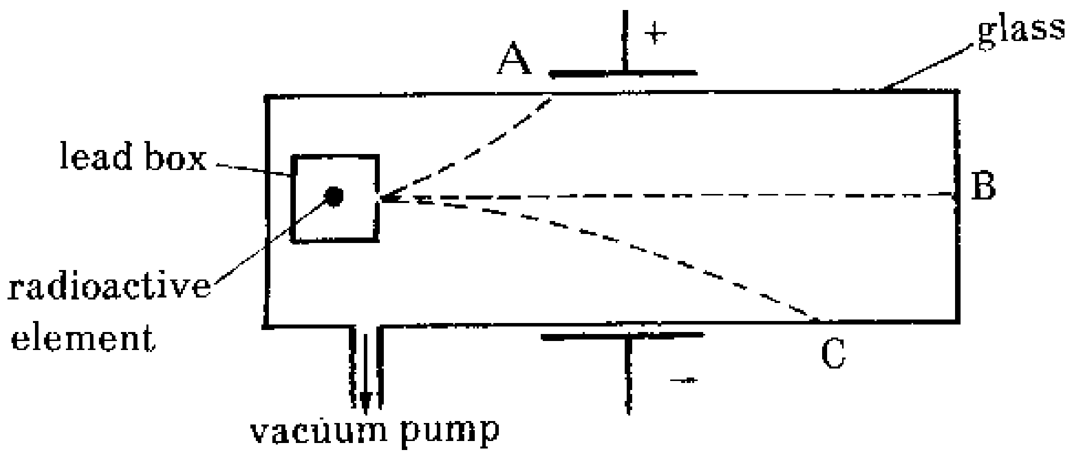
Alpha particles have a high ionizing power compared to beta particles

Deflection for beta particles in electric fields is towards the positive while that of the alpha particles is towards the negative plate

Alpha particles are helium particles which have lost two electrons while beta particle are high energy electrons

Beta particles are deflected much more than the alpha particles due to their smaller charge – mass density

DEFLECTION OF THE ABOVE RADIATION IN AN ELECTRIC FIELD

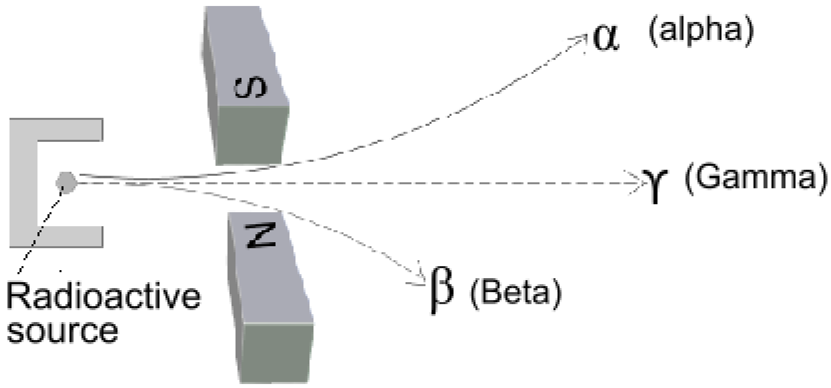


A RADIOACTIVE ELEMENT

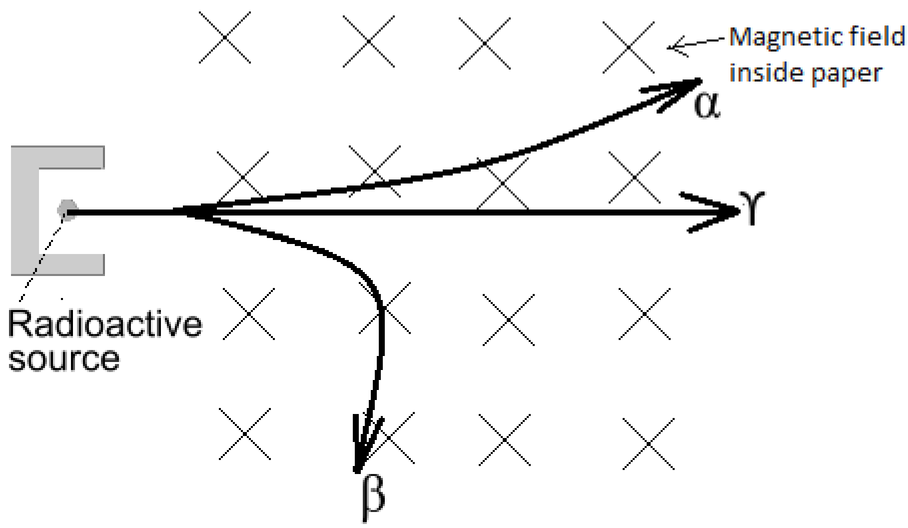
This is an element whose nucleus disintegrates gradually and continuously emits powerful and invisible radiations

- The alpha particles are deflected towards the negative plate indicating that they are positively charged.
- The beta particles are deflected towards the positive plate indicating that they are negatively charged.
- While gamma rays go through the field un deflected showing that the carry no charge.

DEFLECTION BY A MAGNETIC FIELD



OR



- The beta particle is deflected down wards because they are negatively charged.
- While alpha particles are deflected upwards according to Flemings left hand rule.
- Gamma rays are not deflected because they possess no charge.

DANGER OF RADIATIONS

- Beta and alpha particles cause skin burns and sores
- Can cause cancer, leukemia and affect eye sight.
- May damage body cells (reproductive organs and liver)

SAFETY PRECAUTIONS WHEN DEALING WITH RADIOACTIVE SOURCES

- Radioactive sources should be held with forceps.

- Avoid eating, drinking or smoking where radioactive sources are in use.
- Radioactive sources must be kept in lead boxes
- Wash hands thoroughly after exposing to radioactive materials
- Any cut on the body should be covered before dealing with radioactive sources.

USES OF ALPHA, BETA, AND GAMMA RAYS

1. **Industrial uses**
    - Used in tracer techniques to investigate the flow of liquids in chemical plants.
    - Used in the automatic control of thickness of material in industries.
    - Study of wear and tear in machinery.
    - Gamma ray are used to detect faults in thickness of metals sheets in welded joints
2. **Medical uses**
    - Control amount in treatment of cancer
    - They are used to kill bacteria in food (x- rays)
    - Used to sterilize medical equipments like syringes
3. **Archeology**

- Used to determine the time that has elapsed since death of organisms occurred, a process called ***carbon dating***.

4. **Geology**

    They are used to determine the age of rocks

IONISING EFFECTS OF RADIATIONS

- When a radioactive source is brought near the cap of a charged gold leaf electroscope, the leaf falls, this shows that the G.L.E has been discharged as a result of the ionization of air around the cap.
- If the G.L.E is positively charged negative ions or (electrons) from air attracted and the gold leaf falls and if is negatively charged, positive ions are attracted and leaf also falls.

The cloud chamber

When a radioactive source emits particles in an air space saturated with vapour inside a vessel with glass window, the particles collide with the air molecules and knock off electrons due to their high speeds. Because of the knock, positive and negative ion trails are created. If the air space is expanded by moving the piston to increase the volume, cooling occurs and vapour condenses out on ions, thus revealing the paths of the particles (tracks)

ALPHA PARTICLES

These are short straight and bold tracks. This is because they are massive and pursue straight paths, pulling electrons off atoms as they go thus creating many ion pairs

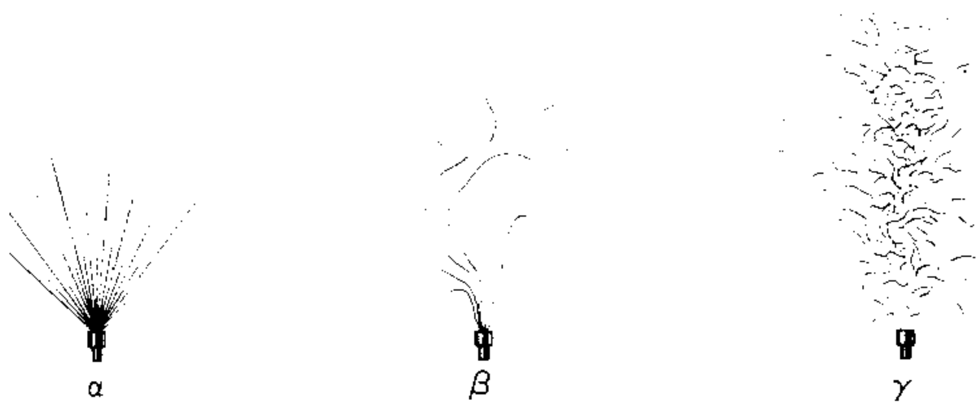
BETA PARTICLES

These display thin irregular cloud tracks. This is because they face a lot of repulsions from electrons of nearby atoms and due to this, they make just a few ion – pairs

GAMMA RAYS

Gamma rays do not produce cloud tracks along their own paths because they do not ionize gases. Gamma rays may however interact with an atom in its path and give off part or all its energy to the atom to eject an electron from it. The electron is given off as a β – particle and comes off from the path of the gamma rays

<u>The tracks as explained above</u>



Back ground radiation

These are radiations which naturally exist even in the absence of radioactive source. They are caused by natural tracks of radioactive materials in rocks. Cosmic rays from outer space.

These cosmic rays are very high energetic radioactive particles which come from deep in space.

So the correct count = actual rate - back ground count rate.

Example

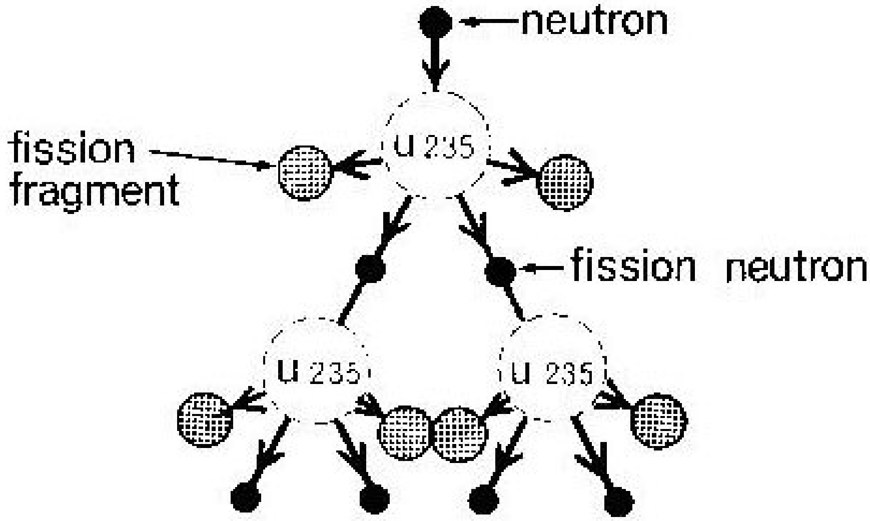
Given that the back ground rate is 2 counts per minute and the Geiger Muller count rate is 25 counts per minute. Determine the approximate number of radiations present.

Count rate = 25 - 2 = 23c/min

NUCLEAR FISSION

This is the splitting of nucleus of heavy atoms into two lighter nuclei. This process can be started by bombardment of a heavy nucleus with a neutron. The products of the process are two light atom and more neutrons which can make a process continue. The products of the reaction are two light atoms and have less mass than the correct value. The difference in the mass is due to energy loss.

$$\underbrace{{}^{235}_{92}U}_{} + \underbrace{{}^{1}_{0}n}_{\text{neutron}} \rightarrow \underbrace{{}^{144}_{56}Ba + {}^{90}_{36}Kr}_{\text{fission fragments}} + \underbrace{2{}^{1}_{0}n}_{\text{neutrons}}$$



APPLICATION OF NUCLEAR FISSION

Used in making atomic bombs

Used to generate electricity

Used to generate heat energy on large scale

CONDITIONS FOR NUCLEAR FISSION TO OCCUR

The Neutron should be moving at a high speed when meeting the heavy nucleus

There should be a heavy nucleus splitting into light nuclei

NUCLEAR FUSION

This is the union of two light atomic nuclei to form a heavy atom. It involves the release of energy e.g.

$$ {}^{2}_{1}H + {}^{2}_{1}H \longrightarrow {}^{4}_{1}He + \text{energy} $$

$$ {}^{2}_{1}H + {}^{2}_{1}H \longrightarrow {}^{4}_{1}He + {}^{2}_{1}n + \text{energy} $$

CONDITIONS FOR A NUCLEAR FUSION TO OCCUR

- Temperature should be very high
- The light nuclei should be at very high speed to overcome nuclear division.

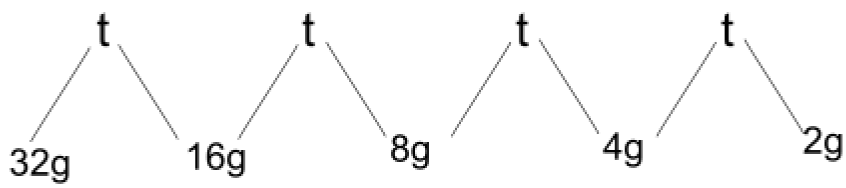
USES OF NUCLEAR FUSSION

- Used to produce hydrogen.
- Used to produce electricity.
- Used to produce heat energy on large scale.

HALF LIFE

It is the time taken for radioactive substance to decay to half of its original mass e.g.

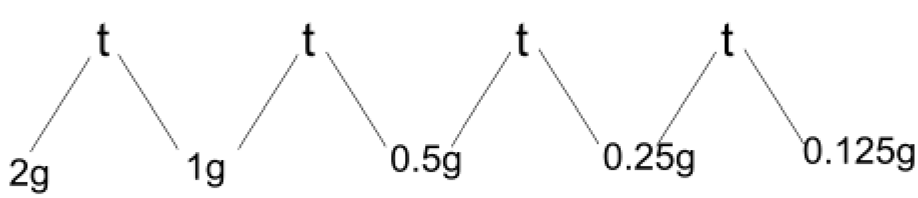
1. If a radioactive element of mass 32 decays to 2g in 96 days, calculate the half life.



4t =96 t=24 days

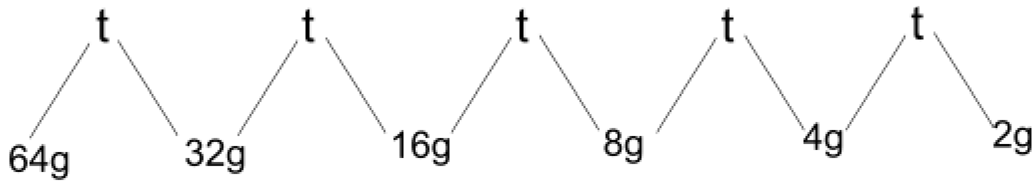
2. A certain radioactive substance takes 120years to decay from 2g to 0.125g. Find the half life

Let it be t



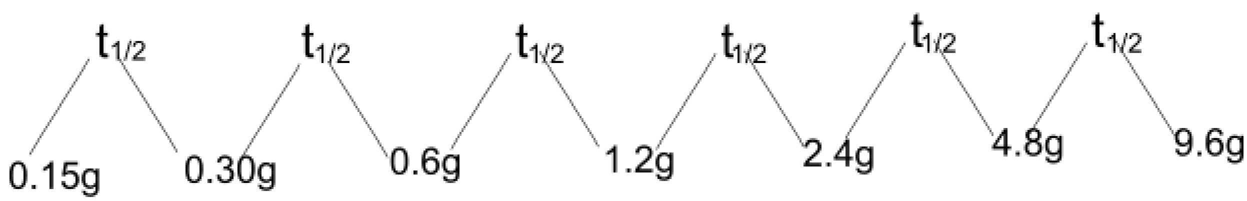
4 t = 120 t =30 years

3. The half life of a substance is 5days. Find how long it takes for its mass to disintegrate from 64g to 2g



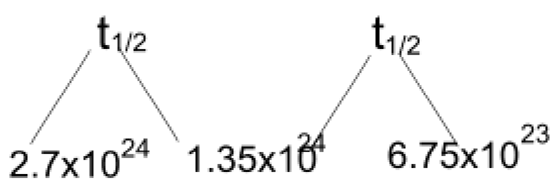
5 x 5 =25 days

4. A radioactive element has a half life of 4years. if after 24hours 0.15g remains calculate the initial mass of the radioactive material



M_o = 9.6 days

5. A certain mass of a radioactive material contains 2.7×10^{24} atoms, how many atoms decayed after 3200years if the half life of material is 1600years



Mass remaining = 6.75×10^{23} atom

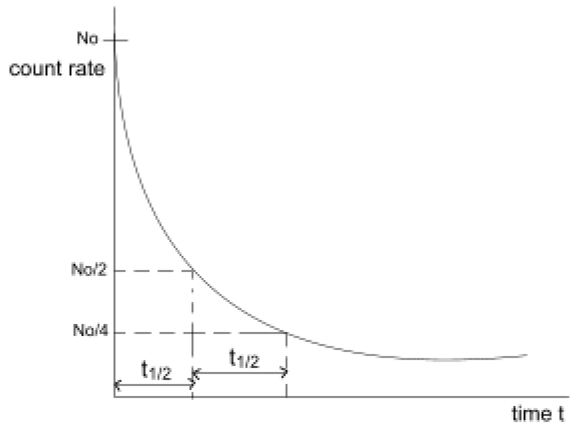
Mass decays = original mass - mass remaining

$= (2.7 \times 10^{24} - 6.75 \times 10^{23})$

$= 2.025 \times 10^{24}$ atoms

GRAPHICAL METHOD OF DETERMINING HALF LIFE

When a graph of account rate against time or radioactive nuclei is drawn, the half life of the radioactive nuclei can be determined as below.



Examples

1) The following values obtained from the readings of a rate meter from a radioactive isotope of iodine

Time (min)	0	5	10	15	20
Count rate (Min^{-1})	295	158	86	47	25

Plot a suitable graph and find the half life of the radioactive iodine

2) The following figures were obtained from Geiger Muller counter due to ignition if the sample of radon gas

Time(min)	0	102	155	…….	300
Rate (min^{-1})	1600	…….	200	100	50

a. plot a graph of count rate against time
b. Determine the half life
c. Find the missing values

d. What is the count rate after 200 minutes
e. After how many minutes is the count rate 1000 minutes?

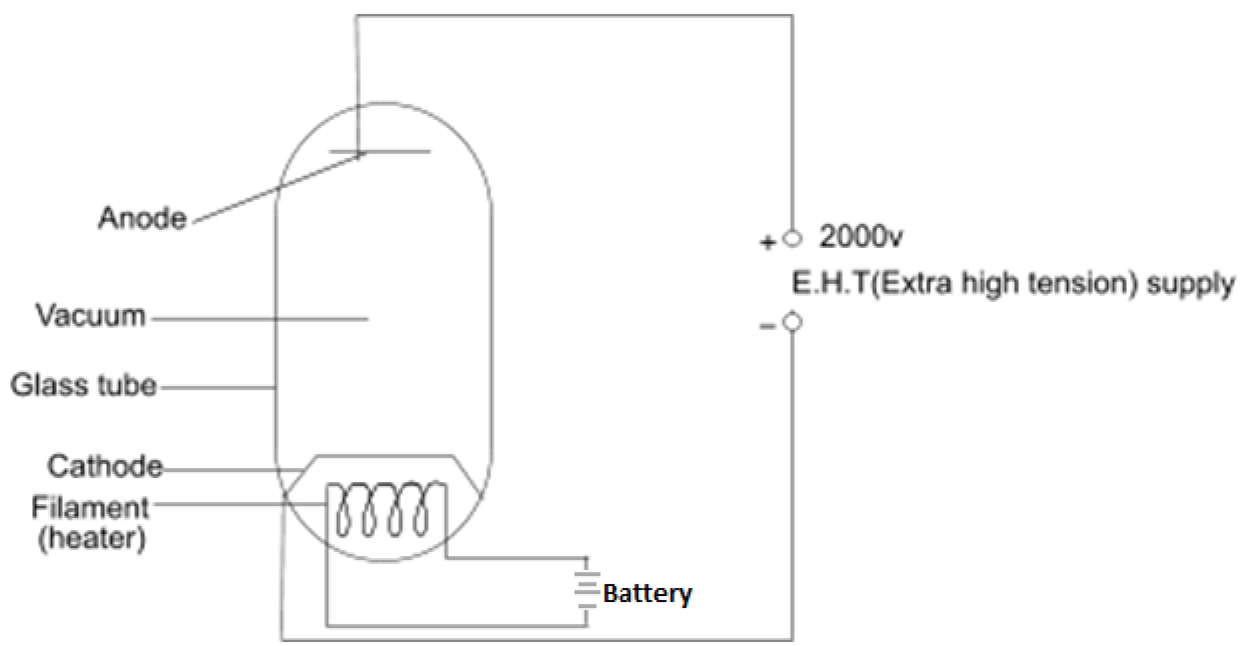
CATHODE RAYS

These are streams of fast moving electrons

They are negatively charged particles

PRODUCTION OF CATHODE RAYS

The circuit is connected as shown



The filament is heated by an electric current through it

The filament heats up the cathode

The cathode emits electrons by thermionic emission

The large p.d across the vacuum accelerates the electrons to move from cathode to the anode

The vacuum ensures that electrons move freely so that they do not collide with air molecules.

PROPERTIES OF CATHODE RAYS

They carry a negative charge

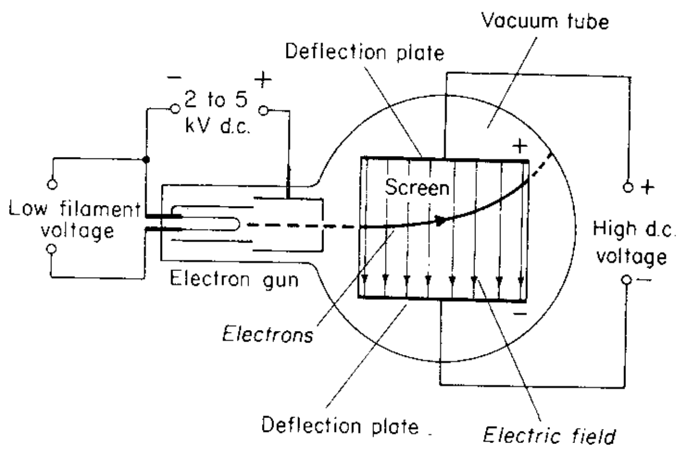
They are deflected by both electric and magnetic field

They ionize gases

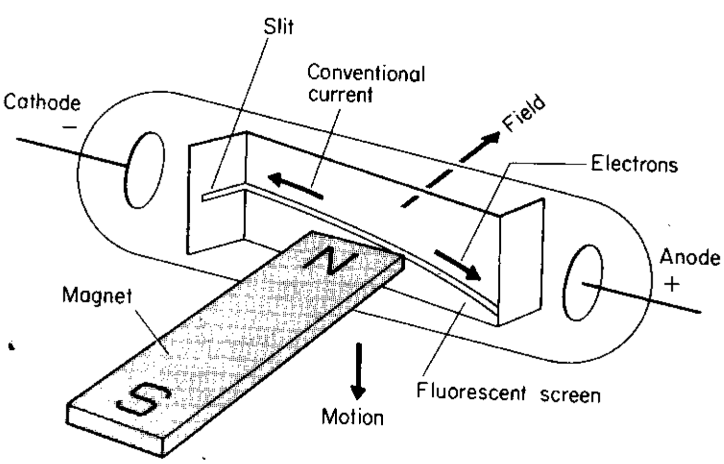
They cause fluorescence to some substance e.g. zinc sulphide

In an electric field, cathode rays are deflected towards the positive plate and in the magnetic field, the direction of deflection is determine using Flemings left hand rule

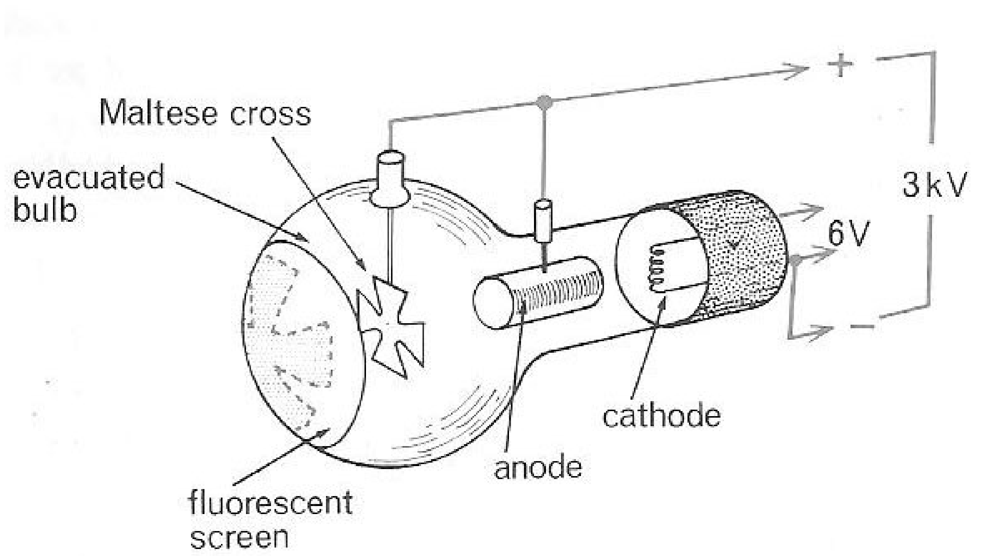
Electric field



Magnetic field



EXPERIMENT TO SHOW THAT CATHODE RAYS TRAVEL IN STRAIGHT LINE (THERMIONIC TUBE)



Cathode rays are incident towards the Maltese cross.

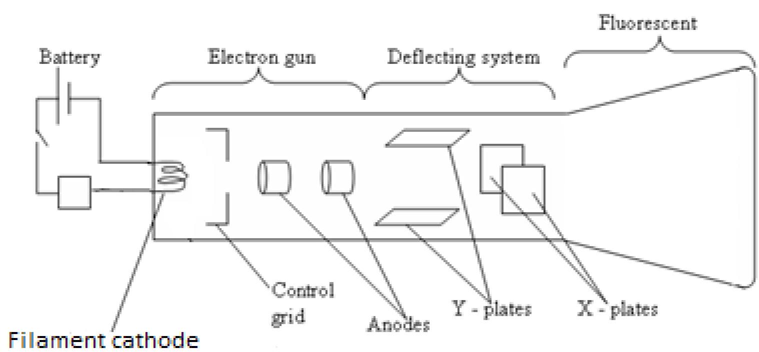
A shadow of the cross is formed on the fluorescent screen.

The formation of the shadow verifies that cathode rays travels in a straight line.

Application of thermionic emission

The thermionic emission is utilized in cathode ray oscilloscope (C.R.O) X –ray tube, TV etc

THE C.R.O



The C.R.O consists of three main components.

1. The electron gun , this consists of the following parts

I) The cathode – used to emit electrons

II) The control grid – this is connected to low voltage supply and is used to control the number of electrons passing through it towards the anode.

III) The anode – the anode is used to accelerate the electrons and also focus the electrons into a fine beam.

N.B

Since the grid control the number of electrons moving towards the anode. It consequently controls the brightness of the spot on the screen. As the grid control is made more negative, it repels most of the electrons, allowing a few to reach the screen hence screen appears dark. When it is made more positive, it attracts the electrons hence brightening the screen.

2. **Deflecting system**

   This consists of the x and y plates. They are used to deflect the electron beam horizontally and vertically respectively.

3. **Fluorescent**

   This is where the electrons beam is focused to form a bright spot. The zinc sulphide coating on the fluorescent screen converts kinetic energy in light and produce a bright spot when the electrons beam is focused on it.

   Time base switch – this is connected to the X – plate and is used to move the bright spot on the screen horizontally. The time base generates p.d across the X – plate in that as the time base is switched on, the spot sweeps steadily and horizontally, repeatedly from left to right and this leads to generation of an Ac voltage.

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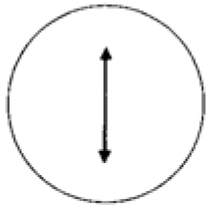
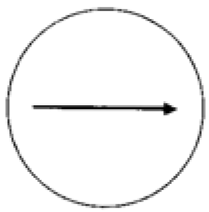
ACTION OF A C.R.O

When alternating current (a.c) is applied to the y- plate and time base (x –plate) is off, the spot is deflected vertically. The vertical line observed.



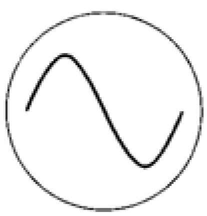
Y−plate a.c.
signal only

When time base (x- plate) is switched on and there is no signal on the y-plate, the spot is deflected horizontally. The horizontal line is observed.



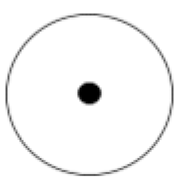
X−plate sweep
only

When a.c is applied on the y-plate and time base is on, a wave form is observed on the screen.



Sweep and
Y−plate signals
combined

When time base is switched off and no signal to the y- plate, a spot is only observed.



Time base off
no signal on y-plate

USES OF A C.R O

1. **Frequency measurements**

This is achieved by comparing a wave form of known frequency with unknown frequency

Method

Adjust the time base of a C.R.O until one complete wave is obtained without altering the control grid of the C.R.O; apply a signal of known frequency.

Then compare the frequency by counting the number of complete waves.

2. **Measurement of p.d**

   A C.R.O can be used as voltmeter because the distance spot is deflected depends on the p.d between the plates

   Method

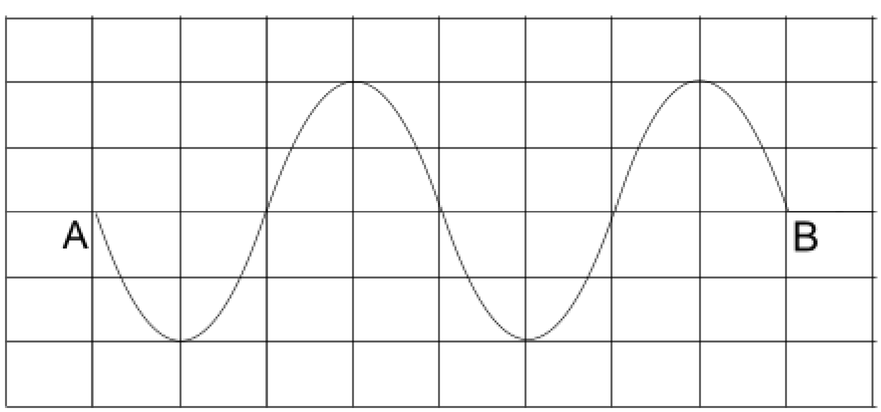
   Connect a cell 1.5V to the y-plate and adjust the grid control until the trace indicating the p.d is 1cm above 0 so that every 1cm deflection represents a p.d of 1.5V

   Get unknown p.d and connect it to y-plate and then compare the deflection by counting the number of cm deflected. This means that we can measure unknown p.d.

3. Used to study wave forms of current and voltage
4. Used in manufacture of T.V.

Example

1. A C.R.O with time base switch on is connected across a power supply; the wave form shown below is obtained.



Distance between each line is 1cm

i) identify the type of voltage generated from the power source

Alternating current

ii) find the amplitude of voltage generated if voltage gain is 5V per cm

Amplitude = 2cm, 1cm = 5V

2cm is equivalent to (5 x 2) V

= 10V

(iii) Calculate the frequency of power source is the time base setting on the C.R.O is

Time for 2 cycles = 8 x 5.0 x 10^{-3}

Time for 1 cycle =

= 0.02s

Frequency = = = 50HZ

2. (a) Give one reason why it is possible to a wider screen in a television set than in a C.R.O.

In T.V, deflection of electron beam is by magnetic field which gives a wider deflection. In C.R.O, it is by electric field which gives a smaller deflection.

(b) State one advantage of using a C.R.O. as a voltmeter.

- Can measure both A.C and D.C voltages.
- Not damaged by over loading.
- Electrons act like a pointer of negligible inertia.
- Has definite resistance hence accurate.

X – RAYS

X – Rays are radiations of electromagnetic wave that are produced when first moving electrons are stopped by dense matter.

In the X – ray tube electrons from the hot cathode are accelerated across the vacuum by a large potential difference. On reaching the Anode, the first moving electrons hit the target of tungsten which decelerates them resulting into the production of X – rays.

The target should be of a high melting point because during the hitting of the target, very high temperatures build up, so the high melting point is to make the target able to withstand the high temperatures.

Key Characteristics of X-Rays:

High Energy and Penetrating Power: X-rays have enough energy to pass through most objects, including human tissue. This makes them valuable for medical imaging and security scans.

Ionizing Radiation: X-rays are ionizing, meaning they have enough energy to remove tightly bound electrons from atoms, thus ionizing them. This property is both useful in applications like cancer treatment and potentially harmful, as it can damage or destroy living tissue.

Production:

X-rays are typically produced in two main ways:

Bremsstrahlung (Braking Radiation): When high-speed electrons are decelerated or deflected by the electric field of atomic nuclei, X-rays are emitted.

Characteristic X-rays: When electrons transition between different energy levels within an atom, typically after being knocked out of their inner shells, X-rays of specific energies are emitted.

Applications of X-rays:

Medical Imaging: X-rays are extensively used in radiography to create images of the inside of the body, helping in the diagnosis and monitoring of conditions such as fractures, infections, and tumors. Techniques like computed tomography (CT) use X-rays to create detailed cross-sectional images.

Dental Imaging: Dentists use X-rays to inspect teeth and jaw structures for cavities, bone loss, and other issues.

Security: X-ray machines are used in airports and other secure areas to scan luggage and packages for dangerous items.

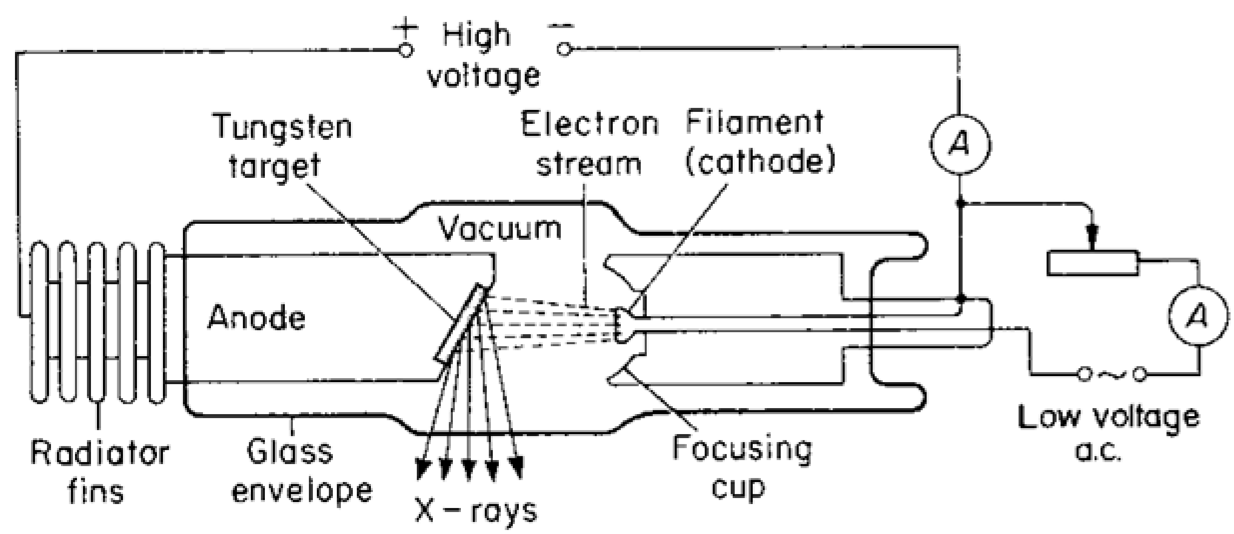
Industrial Applications: X-rays are employed in non-destructive testing to inspect the integrity of materials and structures, such as pipelines, aircraft, and buildings.

Scientific Research: X-ray crystallography is a technique used to determine the atomic and molecular structure of a crystal by scattering X-rays on the crystal and analyzing the diffraction pattern.

Safety and Risks:

While X-rays are invaluable in many fields, exposure to high doses or prolonged exposure to X-rays can be harmful, increasing the risk of cancer and other health issues. Therefore, safety protocols are essential to minimize exposure, such as using lead aprons in medical settings and maintaining adequate shielding in industrial applications.

<u>X – Ray tube</u>



The low voltage source heats the filament

Electrons are emitted from the heated filament by thermionic emission

Electrons are accelerated towards the anode by a high voltage

When a stream of moving electrons hits the target, the electrons give off a high part of their energy which is converted into heat and a small part of their energy is converted into X – rays.

The energy given off by the electrons in form of heat is conducted away by the anode to the cooling fins.

<u>Properties of X – rays</u>

- They are not deflected by magnetic field
- They are not deflected by electric field
- Travel in straight lines
- Have no charge
- Affect photographic paper or film
- Cause fluorescence of some substances
- They penetrate matter
- Cause ionization of gases

<u>Types of X – rays</u>

They include;

1. Hard X – rays
2. Soft X – rays

1. <u>Hard X – rays</u>

   These are X – rays which have a high penetrating power.

   They have very short wave lengths

   These X – rays are produced by high velocity electrons

   The shorter the wave length of the X – rays the greater the penetrating power

   They can penetrate the flesh but are stopped by the bones

2. Soft X – rays

These are X – rays produced by electrons moving at relatively low velocities than those that produce hard X – rays

They have longer wave lengths

They have less energy

They have less penetrating power compared to hard X – rays

They are used to show malignant growth in tissues

Uses of X – rays

a) Medicine

- To locate fractures in human bodies
- Used to destroy cancer cells
- Used to investigate lungs to detect tuberculosis
- Used to treat cancer especially when it hasn't spread by radiotherapy i.e very hard x-rays are directed to the cancer cells so that the latter are destroyed
- Used to detect internal ulcers along a digestive track
- Used to locate swallowed metal objects

b) Industrial

- Used in crystallography censor to study the structure of crystals
- Used to detect cracks in car engines and pipes
- Used in inspection of car tyres
- Used to locate internal imperfections in welded joints e.g pipes, boilers storage tanks e.t.c.
- Used to detect cracks in building

Health hazards of X – rays

- They damage body cells

- They damage eye sight
- They cause cancer
- They can cause genetic changes which may appear after some generations

Safety precautions of X – rays

- Avoid unnecessary exposure to X – rays
- X – ray apparatus should be shielded in thick lead
- Exposure to X – rays should be to the affected part only
- There should not be exposure of X – rays to born or unborn babies
- Wear lead coats while dealing with X – rays
- Exposure should be for a short time

HOW AN X-RAY IS USED TO LOCATE BROKEN PARTS OF A BONE .

Bones are composed of much denser material than flesh hence if x- rays are passed through the body, they are absorbed by the bones onto a photographic plate which produces a shadow photograph and bones

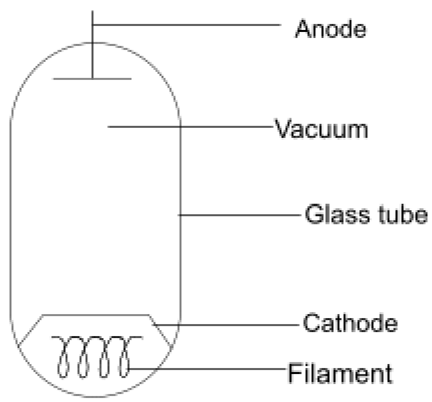
DIFFERENCES BETWEEN CATHODE RAYS AND X-RAYS

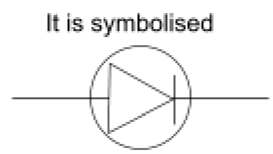
CATHODE RAYS	X- RAYS
Negatively charged	Neutral
Low penetrating power	Highly penetrating
Can be deflected by both electric and magnetic fields	Cannot be deflected by electric and magnetic fields
Travel at a low speed	Travel at high speed

THERMIONIC DIODE (diode valve)

A diode is an evacuated glass containing anode and cathode and restricts current in one direction i.e. does not permit the reverse direction.

A cathode can be directly heated by passing current through it or can be indirectly heated by passing filament wire close to it.



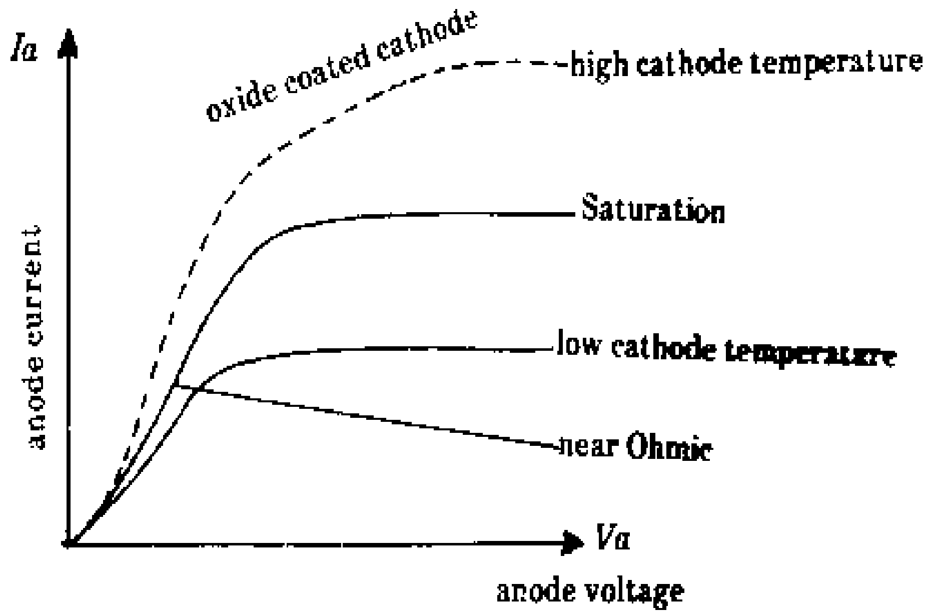


ACTION

When the cathode gets heated, it emits electrons to form a space charge around it which is then attracted by the anode causing flow of electrons.

The electrons at the anode are detected by the milli ammeter connected to the anode

By varying the anode potential for different heater currents a graph of anode current I_a against its voltage V_a is obtained as below.



From the graph, it is observed that –

I) The higher the heater current, the higher number of attractions to the anode.

II) A certain value of anode potential, all electrons available at the cathode are being attracted to the anode ,this is known as saturated point and the corresponding current is known as saturation current.

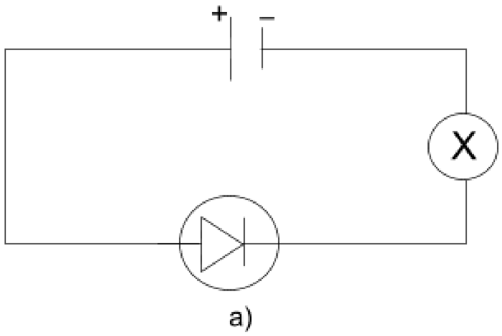
III) Saturation current is the maximum current flowing in a diode at a particular temperature.

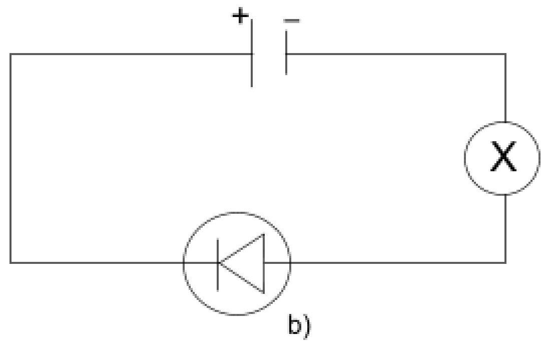
The most important property of diode is that it conducts in one direction with low resistance and in opposite direction, it has a very high resistance. Therefore it acts as a rectifier.

Diode as a rectifier

A rectifier allows current to flow in one direction

Rectification is the process of converting a.c to d.c.





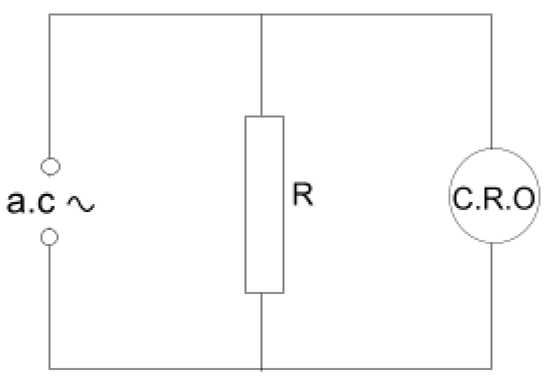
In (a) it is a forward bias so the bulb lights

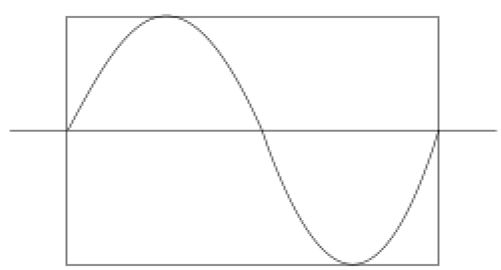
In (b) it is a reverse bias the bulb doesn't light.

PROCESS OF RECTIFICATION

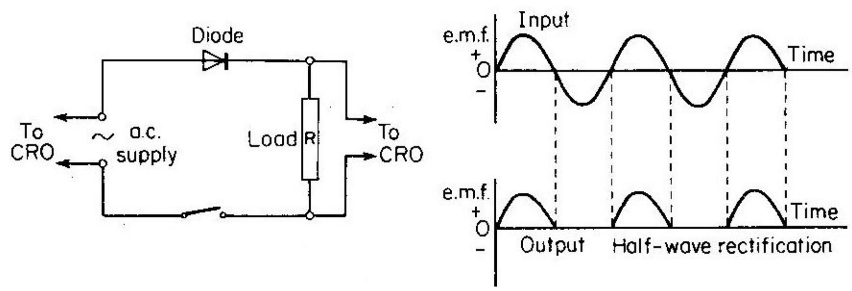
With no diode, the voltage output across the load resistor,

Alternating current input voltage = p.d across the resistor





With one diode, the out voltage is half wave rectified on screen.



The source of a.c is connected in series with the diode

The output from the circuit will flow in one direction in series of pulses as shown above.

This is called half-wave rectification.

The variation in the input and output voltages with time may be seen by connecting the input and output terminals, in turn, to a C.R.O as shown above.

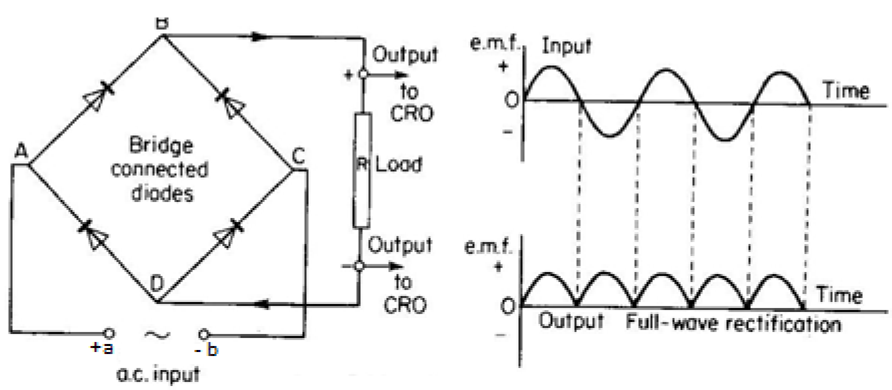
With four diodes, output voltage is full wave is rectified.

Both half cycles of a.c are rectified.

The current follows the direction as indicated in the figure below.

The diodes are all pointing round the sides of square towards B and away from D.

If the current direction is traced through the diodes, as A and C become alternately positive and negative from the a.c input, then the output current will always flow out of B, through the load and back to D, therefore in both half cycles, current flows in the same direction.



EXPLANATION

During half cycle, when a is positive and b is negative, AB and DC will conduct.

During the next half cycle if a is negative and b is positive AD and BC conduct.

In both half cycles current flows through R in one direction

ELECTRIC CELLS

These are devices that can produce electricity by chemical action.

Types of electric cells

(a) Simple cells

(b) Dry cells

(c) Leclanche cells (wet cells)

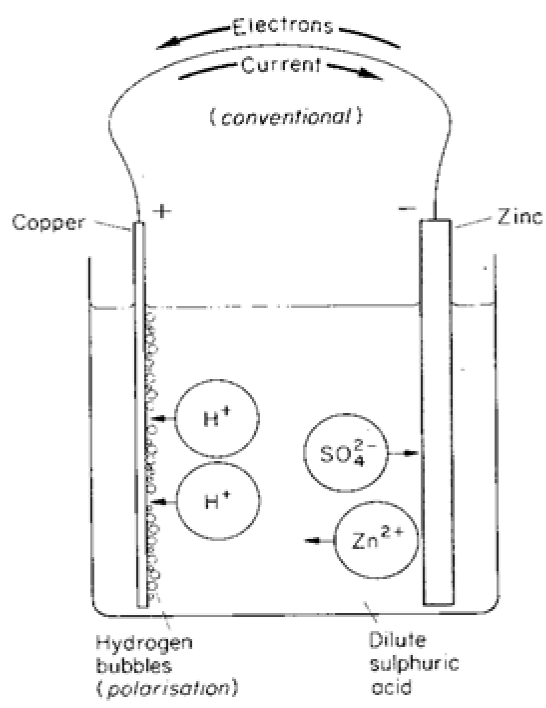
(d) Lead acid accumulator

(e) Alkaline cells(Nickel iron cells)

Simple cells

A simple cell consists of a copper plate as the anode and the zinc plate the cathode, dipped in dilute suphuric acid as the electrolyte

The more reactive metal in the reactivity series forms the cathode i.e. zinc is higher than copper in the reactivity series therefore zinc cathode and copper anode.



How a simple cell works

The electrolyte undergoes Ionization as shown in the equation below

$(aq) \rightarrow 2(aq) + so_4^{2-}(aq)$

The zinc plate slowly dissolves and goes into the solution as zinc ions which displace hydrogen ions to form zinc sulphate.

$Zn(s) \rightarrow Zn^{2+}(aq) + 2e^-$

$Zn^{2+}(aq) + SO_4^{2-}(aq) \rightarrow ZnSO_4(aq)$

The displaced hydrogen ions move to the copper plate. They gain electrons and become neutralized. The two of these atoms combine to form gas that appears as bubbles on the copper plate.

$2H^+(aq) + 2e^- \rightarrow H_2(g)$

This flow of electrons from the cathode to anode causes the flow of electricity from the anode to the cathode hence if a voltmeter is connected between anode and cathode, it deflects.

Defects of a simple cell

A simple cell is found to work for a short time after which current stops flowing because of mainly two reasons;

(a) Polarization

This is the collection of hydrogen bubbles at the anode which partially insulate it from the electrolyte. This slows down and eventually stops the working of the cell.

Prevention/ reduction of polarization

This can be reduced by;

(i) Occasional brushing of the anode.

(ii) Adding a depolarizer e.g. potassium dichromate ($K_2Cr_2O_7$) which oxidizes hydrogen to form water.

(b) Local action

This is the gradual wearing down of the zinc electrode (cathode) as a result of impurities on the plate reacting with the acid to hydrogen bubbles.

Prevention of local action

The zinc plate is cleaned in concentrated acid and then rubbed with mercury. The mercury zinc amalgam covers up the impurities thereby preventing their contact with acid electrolyte.

PRIMARY AND SECONDARY CELLS

Primary cell

This is one in which current is produced as a result of an irreversible reactions i.e. cannot be recharged when it runs down e.g. simple cells, dry cells and laclanche cells. Whenever the cell runs out, it implies that all ionized ions in the electrolyte have reacted to release electrodes.

Secondary cell

This is one which can be recharged when it runs down by passing current backwards through it. A secondary cell is produced as a result of reversible reactions e.g. Lead acid accumulators, Nickel- cadmium alkaline cells.

Differences between primary and secondary cells

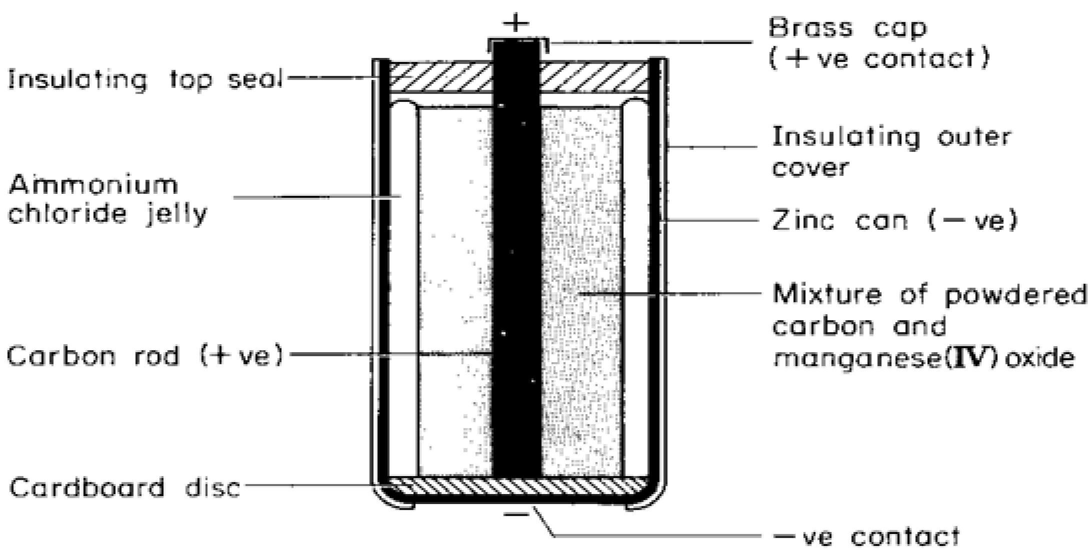
Secondary cell	Primary cell
• Current is produced as a result of reversible reaction.	• Current is produced as a result of irreversible chemical reactions.
• Can be recharged when it runs down.	• Cannot be recharged when it runs down.

DRY CELL

It is used in torches, radios and has an E.M.F of 1.5 volts.

It uses Ammonium chloride jelly as the electrolyte.

The anode is the carbon rod placed in the centre of the Zinc container which forms the cathode.



Action of a dry cell

The source of energy is chemical action between Zinc and ammonium chloride jelly. As a result, hydrogen gas is produced which collects at the carbon rod and polarizes the cell.

The manganese (iv) oxide oxidizes the hydrogen to water in the cell and enables it to supply current for sometime

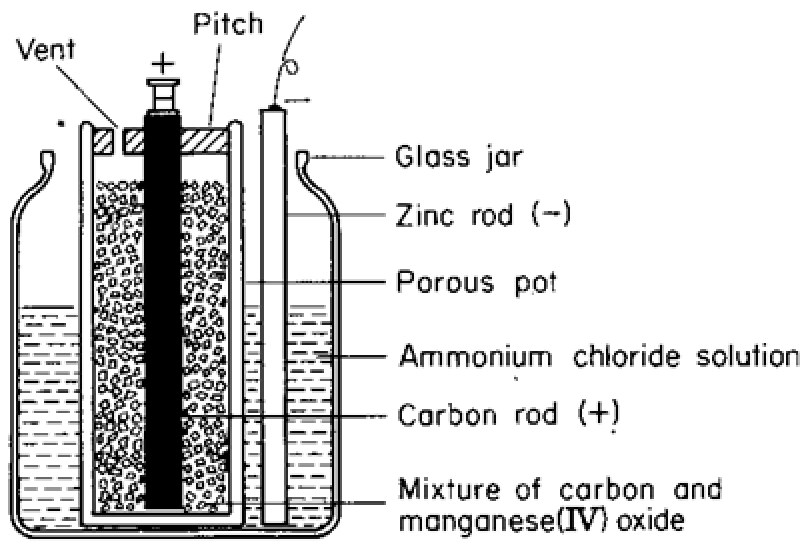
Note

Local action cannot be completely stopped in dry cells and therefore the cell deteriorates with time.

Advantages of a dry cell over simple cells

- It is portable.
- Its electrolyte is in jelly form and cannot pour easily.

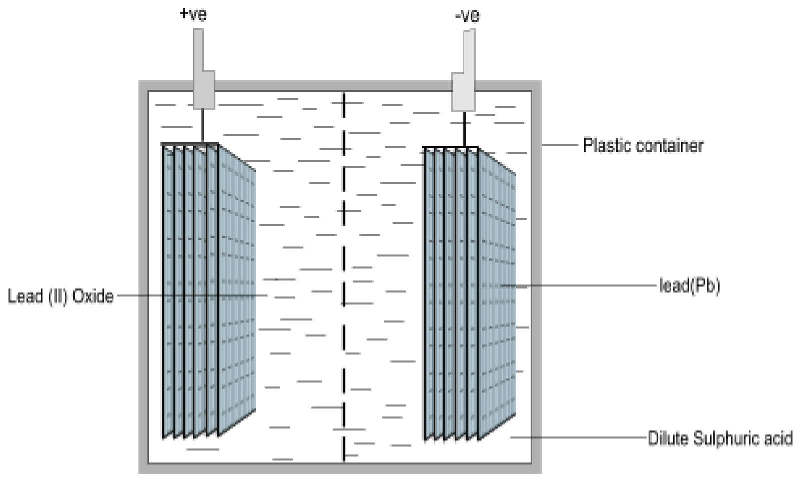
The Leclanche cell



Lead acid accumulators

It consists of lead oxide as a positive electrode and lead as the negative electrode. The electrolyte is dilute sulphuric acid.

The lead acid accumulator supplies much larger currents than the dry cell. It consists of six accumulators in series. During discharge, both electrodes change to lead sulphate and the acid becomes more dilute.



When fully charged, the relative density of the acid is 1.25 which falls to 1.18 at cell discharge.

Care and maintenance of lead acid accumulators.

The lead acid accumulator can be used for a long time provided the following are taken:

- The liquid level must be maintained using distilled water. This ensures that the electrodes are not exposed.
- The cell should be charged if the relative density of the electrolyte falls below 1.25.
- The battery should be kept clean so that the current does not lick away across the casing and across the terminal.
- The positive terminal should not be connected directly to the negative terminal. When this is done (short circuit), too much current is taken from the cell. This tends to destroy it.
- The battery should be charged regularly and should not be left uncharged condition for a long time. The effect of charging current is to change lead sulphate on both positive and negative plate into lead (ii) oxide and to return the sulphate into the electrolytes.

The Nickel- Cadmium Alkaline Cells or Nife Accumulators.

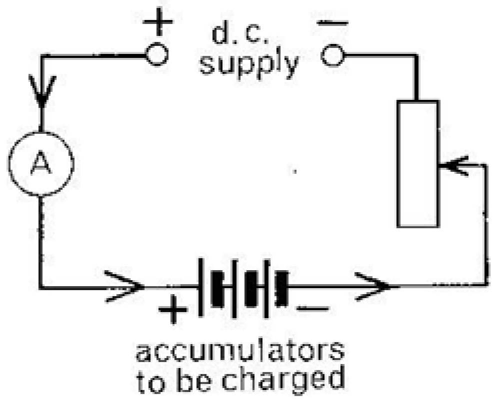
This is called so because the electrolyte is an alkali such as potassium hydroxide dissolved in water. The positive electrode is Nickel hydroxide and negative is iron.

An alkaline accumulator has the following advantages over lead acid accumulator.

- Lasts longer.
- Keeps the charge longer.
- Its E.M.F is relatively small.

Charging an accumulator

A charging circuit is connected as in the diagram below;



The supply must be d.c (direct current) of greater E.M.F than that of the accumulator. The positive terminal of the supply is connected to the positive terminal of the battery and negative to the negative. The current is adjusted to a recommended value.

Before charging, accumulators must be topped up with distilled water.

CURRENT ELECTRICITY

Current is the rate of flow of electric charge. i.e.

Charge flows in the direction opposite to the conventional flow of current.

SI unit of current is Amperes (A)

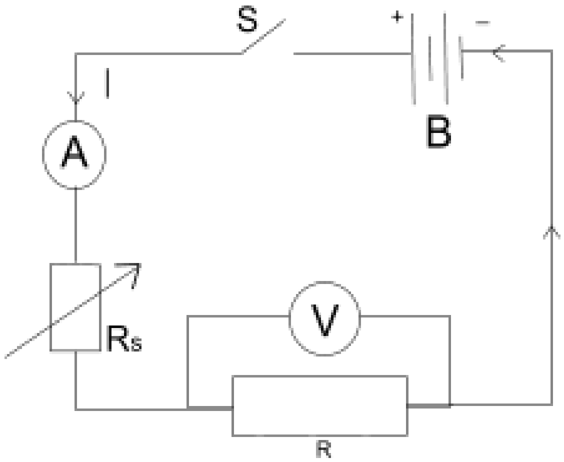
SI unit of charge is coulombs (C)

Coulomb

This is a charge passing any point in one second when current flowing is one ampere.

Circuit

This is a path along the line of conductors through which current flows.



Potential difference

This is the work done in moving a coulomb of charge from one point to another. SI unit is volts (V)

Volt

This is the potential difference between two points in a circuit when the work done to move one coulomb of charge between them is one joule (1J)

ELECTROMOTIVE FORCE (E.M.F)

It is the total work done in joules per coulomb of electricity conveyed in a circuit in which the cell is connected

OR

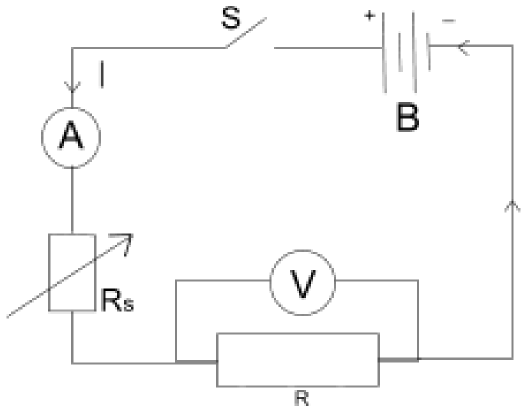
It is the sum of all p.ds across all various components of a circuit in which the cell is connected including the p.d required to drive current through the cell itself. S.I unit is **volts (v).**

OHM'S LAW

It states that the current flowing through a conductor is directly proportional to the potential difference across the ends of the conductor provided temperature and other physical conditions kept constant.

V = IR

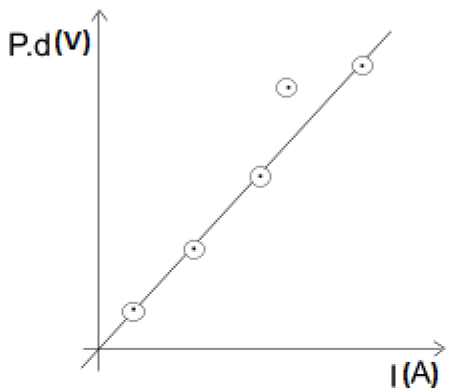
An experiment to verify ohm's law



- The circuit is set up as above
- The rheostat is set to a minimum value to let the maximum current pass through it
- The switch S is closed and both the voltmeter readings and ammeter readings noted
- The above procedure is repeated for various values of V and I
- The readings are recorded in the table as shown;

I/A	V/v
-	-
-	-
-	-

The results in the table are then used to plot a graph of V against I as shown;



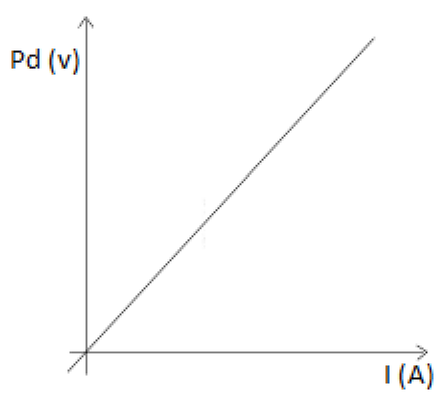
A straight line graph through the origin verifies ohm's law i.e. and the resistance of the conductor is given by the slope of the graph.

Limitations of ohm's law

- Ohm's law is only obeyed when the physical conditions of a conductor are constant i.e. temperature, length of conductor and cross sectional area of conductor.
- Ohm's law does not apply to semi- conductors e.g. diodes and electrolytes. The above two are referred to as non- ohmic conductors.

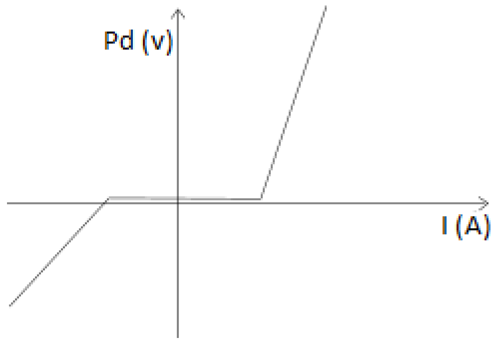
Characteristic graph for ohm's law

(a) Ohmic conductor

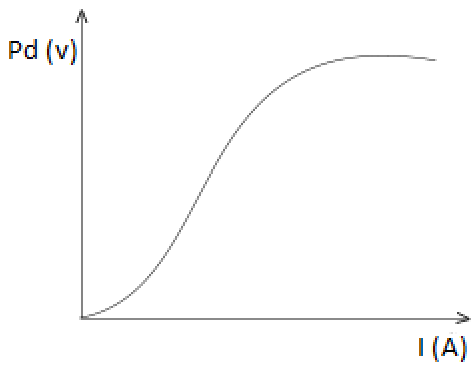


(b) Non- ohmic conductor

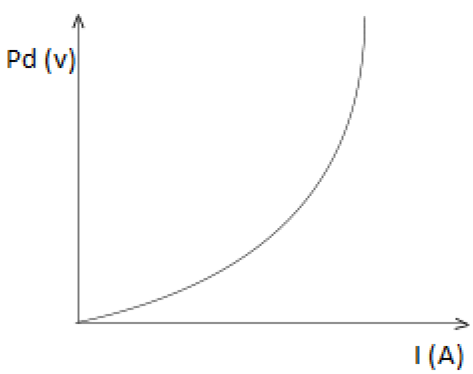
(i) Dilute sulphuric acid



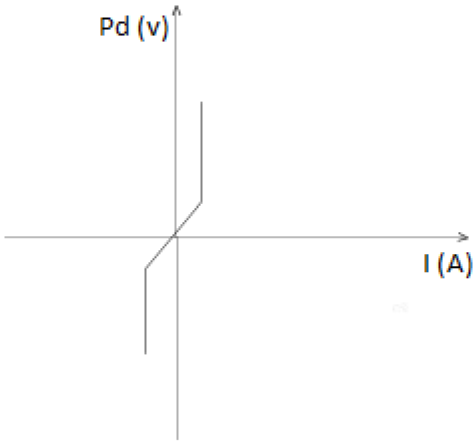
(ii) Thermionic diode



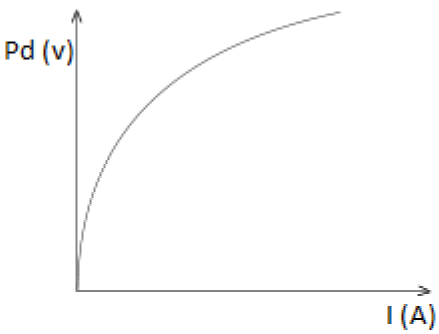
(iii) Semi-conductor junction diode



(iv) Neon gas



(v) **Tungsten filament**



RESISTANCE AND RESISTORS

Resistance is the opposition to the flow of current. S.I unit is ohms (Ω).

Definition of an ohm

It is the resistance of the conductor which allows the current of one ampere to flow through it when the potential difference between the ends of the conductor is one volt.

A resistor is a conductor which opposes the flow of current through it.

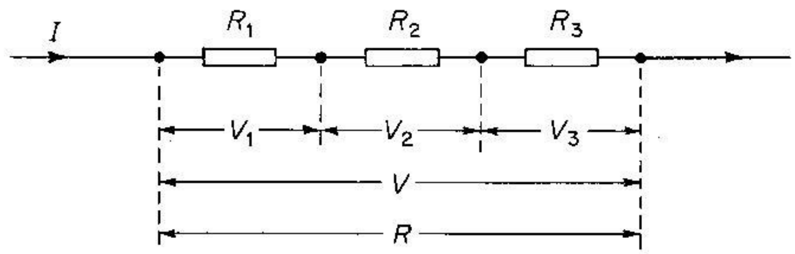
Arrangement of Resistors

Resistors are arranged: -

- In series.
- In parallel.

In series connection

Consider three resistors of resistance R_1, R_2, R_3 connected end to end as shown.



The same current is passing through R_1, R_2 and R_3

Total potential difference $v = v_1 + v_2 + v_3$

From ohm's law

$V = IR$

$IR = IR_1 + IR_2 + IR_3$

$IR = I(R_1 + R_2 + R_3)$

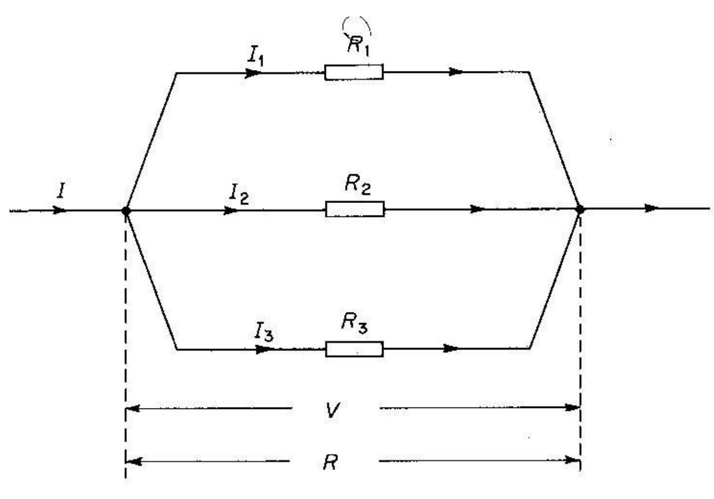
$R = R_1 + R_2 + R_3$

Note

- Effective resistance in series is the sum of resistances
- Effective resistance is greater than the greatest resistance

Parallel connection

When resistors are connected in parallel as shown below, the potential difference across the resistor is the same.



Total current is equal to sum of the individual currents

$I = I_1 + I_2 + I_3$

From ohm's law,

= + +

= V

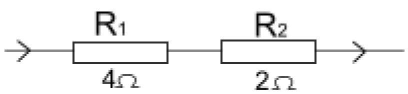
=

Effective resistance is smaller than the smallest resistance in parallel

Note:

For two resistors in parallel

a)

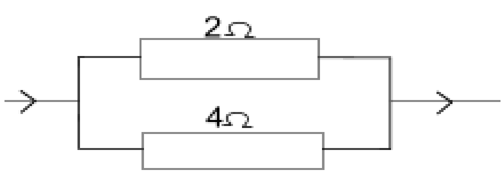


Effective resistance = $R_1 + R_2$

= 4+2

= 6Ω

b)



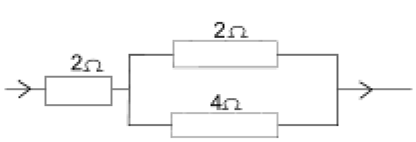
Effective resistance =

=

=

= 1.33Ω

c)



Effective resistance =

=

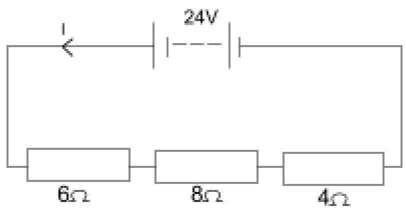
R_P = = 0.8Ω

$\therefore R_1 + R_P$

$= 2 + 0.8$

$= 2.8\Omega$

d)



Effective resistance =

FACTORS AFFECTING THE RESISTANCE OF THE CONDUCTOR

1. **Length of the conductor**

   The longer the conductor the higher the resistance
2. **Area of cross section of a conductor**

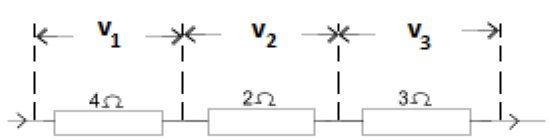
   The greater the diameter, the lower the resistance i.e the thicker it is, the less the resistance. Doubling the thickness of the conductor reduces its resistance to a quarter
3. **Temperature**

   The higher the temperature the higher the resistance
4. **Nature of the conductor**

   A number of free electrons around the nucleus of an atom affects the resistance to flow of current. The higher the number of free electrons in a conductor, the lower the resistance

CALCULATIONS OF VOLTAGE

Consider a current of 3A passing through four resistors of resistance 4Ω, 2Ω and 3Ω as shown below



Calculate the potential difference across each resistor

p.d $v_1 = IR_1$ p.d $v_2 = I\,R_2$ p.d $v_3 = I\,R_3$

= 3 X4 = 3 X 2 = 3 X3

= 12 V = 6V = 9V

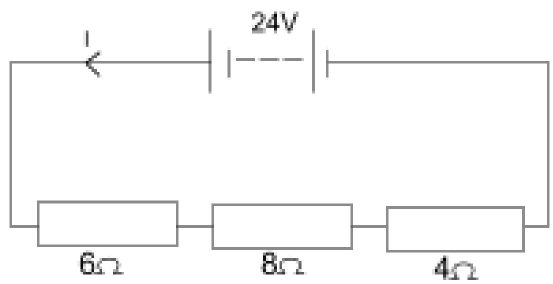
TERMINAL p.d

It is the p.d across the terminals of the cell when the cell is producing current in a resistor

OR

It is the p.d across the external resistor in which the cell is connected

A p.d of 12v is applied across a network of resistors as shown below



Calculate

i) The effective resistance

ii) Total current through the circuit

iii) P.d across the 8Ω resistor

i) $R = R_1 + R_2 + R_3$

$= 6+8+4$

$= 18\Omega$

ii) Current I =

=

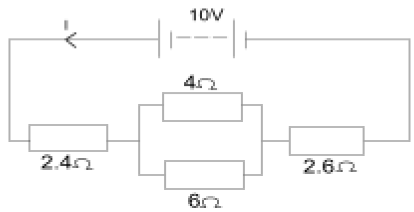
= 1.33A

iii) $V = IR_2$

=

$= 10.7v$

3. A battery of E.M.F 10 volts and negligible internal resistance is connected across resistors of 6Ω, 4Ω and 2.6Ω



Calculate the effective resistance in the circuit.

$R_p =$ $\therefore R = R_1 + R_p + R_3$

$=$ $= 2.4 + 2.4 + 2.6$

$=$ $= 7.4Ω$

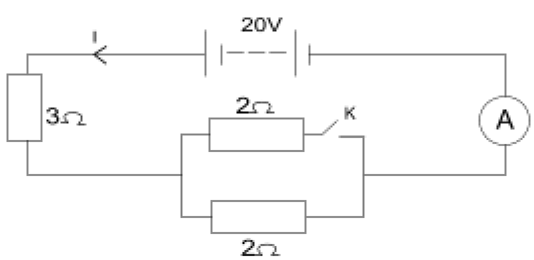
$= 2.4Ω$

ii) The p.d across the resistor in the parallel setting

iv) Current through R_1 and R_3

$I_1 = I_3 = 1.35A$

5. A source of EMF 20v and negligible internal is connected to resistors of 2Ω, 3Ω and 2Ω as shown below



Find the ammeter reading when the switch is

i) Closed

Effective = current I = =

$= 1 + 3$ $= 5A$

$= 4Ω$

ii) When K is open, current flows through the lower 2Ω resistor, the upper 2Ω will be out of circuit

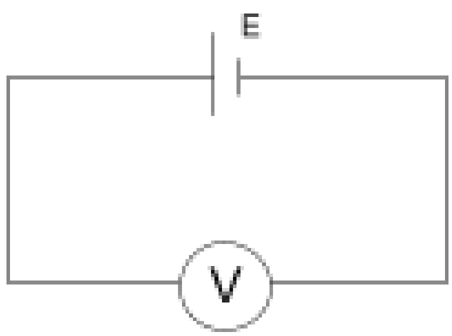
Effective resistance R = 3+2

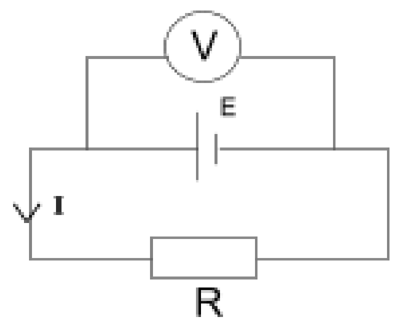
= 5Ω

Current I = = = 4A

INTERNAL RESISTANCE

This is the resistance within the cell that opposes the flow of current. Consider these circuits





When the voltmeter is directly connected to the cell, it reads V =E

When the cell is connected to a standard resistor R the voltmeter reading is V but V is less than E

The p.d consumed within the cell equals to E – V

So internal resistance r =

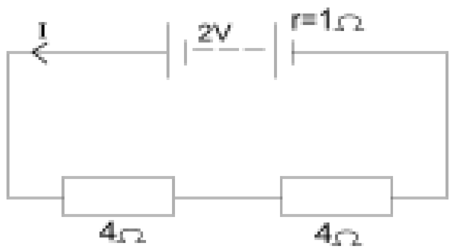
But v = IR, I = E – IR

E = I + IR

E = I (R+r)

e.g 2 resistors each of 4Ω are connected to a 2v cell and an ammeter as shown below

a) Find the reading of the ammeter if the internal resistance of the cell is 1Ω



Total resistance = $R_1 + R_2$

$= 4 + 4$

$= 8\Omega$

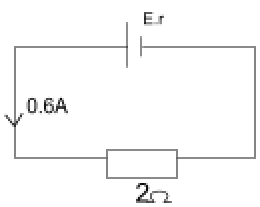
E = I (R+ r)

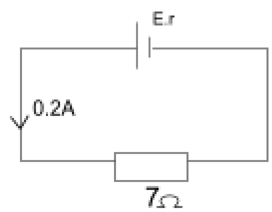
2 = I(8 +1)

I =

Ammeter reading is

2. A cell supplies a current of 0.6A through a 2Ω resistor and a current of 0.2A through a 7Ω resistor. Find the internal resistance of the cell and its EMF.





E = I (R + r)

E = 0.6 (2+r) ….(i)

E = 0.2(7+r) …..(ii)

Equating (i) to (ii)

0.6 (2+r) = 0.2(7+r)

1.2 + 0.6r = 1.4 +0.2r

0.6 – 0.2r = 1.4 – 1.2

0.4r = 0.2

Internal resistance, r = 0.5

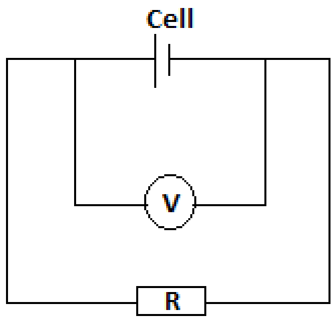
EM F, E = 0.6 (2 + 0.5)

= 1.50V

EXPERIMENT TO DETERMINE THE INTERNAL RESISTANCE OF A CELL

A voltmeter of high resistance is connected across the terminals of the cell to determine its e.m.f E

A resistor of resistance R = 1 Ω is connected across the terminals of the cell as shown below



The reading V on the voltmeter is noted and recorded

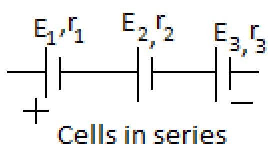
The internal resistance r of the cell is calculated from;

The experiment is repeated for various values of R and the average value of r calculated

CONNECTING CELLS

Cells may be connected in series or in parallel

a) Series connection

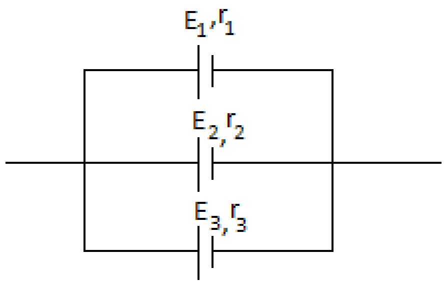


So effective E.M. F is the sum of the individual E.M.Fs

i.e $E = E_1 + E_2 + E_3$

Effective internal resistance $r = r_1 + r_2 + r_3$

b) **Parallel connection**



Cells in parallel

So effective e.m.f is equal to the e.m.f of one cell

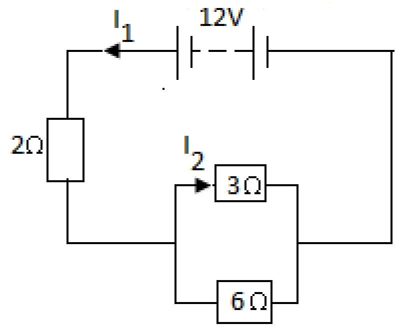
i.e. $E = E_1 = E_2 = E_3$

Effective internal resistance is the sum of the reciprocal of the internal resistances

i.e = + +

Example

1. Two identical cells of emf 1.5V and internal resistance 0.2Ω are connected
   a) In series b) in parallel. Find the current in each case when the cells are connected to the 1Ω resistor. If the 1Ω resistor is substituted by a 3Ω resistor, calculate the new current in both cases
2. 6 cells each of 2V and internal resistance 0.1Ω are connected in series with an ammeter besides them of negligible resistance. A resistor R = 1.4Ω and a metal filament lamp are connected in series with the cell. The Ammeter reading is 3A. Calculate;
   (a) resistance of the lamp
   (b) p.d.V across the lamp
3. a) Define the terms
   i) electromotive force
   ii) the volt
   b)



A battery of e.m.f 12V and negligible internal resistance is connected to resistances 2Ω, 3Ω, 6Ω as shown above. Find the currents $I_1$and I_2

ELECTRICAL POWER AND ENERGY

Quantity of electricity Q when the applied p.d is v

Work done = product of p.d and quantity of electricity

= VQ

But Q = It

Electrical work done = VIt

But V = IR

Work done = I^2Rt

Also I =

=

Electrical energy = electrical work done = VIt = I^2Rt =

ELECTRICAL POWER

This is the rate at which heat is generated in the conductor when current flows through it

Electrical power =

P = = VI = I^2R =

S.I unit of work is watts.

1 watt = $1Js^{-1}$

A watt is the rate of working of 1J per second

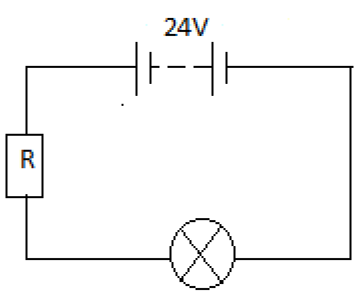
Other units of power include

- Kilowatt (kW)
- Mega watt (MW)

(1kw = 1000w and 1 MW = 1000kW = 1,000,000W)

Example

1. A current of 2A passes through a resistor of 3Ω. Calculate the p.d across the resistor and the power used by the resistor.
2. A lamp is rated 240V,60W
   a) What does that statement mean?
   b) Find,
      i) Current consumed by the lamp
      ii) Resistance of the filament
3. A battery of e.m.f 24V is connected in series with a resistor R and a lamp rated 10V, 20W as shown below;



If the bulb is operating normally, find;

i) The p.d across the resistor

ii) The value of R

iii) The power dissipated in the resistor

ENERGY COSTS (COST CALCULATIONS)

Electricity boards charge for electric energy they supply, the boards' trade units of electrical energy is called kilowatt hour (KWh)

Kilowatt hour is the electrical energy used by a rate of working of 1 kW appliance in 1 hour.

Electrical cost = power consumed in kW x number of hours x cost per unit.

Example

1. Find the cost of running five 60w and four 100w lamps for 8hours if electrical energy cost 5/= per unit

   Total power consumed = 5 x 60 + 4 x 100 = 700w = 0.70kW

   Electrical cost = 0.70 x 8 x 5 = 28/=
2. A house has one 100w bulb, two 75 watts bulbs and five 40w bulbs. Find the cost of having all lamps switched on for two hours every day for 30 days at a cost of 30/= per unit

   Total power consumed = 1 x 100 + 2 x 75 + 5 x 40 = 450w = 0.45kW.

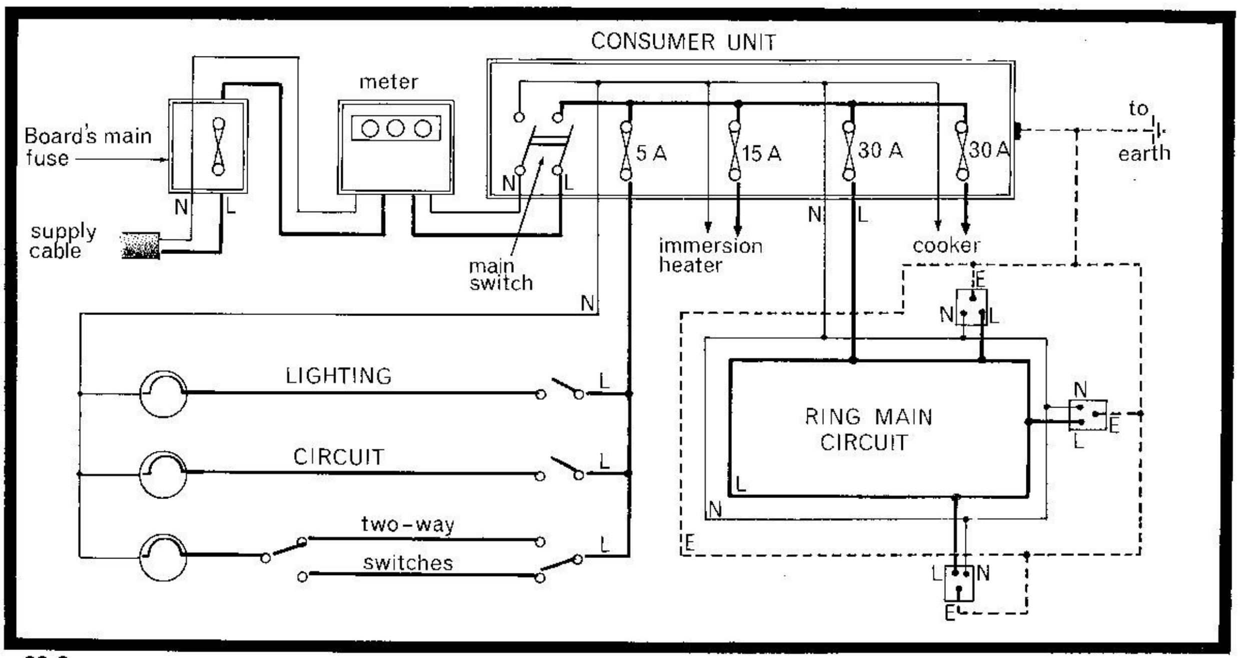
   Electrical cost = 0.45 x 2 x 30 × 30 = 810/=

QUESTIONS

1. Calculate the cost of running an electric fire alarm for 2½ hours if it takes 13A on 100v supply and each unit cost 40/=
2. A 2 kW electric fire alarm is used for 10 hours each week , a 100w bulb is used for 10hours each day find the total cost for each week if a unit of electricity cost sh. 300
3. A house contains three 60w lamps and two 100w lamps. They are switched on for 8 hours, if one unit of electricity costs 250/= how much money should be paid?
4. A 2 kw heater is used for 10 hours and a 100w lamp is used for 8 hours each day find the total cost paid for electricity at the end of the month if each units costs 100ǂ and the month is assumed to have four weeks

5. An electric heater is immersed in 0.05 kg of oil in a calorimeter of negligible heat capacity . the temperature of oil rose from 20^oc to 50^oc in 100seconds is the specific heat capacity of oil is $2000Jk^{-1}$. calculate
   (i) Power supplied by the heater
   (ii) The cost of running the heater for 100s each day for 8 days if each unit costs 400ɨ
   (iii) State any assumptions made .

HOUSE CIRCUIT: DOMESTIC INSTALLATION



IN SUPPLY CABLE

Electricity enters the house through the supply cable from the pole the supply cable consists of two insulated wires the live and the neutral wire. The neutral is earthed at the local substation and is therefore at zero potential while the live wire is at a potential of 240v. The live wire is either red or brown while the neutral is black or blue

THE MAIN FUSE AND METER

Each of the two wires (live and neutral) is connected to the meter through the main fuse box and a thick copper wire is connected from the meter to the earth and it is therefore at zero potential. It protects the meter and the house against damage in case of overloading or short circuit.

CONSUMER UNIT

From the meter the cables are passed to the consumer unit which contains the main switch to switch off all current in the house it is a double hole switch which breaks both the live and the neutral . the consumer unit also contains a single pole fuse for each of the following circuits

a) Lighting circuit connected to 5A fuse
b) Immersion heater circuit controlled by 15A fuse
c) The ring main circuit is controlled by 30A fuse

Each connected in parallel. it is connected to the live and the neutral so that faults in one circuit will not affect other circuit . in wiring the lighting circuits only two wires are required but for ring circuits the heater and the cooker the earth wire must be introduced. **Earthing** prevents electric shocks

THE RING MAIN CIRCUIT

This is a cable which runs into complete rings round the house . the power sockets each rated 30A are tapped from this cable

SAFETY DEVICES

1. **The fuse**

   It melts and breaks the circuit in case of overloading or short circuit. the earthing which prevents electric shock

   Switch in the live wire which breaks and completes the circuit

   Safety precautions

   - Electric cables must be properly insulated
   - Keep hands dry whenever dealing with electric supply
   - Never try to repair an electric machine unless you are trained or wearing gloves

- Fix sockets at a height beyond reach of children
- Keep proper plug in the circuit
- In case one gets a shock switch off the main switch immediately

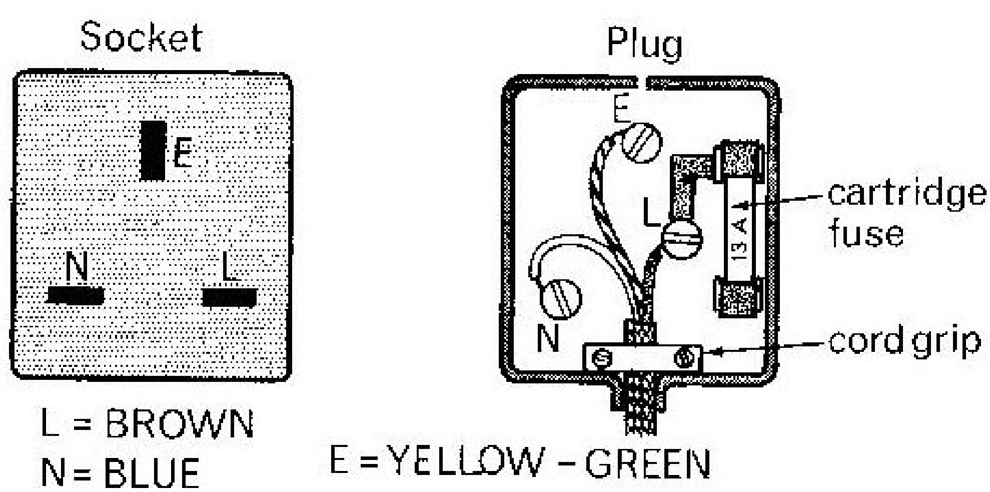
2. **Circuit breaker**

   This is used to disconnect the mains current when there is an accidental earthing of the live wire

ADVANTAGES OF PARALLEL CONNECTION

- When appliances like bulbs are connected in parallel only one switch is required
- A short circuit in one appliance does not affect other appliances
- All appliances will be on the same p.d and therefore will work normally
- There is no overloading.

WIRING A THREE PIN PLUG



The fuse in the plug is connected to the live wire in the circuit . the earth wire from the three pin plug is connected to a casing of the appliances so that in the event of a short circuit the person handling the faulty appliance does not get electric shock

APPLICATION OF ELECTRICAL HEATING

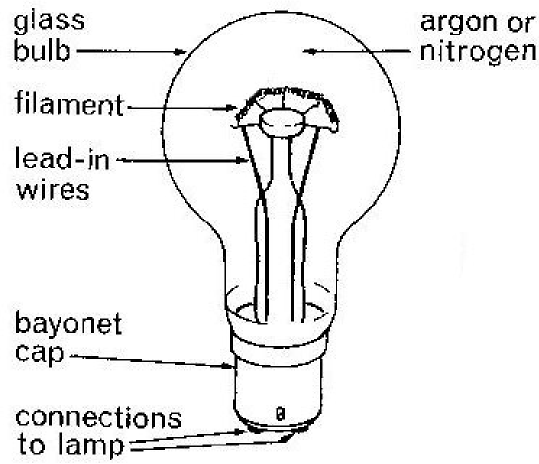
It is used in electrical appliances like

i) Electric bulbs and tubes

ii) Electric flat iron

iii) Electric kettles

iv) Cookers e.t.c



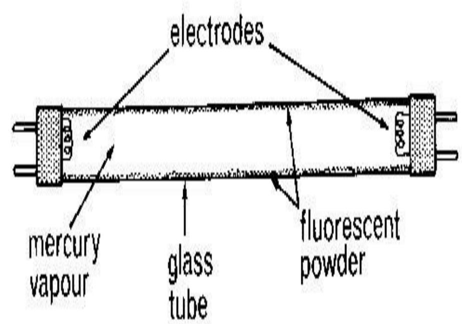
FILAMENT LAMP

It consists of the filament made of tungsten which dissipates so much heat that it become quite hot and it emits light . it is filled with an inert gas e.g nitrogen or argon at reduced pressure .

The gas prevents evaporation of tungsten and increases its operating temperature otherwise it condenses or blackens it. Efficiency of the bulb is improved by using a cold filament which reduces the space occupied by the filament and also reduces the rate of heat loss by convection

FLUORESCENT TUBES

Fluorescent tube is made of a glass tube coated inside with a fluorescent powder and containing mercury vapour



How it works

When the tube is switched on , the mercury vapour emits ultra violent radiations .the radiations strike the powder and the powder glows emitting light the colour of light emitted depends on the colour of the powder

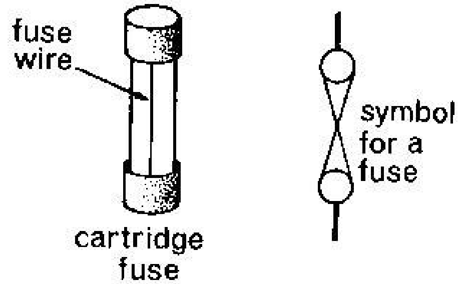
ADVANTAGES OF FLUORESCENT TUBES OVER FILAMENT LAMPS

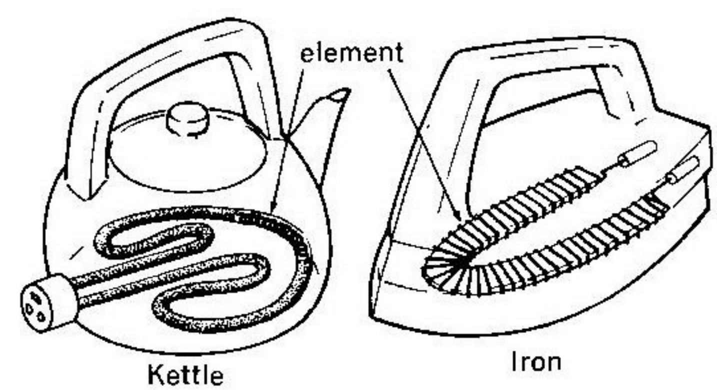
They are more efficient cheaper to run and durable

Electric flat iron and kettle

Heating appliance contains a heating element often made of nichrome wire . the is an alloy of nickel

And chromium . Nichrome wire is used because it does not oxidize when it becomes red hot


fuse
wire
cartridge
fuse
symbol
for a
fuse


element
Kettle
Iron

FUSE

It is a short length of a thin wire of low melting point which breaks the circuit when the current through it exceeds a safe value .

It is a protective resistor which melts when there is excessive current flow.

MAGNETISM

Magnetism is a physical phenomenon by which materials exert attractive or repulsive forces on other materials, i.e. A magnet is a substance which can attract certain materials such as iron, cobalt, nickel and some alloys.

It is one of the fundamental forces of nature and is caused by the motion of electric charges.

The key concepts and principles involved in magnetism:

1. Magnetic Fields and Magnetic Forces

Magnetic Field (B-field): A magnetic field is a vector field that surrounds magnets and electric currents. It represents the force that a magnetic object, such as a compass needle, would experience at any point in space. The direction of the magnetic field is defined as the direction in which the north pole of a compass needle points.

Magnetic Force: The force experienced by a charged particle moving through a magnetic field is given by the Lorentz force law. This force is perpendicular to both the velocity of the particle and the magnetic field.

2. Sources of Magnetism

Permanent Magnets: These materials have persistent magnetic fields. The most common examples are iron, cobalt, and nickel. The magnetic properties arise from the alignment of magnetic domains within the material.

Electromagnets: These are created by running an electric current through a coil of wire. The magnetic field strength can be increased by increasing the current or adding a ferromagnetic core.

3. Magnetic Materials

Ferromagnetic Materials: These materials, such as iron, can become strongly magnetized. They have regions called domains, where the magnetic moments of atoms are aligned. When these domains are aligned in the same direction, the material becomes magnetized.

Paramagnetic Materials: These materials have unpaired electrons that align with an external magnetic field, causing a weak attraction.

Diamagnetic Materials: These materials create an opposing magnetic field when exposed to an external magnetic field, leading to a very weak repulsion.

4. Magnetism at the Atomic Level

Electron Spin and Orbital Motion: The magnetic properties of materials are primarily due to the spin and orbital motion of electrons. Each electron acts like a tiny magnet due to its spin, and the orbital motion of electrons around the nucleus also generates a magnetic field.

Exchange Interaction: In ferromagnetic materials, the exchange interaction between adjacent electron spins causes them to align parallel to each other, resulting in a net magnetic moment.

5. Applications of Magnetism

Motors and Generators: Electromagnetic induction is the principle behind electric generators and motors. A changing magnetic field induces an electric current in a conductor, and vice versa.

Data Storage: Magnetic materials are used in hard drives and magnetic tape to store data by magnetizing small regions in a pattern that represents binary information.

Medical Imaging: Magnetic Resonance Imaging (MRI) uses strong magnetic fields and radio waves to generate detailed images of the inside of the body.

6. Earth's Magnetism

Geomagnetic Field: The Earth itself acts like a giant magnet due to the movement of molten iron in its outer core. This geomagnetic field protects the planet from solar wind and cosmic radiation.

Compass Navigation: The Earth's magnetic field allows compasses to work, providing a reliable means of navigation for centuries.

Summary

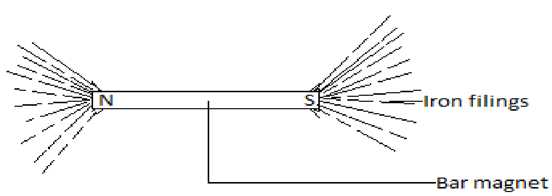
Magnetism is a result of electric charges in motion, manifesting as magnetic fields and forces. It arises from the intrinsic properties of particles, particularly electrons, and their interactions. Magnetism plays a crucial role in many technologies and natural phenomena, making it a fundamental aspect of both science and daily life.

<u>Magnetic poles</u>

These are regions around a magnet where resultant attractive force of a magnet appears to be concentrated

<u>Demonstration of magnetic poles</u>

When a bar magnet is placed in Iron filings, it is observed that the Iron filings cling to the magnet in tufts near its ends. Few, if any cling to the middle. This shows that magnetic force is more at either ends. These regions (either ends) are the magnetic poles.



The magnetic poles are two and these are;

- North pole (N)
- South pole (S)

<u>Ferromagnetic substances</u>

These are substances which are strongly attracted by a magnet. They include; Iron, Cobalt and Nickel

<u>Non – ferromagnetic substances</u>

These are substances which are not attracted by a magnet. They include; Copper, Brass, Wood and, Glass and others.

Suspending a magnet

When a magnet is freely suspended such that it can swing freely, it oscillates to and fro, then comes to rest in approximate N – S direction.

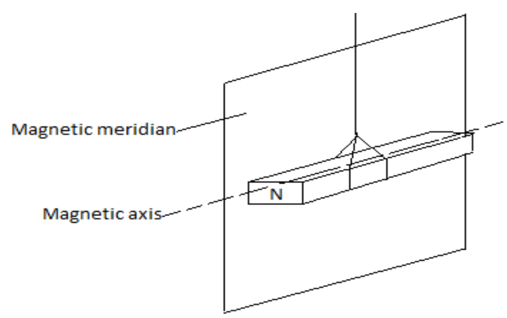
When the suspended magnet comes to rest, the pole towards the north is the North pole (North seeking) and the other towards the south is the South pole (South seeking)

Magnetic axis

This is the axis through a magnet about which the magnet's magnetism is symmetrical

Magnetic meridian

This is the vertical plane containing the magnetic axis of a freely suspended magnet at rest under the action of the earth's magnetic field



Laws of Magnetism

These are two and they are following;

1. Like poles repel
2. Un like poles attract

Test for polarity of a magnet

A magnet with known poles is freely suspended and approached in turn with either ends of the unknown magnet to be tested.

Repulsion indicates similar polarity

Attraction indicates that the unknown is either a magnet approaching with an opposite pole or a ferromagnetic material

The sure test for polarity

Repulsion is the only sure test that confirms a material as a magnet

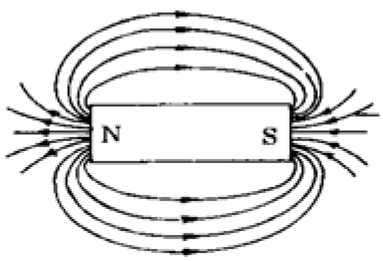
Magnetic field

Magnetic field is the space surrounding a magnet in which magnetic force is exerted

Magnetic flux

These are magnetic field lines showing the direction of the magnetic field

The magnetic field lines run from the North Pole to the South Pole

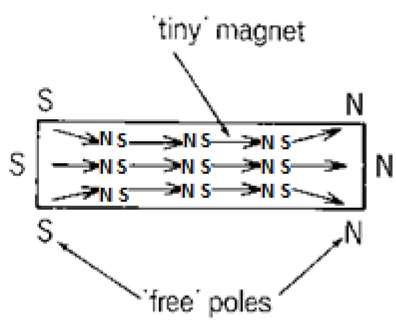


Note:

The direction of the magnetic flux at any point is the direction of the force on a North Pole placed at that point

The Domain theory of a magnet

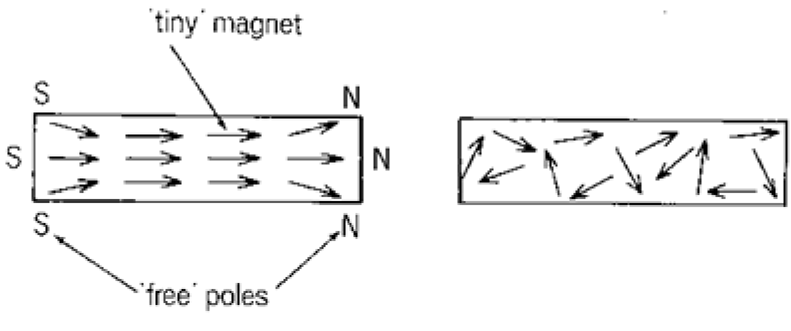
The theory states that a magnet is made up of many tiny magnets called molecular magnets and each of these tiny magnets has the two poles and pointing in the same direction



Breaking a magnet

When a magnet is cut into two pieces, the North pole is never separated from the South pole but rather the two pieces become magnets with the North and South poles but the formed magnets are of reduced strength.

Arrangement of molecular magnets in a magnetized and Un-magnetized ferromagnetic materials



(a) Magnetized bar (b) Unmagnetized bar

Magnetization

This is the process by which the randomly arranged molecular magnets are made to face in one direction

Methods of magnetization

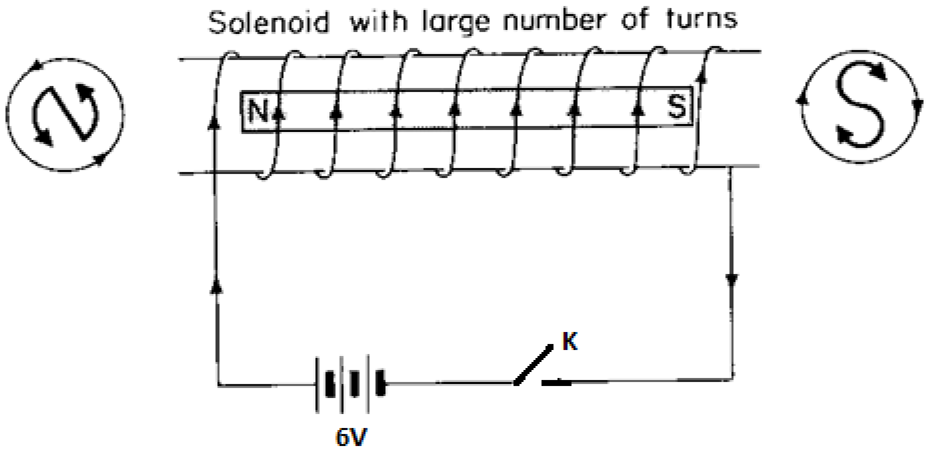
These are three and they include;

I. Electrical method
II. Stroke method
III. Induction method

I. Electrical method

A cylindrical coil (solenoid) wound with 500 and above turns is connected in series with a 6V or 12V battery and a switch

A steel bar is placed inside the solenoid as shown below



The switch K is switched on and then off

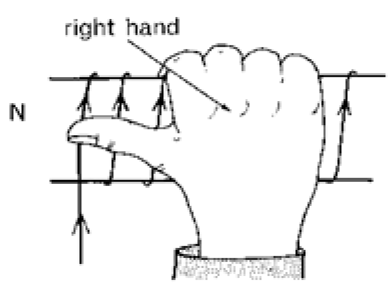
On removing and testing the steel bar, it is found to be magnetized

Determining the polarity of an electrically magnetized steel bar

This can be done in two ways;

I. On looking at one end of the solenoid and current is in the anti – clockwise direction, the bar end next to that end is the North pole and the other the South pole. On looking at the end and current is in clockwise direction, then the bar end next to that end is the South pole

II. ***The Right hand grip rule:*** Grip the solenoid with the right hand such that the fingers point the direction of the current, then the direction in which the thumb points is the North pole



II. Stroke method

This can be done in two ways, i.e. Single stroke or Double stroke

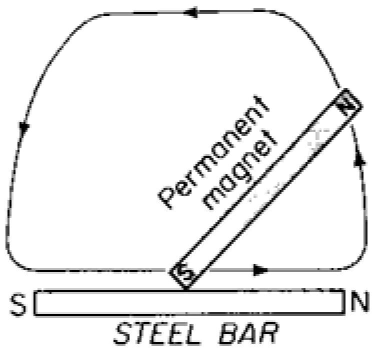
Single stroke

The steel bar to be magnetized is laid on a wooden table

A known end of a permanent magnet is placed at one end of the steel bar and stroked along the steel bar to the other end

The magnet is lifted high to the starting end and the process repeated for several times

After the stroking, the steel bar is found to be a magnet



Double stroke

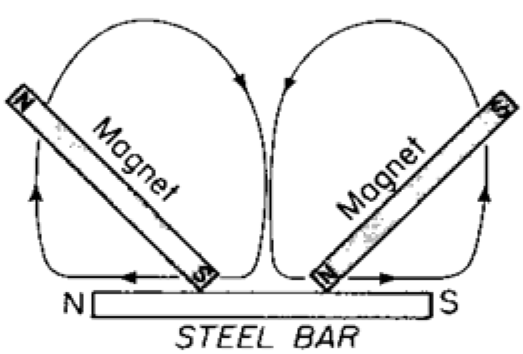
The steel bar to be magnetized is laid on table

Two opposite poles of permanent bar magnets are placed at the middle of the steel bar

The steel bar is then stroked to either ends

With the same poles, the bar magnets are lifted high and the stroking repeated for several times

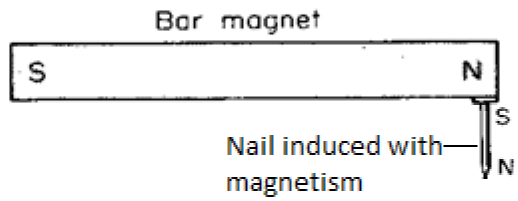
After several times of stroking, the steel bar is found to be magnetized



III. <u>Induction method</u>

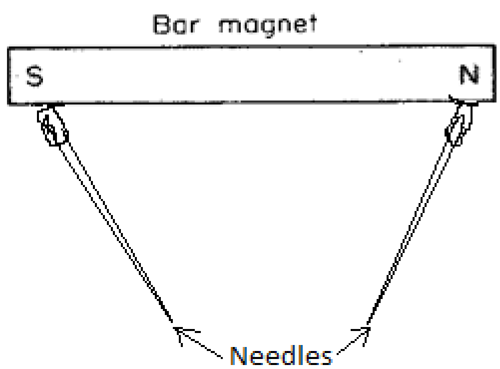
The smaller piece of magnetic material (nail) to be magnetized is placed in contact with one end of a permanent magnet for some time

It is found out that after some time, the magnetic material becomes a magnet and can attract other pieces as shown below



Note

The end of the magnetic material closer to the pole of a permanent magnet is induced with an opposite pole and the other end with the similar pole



This is because since the needles are placed at opposite poles of a bar magnet, the ends of the needles are induced with opposite poles and hence will attract since unlike poles attract

<u>Demagnetization</u>

This is the process by which the molecular magnets facing in one direction are disorganized to face randomly

Methods of demagnetization

- Heating

When a magnet is heated, it loses its magnetism. This is because the temperature increases due to heat which in turn increases the rate of vibration of the molecular magnets hence vibrating randomly

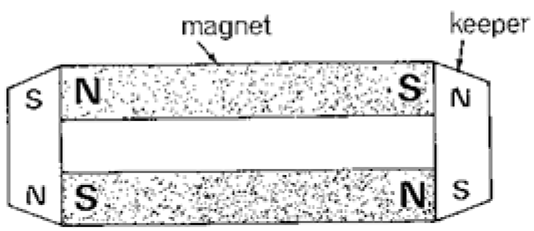
- Hammering/Hitting

  Hammering destroys the order of molecular magnets hence demagnetizing the material

<u>Storing a magnet</u>

A bar magnet tends to weaken with time due to the repulsion between the free poles near the end which disorganizes the alignment of the domain

To prevent this, magnets are stored in pairs with the poles opposite and pieces of soft iron called keepers placed across the ends as shown below



The keepers become induced magnets and their poles neutralize the poles of a bar magnet

The domains in both magnets and keepers form closed chains with no free poles

<u>Earth's magnetic field</u>

The Earth has a magnetic field and itself behaves as a magnet

Evidence showing the Earth's magnetism

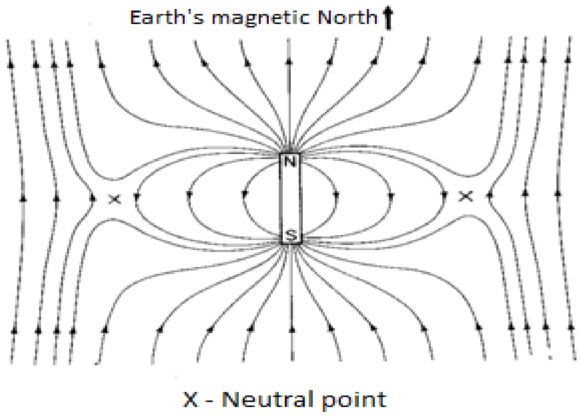
- A compass needle points approximately towards the North
- A freely suspended magnet comes to rest in the North – South direction

Note

The Earth's magnetic poles do not coincide with the Earth's geographical poles, which is why the compass needle does not point in the true North (Geographical North)

<u>Combined field due to the earth and a bar magnet</u>

a) With the North pole of the bar magnet pointing North

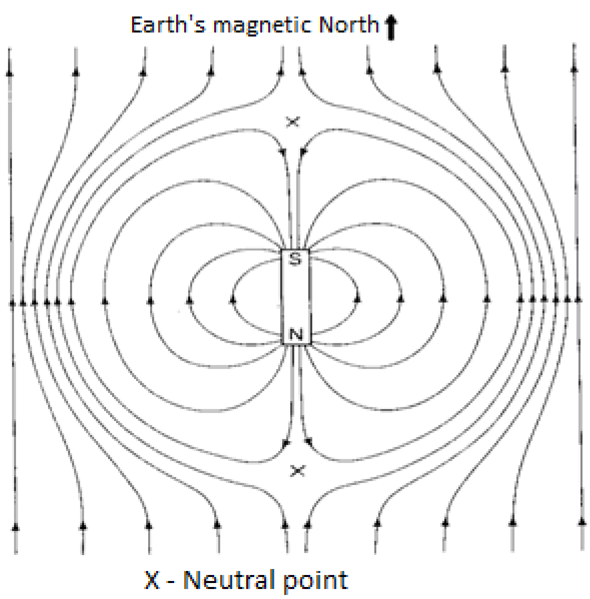


Note

A neutral point is a region around a magnet where the resultant magnetic field is zero

Point X in the figure above is neutral because the fields due to the Earth and the magnet are equal and opposite, hence the resultant magnetic field is zero

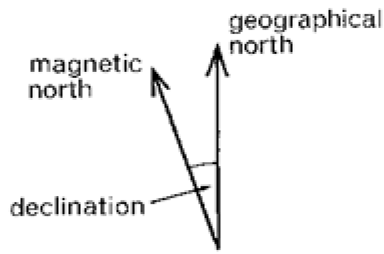
b) The North pole of the Magnet pointing South



Definitions

Angle of declination

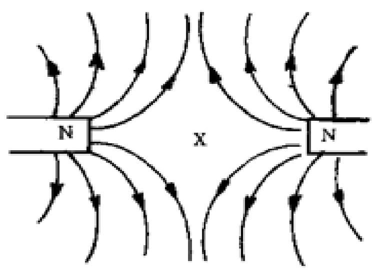
This is the angle between the geographic North and the magnetic North



Angle of dip/Inclination

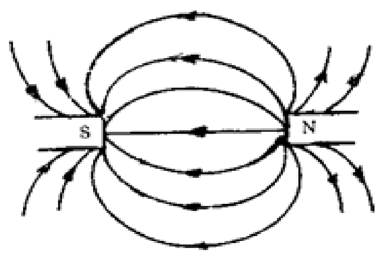
This is the angle a freely suspended magnet at rest due to the earth's magnetic field makes with the horizontal

Fields due to magnets

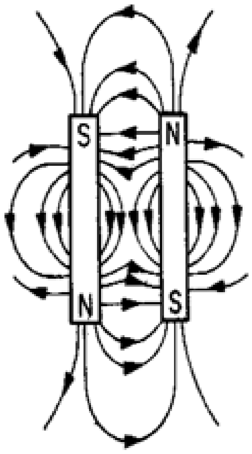


Two like poles close to each other

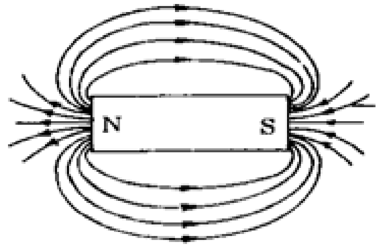
X - Neutral point



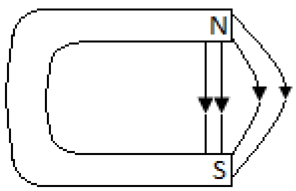
Unlike poles close to each other



Unlike poles close to each other



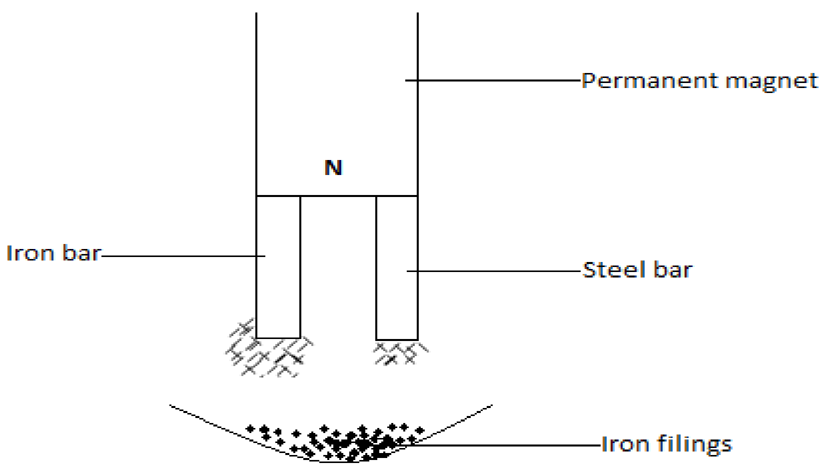
Isolated Bar magnet



Field due to a horse shoe magnet

Magnetic properties of Steel and Iron

When bars of Iron and steel of the same size are placed in contact with a pole of a permanent magnet as shown below and placed in Iron filings



More Iron filings are attracted to the Iron than those on steel

When the Iron and steel bars are removed from the magnet, all Iron filings fall off and little if any falls off the steel bar

It can be concluded that, the induced magnetism of Iron is stronger than that of steel From the above experiment, Iron can be regarded as a soft magnetic material and steel a hard magnetic material

Definitions

1. ***Soft magnetic materials***

   These are materials that can easily lose their magnetism

2. ***Hard magnetic materials***

   These are materials that retain their magnetism for a long time

Uses of soft magnetic materials

- Used in transformers
- Used in electromagnets e.g. those found in electric bells
- Used in magnetic shielding

Uses of Hard magnetic materials

- Used for making permanent magnets e.g. those used in radio speakers and motors

Differences between temporary and permanent magnets

Temporary magnets	**Permanent magnets**
• Does not retain its magnetism • Made by soft magnetic material • Can be produced by a magnetic field	• Retains its magnetism • Made by hard magnetic material • Cannot be produced by a magnetic field

Application of temporary magnets

- Used in electric bells
- Used in telephone receivers
- Used in recording heads like VHS, tape recorders e.t.c.
- Used in relay switches

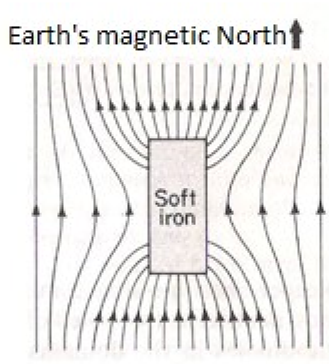
Application of permanent magnets

- Used in loud speakers as in radios

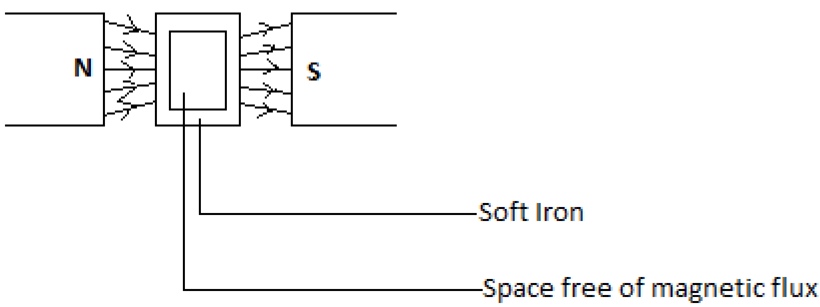
- Used in dynamos
- Used in electric motors

Magnetic screening (shielding)

This occurs when soft Iron is placed in a magnetic field and almost all the magnetic flux passes through the soft Iron with little if any passing through air



This can be demonstrated by soft Iron ring in a magnetic field



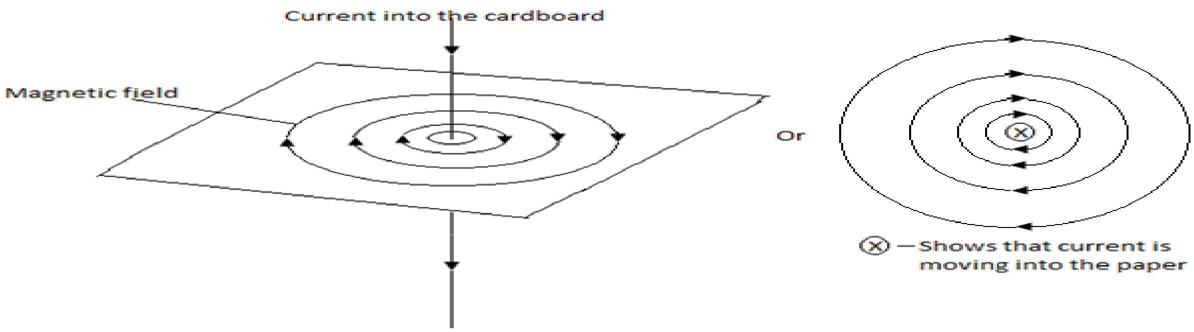
Magnetic screening is applied in making thick walled soft Iron boxes for protecting delicate measuring instruments from external magnetic fields

ELECTROMAGNETISM

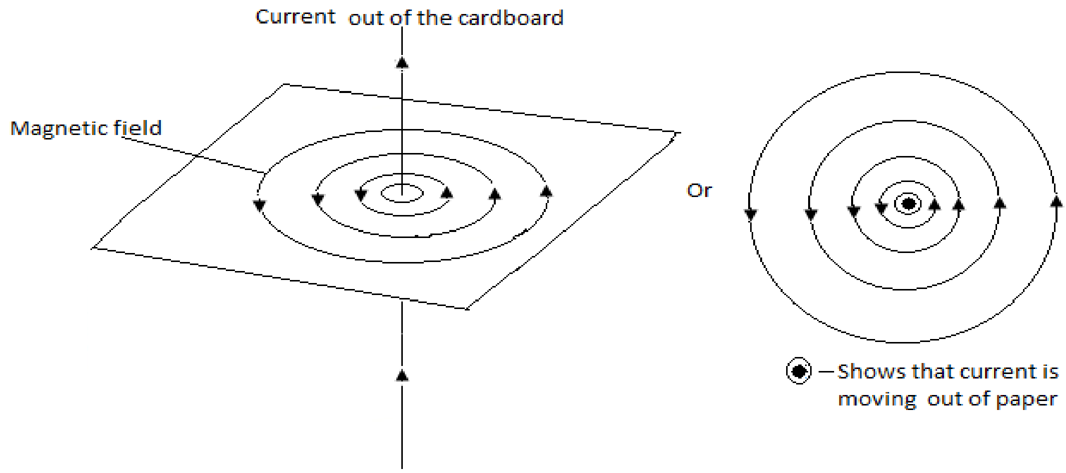
Magnetic field due to a conductor (wire) carrying current

When current flows through a wire carrying current, a magnetic field is created around the wire

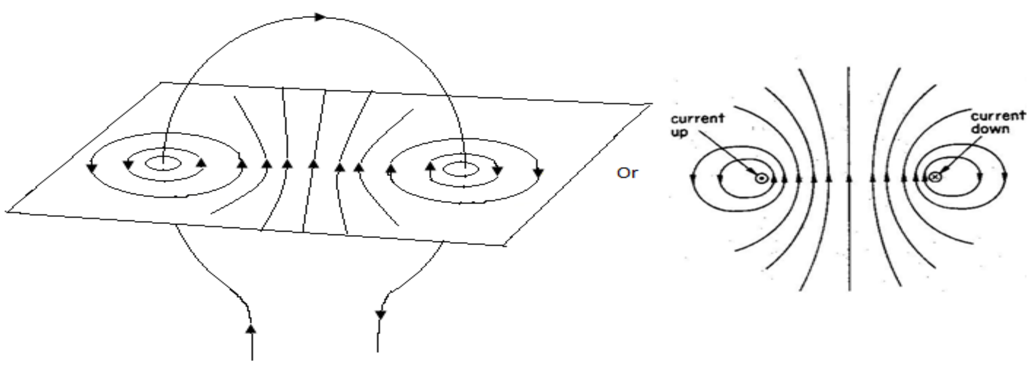
a) Field due to a straight wire carrying current into a cardboard



b) Field due to current moving out of the cardboard/paper



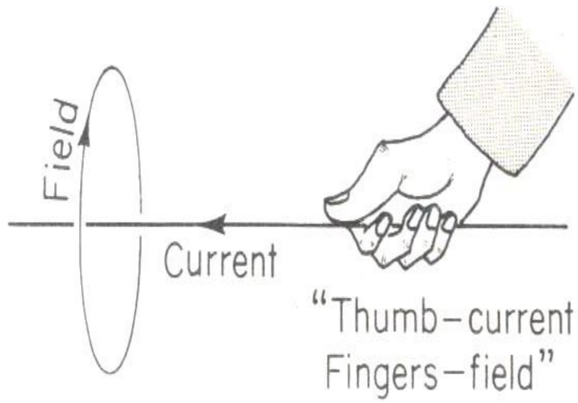
c) Field due to a current carrying circular coil



The field lines at the centre of the coil are straight and at right angles to the plane of the coil

<u>Determination of the direction of the field due to a current carrying conductor</u>

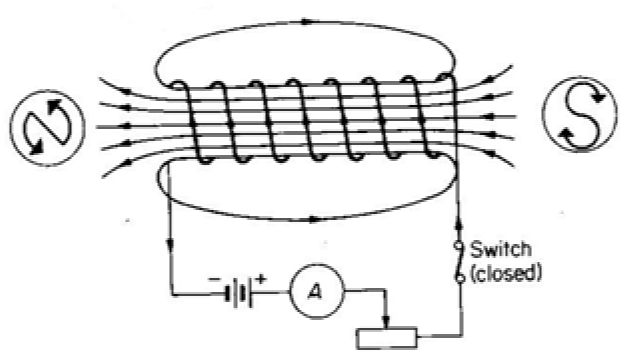
This can be done by the 'right hand grip rule'. It states that; Imagine the wire as grasped in the right hand, with the thumb pointing along the wire in the direction of current, then the fingers point in the direction of the field due to the conductor



Another way to determine the direction of the field is the right hand screw rule

It states; If a right handed screw moves forward in the direction of the current, the direction of rotation of the screw gives the direction of the field

d) Field due to a solenoid



<u>How to increase the strength of the field in a solenoid</u>

- Increasing the number of turns
- Increasing the current flowing through the solenoid
- Using low resistance copper wires in windings

<u>Electromagnets</u>

An electromagnet has a core of soft Iron around which a coil of low resistance copper wires is wound. When current flows in this coil, the soft Iron core is magnetized

<u>Why soft Iron is used in electromagnets</u>

- It is strongly magnetized
- It is easily magnetized and demagnetized

How the strength of electromagnets can be increased

- Increasing the current flowing in the coil
- Increasing the number of turns in the coil
- Making the poles closer to each other
- Using soft Iron core
- Using low resistance copper wires

Practical application of electromagnets

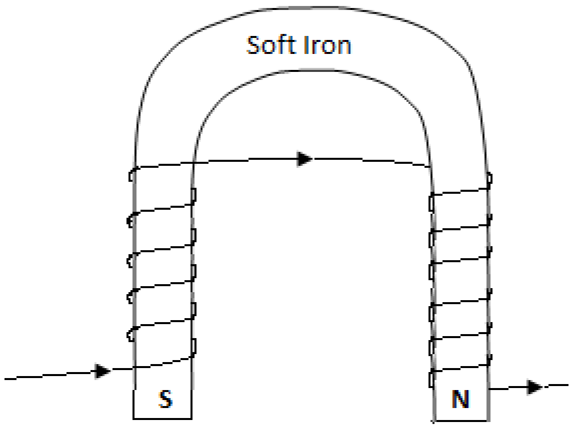
- Used in electric bells
- Used in electromagnetic relays
- Used in lifting magnets to sort metals
- Used in telephone receivers

Advantages of electromagnets

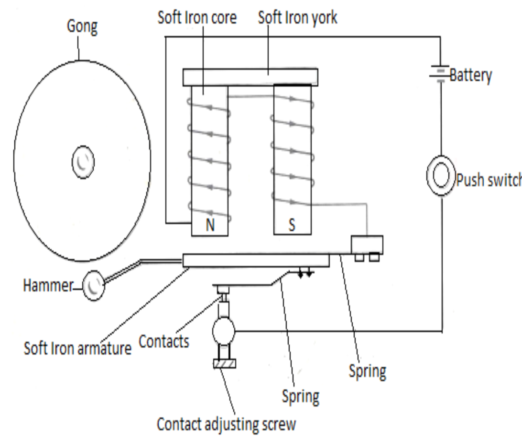
- They can easily be magnetized and demagnetized
- Their magnetism can be controlled by varying the current through them
- They can be made in any shape
- The poles can easily be interchanged by interchanging the batteries' terminals

The U – shape of an electromagnet

Soft Iron in an electromagnet is in a U – shape (horse shoe) in order to increase its strength by shortening the distance between the poles



<u>**The electric bell**</u>



An electric bell changes electrical energy to sound energy. When the switch is closed, the circuit is completed.

Current flows through the electromagnet and it is magnetized

The core attracts the soft Iron on which the hammer is attached which in turn hits the gong and sound is heard

Contact is broken and the electromagnet is demagnetized

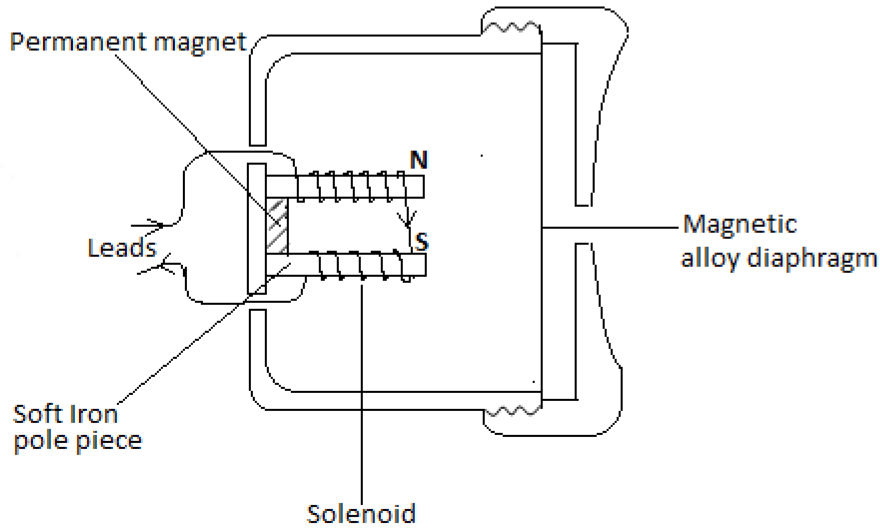
The spring pulls back the soft iron and contact is regained

The process continues as before as sound is heard

<u>The telephone receiver</u>

A telephone receiver changes electric energy to sound energy

A microphone changes sound energy to electric energy

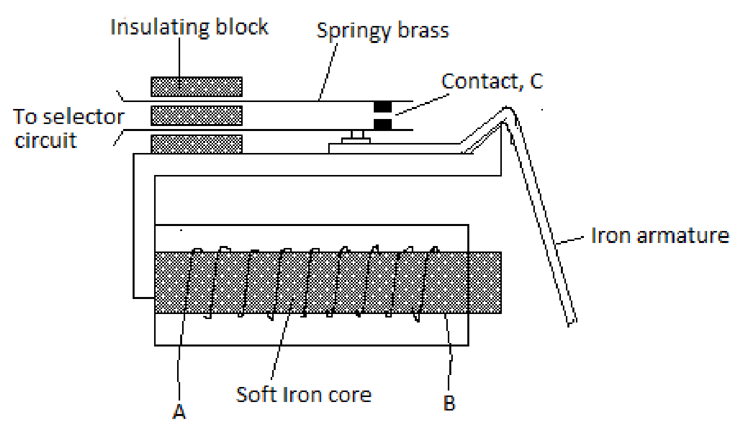


The varying current from the microphone passes through the coils of the electromagnet

This magnetizes the electromagnet which pulls the diaphragm towards itself at varying distances depending on the strength of the current through the electromagnet from the microphone

The diaphragm moves in and out and produces sound waves at the same frequency as those that entered the microphone

The electromagnetic relay



This is a switch worked by an electromagnet. It is useful if it is required for one circuit to control another especially if current in the second circuit is large

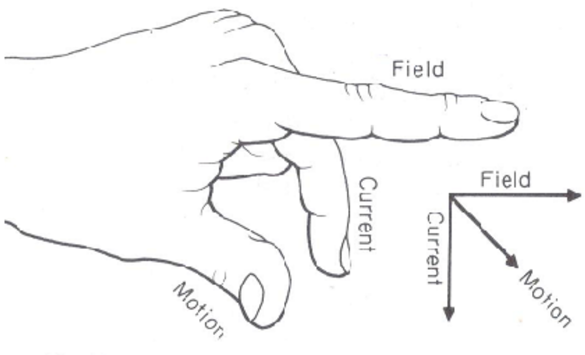
The relay is also used in telephone circuits. Whenever a number is dialled, pulses of current flow through a solenoid wound on soft Iron core

Each time current passes through terminals AB, the core is magnetized and attracts the L – shaped Iron armature thereby causing it to rock on its bearing and close the two contacts C. These contacts close a special circuit at the telephone exchange which operates switches to select the required number

Force on a conductor carrying current in a magnetic field

When a wire carrying current is placed in a magnetic field, it experiences a force and moves depending on the direction of the current and the field

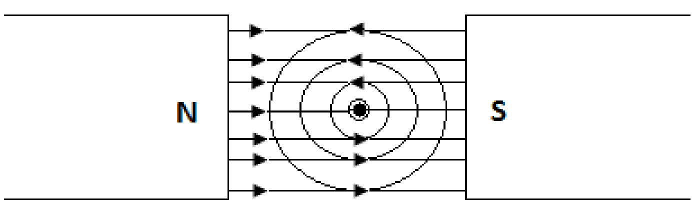
The direction of the force on the conductor can be predicted by Fleming's left hand rule which state; Hold the thumb, and the first two fingers of the left hand at right angles to each other, with the **F**irst finger pointing the direction of the **F**ield, se**C**ond finger pointing the direction of **C**urrent and the thu**M**b pointing the direction of **M**otion (force on the conductor)



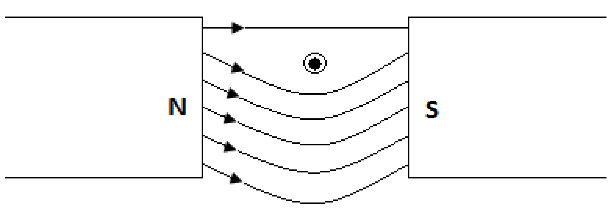
Fleming's left-hand rule (motor rule)

Example

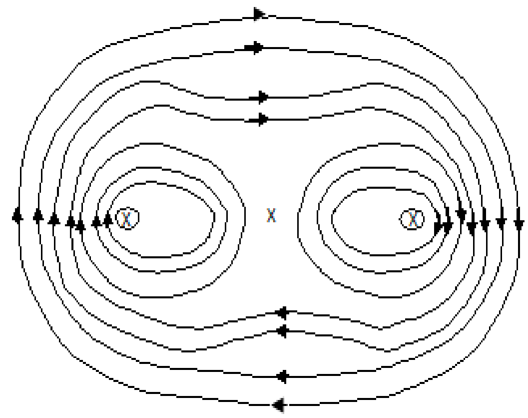
The figure below show a wire currying current in a magnetic field



With the aid of a diagram show how the resultant field will appear due to the interaction of the field due to a magnet and the current



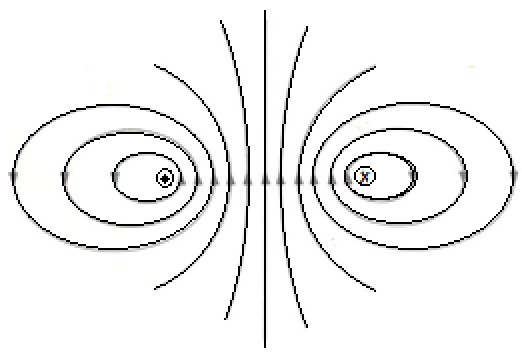
There are more lines of force below the conductor than above because below the conductor, the field due to the magnet and that due to the current are in the same direction, this makes the force greater below than above. The conductor will move upwards



Force due to two parallel conductors carrying current

a) Parallel wires carrying current in the same direction

b) Two conductors carrying current in opposite directions



Factors affecting the magnitude of force on a current carrying conductor in a magnetic field

- Magnitude of current through the conductor
- The strength of the magnetic field
- The length of the conductor

Note

The effect of the magnetic field on a current carrying conductor is referred to as ***motor effect***

Application of the motor effect

- Simple d.c motor
- Moving coil galvanometer

- Moving coil loud speaker.

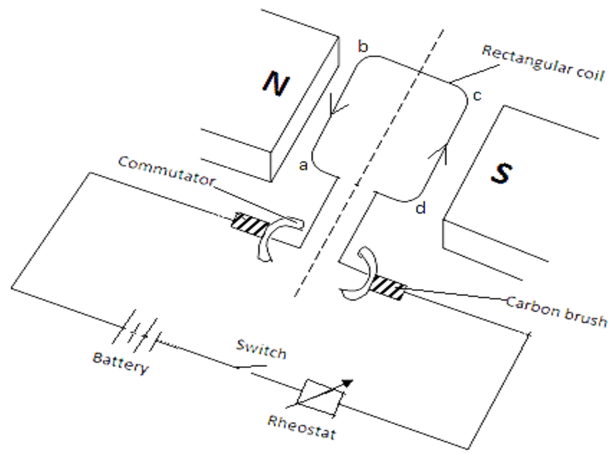
<u>The simple D.C motor</u>

The D.C motor transfers electrical energy into mechanical energy

<u>Structure</u>

It consists of a rectangular coil of wire placed between pieces of strong magnet whose ends are connected to the commutators.

The coil is free to rotate in uniform field



<u>Mode of operation</u>

The switch is closed

Current is passes through the coil

Equal opposite forces are exerted on the coil causing it to rotate

When the coil reaches the vertical position, the carbon brushes lose contact with the commutators and hence the current is cut off

The momentum of the coil however carries it beyond the vertical and the commutators reverse connect and the coil continues to rotate in the same direction

<u>How to increase the strength of a motor</u>

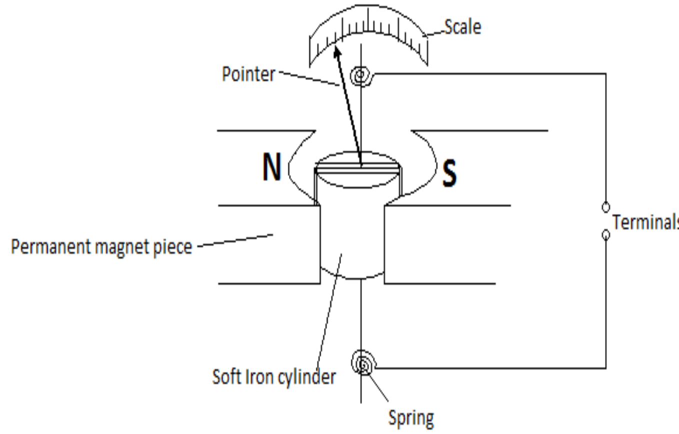
- Increase in the number of turns of the coil.
- Increase in the amount of current.
- Increase in the strength of the magnet.
- Winding the coil on a soft iron armature.

The moving coil Galvanometer

Structure

Consist of a fine insulated copper wire wound on a soft iron cylinder. The cylinder is pivoted on jeweled bearings

The coil is connected to the pointer which moves over the scale when it turns.



Operation

A current to be measured is let in and out through the hair springs.The vertical side of the coil experience equal and opposite force which constitute a couple.

The couple then turns the coil until the rotational couple of the springs balance with the torque due to the magnetic field

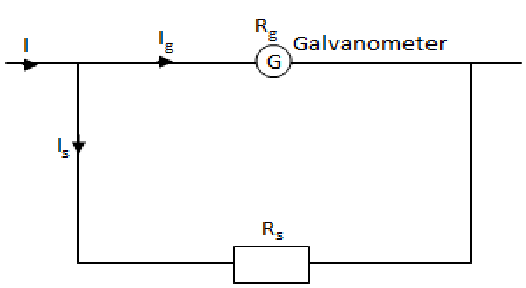
The position of a coil is then the measure of current

How to increase the sensitivity of the galvanometer

- Increase in the number of turns on the coil
- Using a stronger magnet with a high magnetic flux
- Using weak hairy springs
- Using a beam of light reflected onto the scale instead to the pointer
- Suspending the coil freely

Converting a galvanometer to an ammeter

This is done by connecting a resistor of low value called a shunt in parallel with the galvanometer



Since the galvanometer is in parallel with the shunt, the p.d across the galvanometer is equal to the p.d across the shunt

i.e.

is voltage across the galvanometer

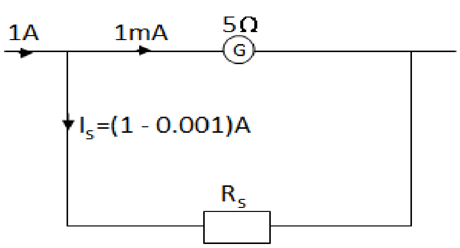
is the voltage across the shunt

Total current I to be measured by the galvanometer when converted to an ammeter is;

Hence

Example 1

A moving coil galvanometer has resistor of 5Ω and gives a full scale deflection of 1mA. It is to be converted to an ammeter which has a full scale deflection of 1A. How can this be done?



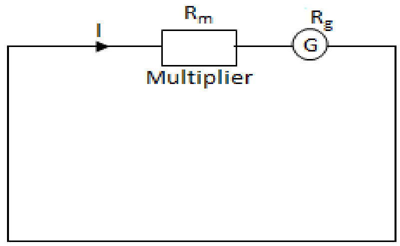
It is done by connecting a 0.005Ω resistor in parallel with the galvanometer

Example 2

What value of the shunt should be connected in parallel with a 10Ω resistor with a full scale deflection of 1mA in order to read a current ranging from 0 – 1 A

Converting a galvanometer to a voltmeter

This is done by connecting a resistor of high value called a multiplier in series with the galvanometer



is the full scale deflection of the galvanometer

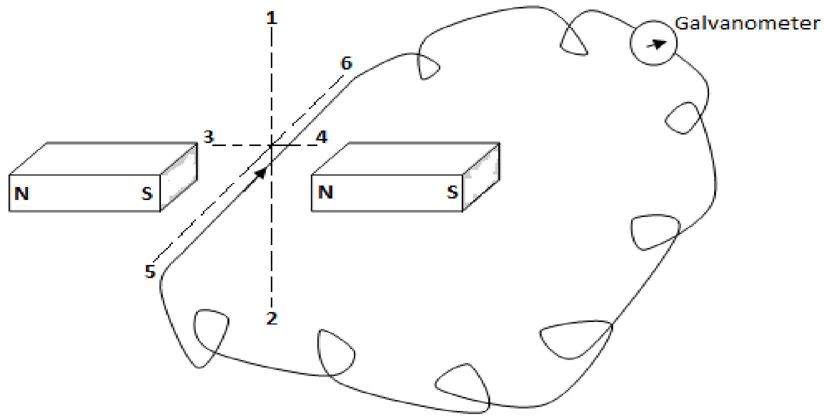
Example

The resistance of a galvanometer is 10Ω and its full scale deflection is 25mA. Calculate the resistor that should be connected such that it reads 3V

Electromagnetic Induction

This is the process by which an electric current is produced from a magnetic field

Experiment to demonstrate electromagnetic induction



The conductor is connected to a galvanometer as show above

The conductor is moved in the directions; 1, 2, 3, 4, 5 and 6

Deflection in the galvanometer is only observed when the conductor is moved in the direction 1 and 2. This is because it is only in directions 1 and 2 where the conductor cuts the magnetic field and this results into an induced current leading to the deflection of the galvanometer

When the conductor is moved in other directions 3, 4, 5 and 6, there will be no deflection in the galvanometer since there will be no cutting in the magnetic field

Laws of electromagnetic induction

1. ***Faraday's law***

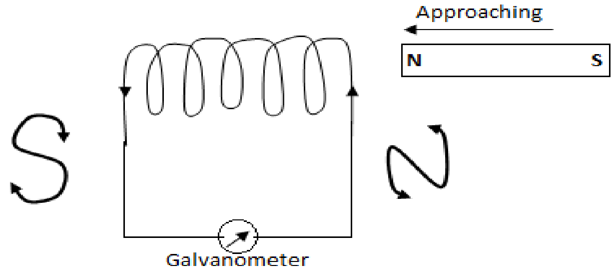
   It states that the size of the e.m.f induced in a conductor is directly proportional to the rate at which the conductor cuts the magnetic field lines

2. ***Lenz's law***

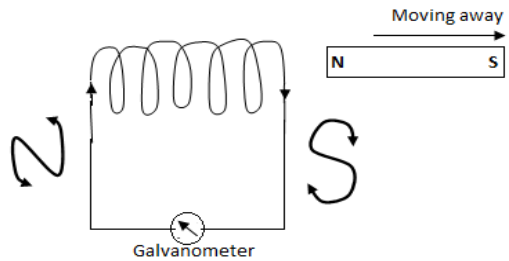
   It states; the direction of induced current flows such as to oppose the change causing it

Experiment to demonstrate the laws of magnetism

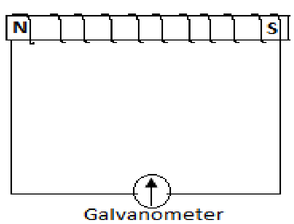
1. Bar magnet approaching the coil



2. Bar magnet moving away from the coil



3. Bar magnet resting inside the coil



From the diagrams above;

1. When the bar magnet approaches the coil, the galvanometer deflects. This is because the coil cuts the magnetic field which results into an induced e.m.f hence induced current flows
2. When the bar magnet is pulled away, the galvanometer deflects in the opposite direction. This is due to the cutting of the magnetic field which results into an induced e.m.f hence an induced current
3. The bar magnet is made to rest in the coil and no deflection in the galvanometer since there is no change in the magnetic field linked with the coil

Note

The direction of induced current is determined by Fleming's right hand rule (Dynamo rule)

Application of electromagnetic induction

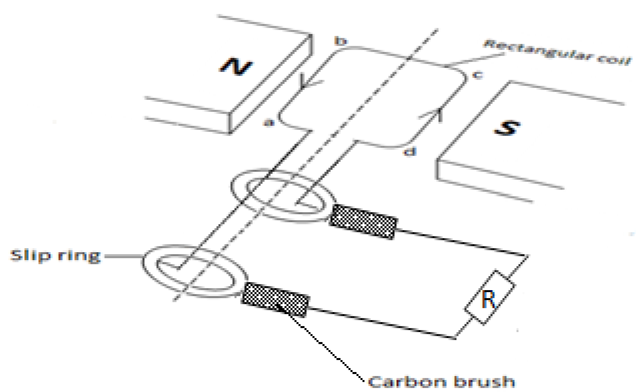
The simple A.C generator (Dynamo)

A generator is a device that converts kinetic energy to electrical energy

Structure

A simple A.C generator consists of a rectangular coil in a magnetic field between poles of a permanent magnet

The ends of the coil are connected to two slip rings pressing against carbon brushes



Mode of operation

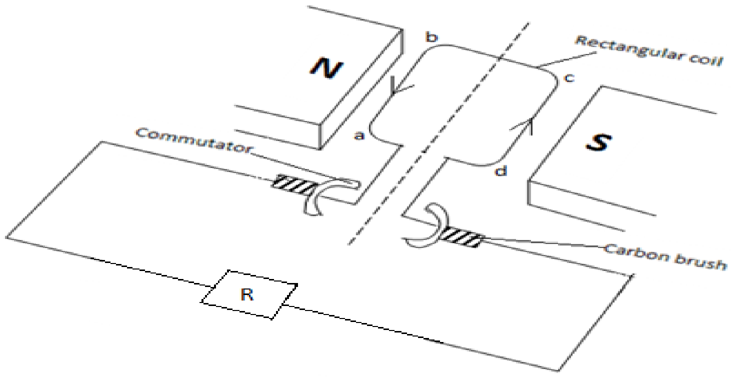
When the coil is rotates in the magnetic field, the field linking it changes

An e.m.f is induced in the coil and induced current flows in the coil.

The induced current is led away by means of slip rings and appears across the load resistor R

The simple D.C generator

An A.C generator is converted to a D.C generator by replacing the slip rings with half split rings (Commutators)



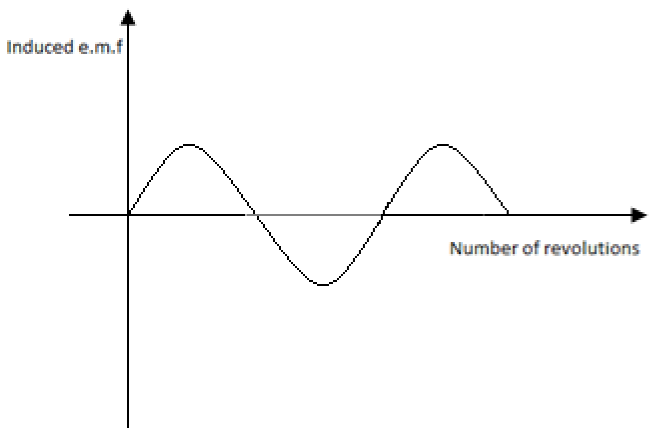
When the coil rotates, its sides ab and cd cut the magnetic field

An e.m.f is induced in the coil, hence an induced current flows

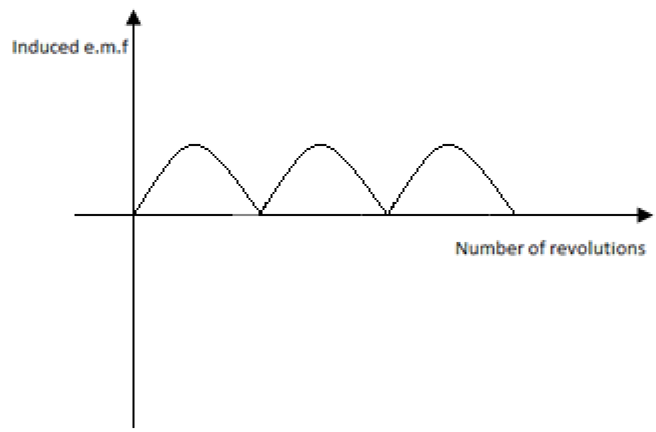
The induced current is delivered into the external resistor R

<u>Sketches of the variation of induces e.m.f with rotation of the coil</u>

1. *For A.C generator*



2. *For D.C generator*



Comparison of a D.C generator with an electric motor

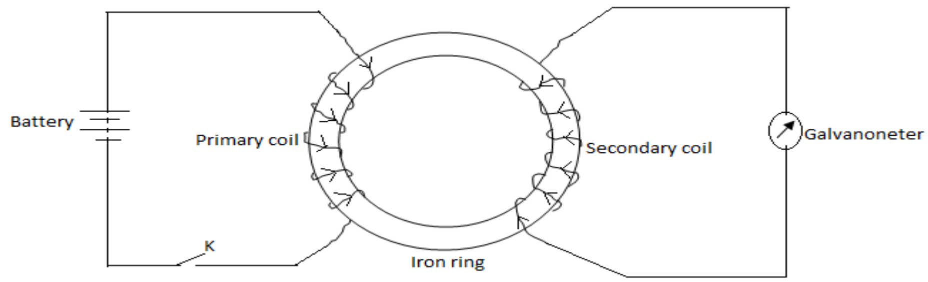
The D.C generator and an electric motor are identical in construction. If a simple D.C generator is connected to a battery, it will run as a motor. If on the other hand, a simple electric motor is made to rotate, it will behave as a generator and deliver current at the brushes

How to increase e.m.f in a simple generator

- Increasing the number of turns on the coil
- Winding the coil on a soft Iron armature
- Using a strong magnet
- Increasing the speed of rotation

Advantages of A.C over D.C

- There is little or no power losses
- A.C can easily and cheaply be stepped up and stepped down
- Frequency of the supply can be precisely controlled
- Thinner cables can be used since voltage can be stepped up and down
- Mutual induction
- This is when two coils are arranged with one carrying current (primary) and the change in current in one induces a current in the second coil (secondary)



- The apparatus above was discovered by Faraday and it is known as Faraday's Iron ring experiment
- When switch K is closed, the galvanometer deflects momentarily and when it is opened, it deflects momentarily in the opposite direction
- This is due to a change in the current in the primary coil which induces an e.m.f in the secondary coil and hence an induced current flows
- **Note**
- If an a.c voltage is used in the primary coil instead of a d.c voltage, an alternating current will be induced in the secondary coil

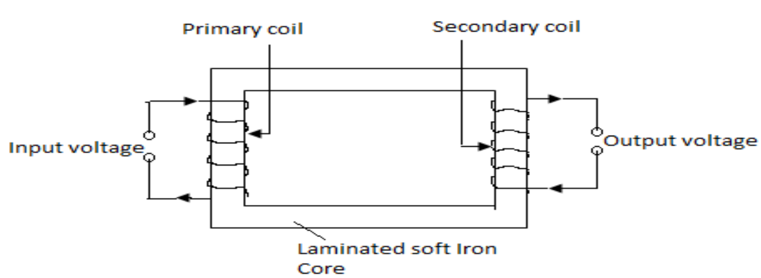
Application of mutual induction

It is applied in transformers

The Transformer

A transformer is a device which changes A.C voltage from one value to another

A transformer consists of two coils (primary and secondary) wound on a soft iron core made up of insulated sheet of iron wire



When an alternating p.d is applied to the primary

The resultant current produces a large alternating magnetic flux which links the secondary and induces an e.m.f in it, hence the output voltage

Types of transformers

There are two types of transformers;

1. Step up transformer
2. Step down transformer

1. Step up transformer

   This is the one in which the number of turns in the secondary coil is greater than that in the primary coil

   i.e.

2. Step down transformer

   This is the one in which the number of turns in the secondary coil is less than that in the primary coil

   i.e.

Energy losses in a transformer

- Energy loss due to resistance in the windings
- Leakage of the magnetic field lines
- Loss due to Eddy currents
- Energy loss due to magnetic reversal (Hysteresis)

How to minimize energy losses in a transformer

- Using low resistance copper wires
- Use of a laminated soft Iron core to minimize Eddy currents
- Carrying out efficient core design to ensure that all the field is linked with the coil in the secondary
- Using soft magnetic material in order to prevent magnetic reversal

Examples

1. A transformer steps down a voltage from 240V to12V for a radio. If the primary windings are 300 turns, how many turns on the secondary windings?
2. An electric power generator produces 24kW at 240V. The voltage is stepped up to 4000V. If the transformer is 100% efficient, calculate the current in the secondary coil
3. A transformer 80% efficient is connected to a 240V A.C supply to operate a heater of resistance 240Ω. If the current flowing in the primary circuit is 5A, calculate the potential difference across the heater

THE SOLAR SYSTEM: EARTH AND SPACE SYSTEM

Objectives

- ✓ How the Earth orbits around the sun and the moon around the Earth and the time taken for these orbits.
- ✓ The cause of day and night.
- ✓ Why the shape of the moon appears to change over a period of time when viewed from the Earth.
- ✓ How the tilt of the Earth gives rise to seasons in some parts of the world.
- ✓ The implications of the above for activities on Earth.
- ✓ Use a model to explain how the earth and moon move relative to the sun and use it to explain eclipses.
- ✓ The connection between the moon and ocean tides.
- ✓ The components of the solar system, and make a scale model of the planets and place them in order showing their relative distance from the Sun.
- ✓ The main characteristics of the inner four and outer four planets.
- ✓ Why the Earth is the only planet which supports life.
- ✓ The asteroid belt and where it is found in the Solar System.
- ✓ The origin and structure of the universe.

THE EARTHS' ORBIT ABOUT THE SUN & MOONS' ORBIT ABOUT THE EARTH.

The Earth revolves in an orbit around the Sun in **365.25 days,** with reference to the stars, at a speed ranging from 29.29 to 30.29 kms^{-1}. The 6 hours, 9 minutes (0.25 days) adds up to about an extra day every fourth year, which is designated in a leap year, an extra day added as February 29th. The Moon takes **about one month** to orbit the Earth (27.3 days to complete a revolution, but 29.5 days to change from the present Moon to New Moon). As the Moon completes each 27.3-day orbit around Earth, both Earth and the Moon are moving around the Sun. The Earth and the Moon's orbits are maintained by a gravitational force that attracts and keeps them in the orbit.

DAY AND NIGHT

Day and night are due to **the Earth rotating on its axis**, not its orbiting around the sun. The term 'one day' is determined by the time the Earth takes to rotate once on its axis and includes both day time and night time. When the Earth rotates a given part facing the sun, that part experiences day and when that Earth's part faces away from the sun, then that part experiences night.

Daytime is when you can see the sun from where you are, and its light and heat can reach you. Nighttime is when the sun is on the other side of the Earth from you, and its light and heat don't get to you.

We get day and night because the Earth spins (or rotates) on an imaginary line called its axis and different parts of the planet are facing towards the Sun or away from it.

It takes 24 hours for the world to turn all the way around, and we call this a day. Over a year, the length of the daytime in the part of the Earth where you live changes. Days are longer in the summer and shorter in the winter. It's summarized as below;

- ✓ It takes 24 hours for the Earth to turn all the way around (rotation). That makes one day and one night.
- ✓ At any moment, half of the world is in daytime and half is in nighttime.
- ✓ The world is like a ball. We call the top half the Northern hemisphere and the bottom half the Southern hemisphere. The (imaginary) line between them is called the equator.

- ✓ In the Northern hemisphere, we have summer in June, July and August and winter is in December, January and February.
- ✓ In summer the days are longer than they are in winter.
- ✓ **In London, the longest day is about 16 hours and 39 minutes and the shortest is 7 hours and 45 minutes.**
- ✓ In the Southern hemisphere the seasons are the other way around. When it is summer in Europe, it is winter in Australia. Imagine celebrating Christmas on a long, hot summer day.
- ✓ The (imaginary) line between the Eastern and Western hemispheres is called the 'Prime Meridian' and it goes through Greenwich Royal Observatory in London.
- ✓ The world is split into time zones. Continental Europe is in the time zone to the east of Britain, so time is one hour ahead there; when it is 1pm in Britain it is 2pm in France.

CHANGES IN THE SHAPE OF THE MOON

The Moon doesn't emit (give off) light itself, the 'moonlight' we see is actually the Sun's light reflected off the lunar surface. So, **as the Moon orbits the Earth, the Sun lights up different parts of it**, making it seem as if the Moon is changing shape. In actual fact, it's just our view of it that's altering

- ✓ It is a universal fact the Moon does not produce light itself. It is the Sun who produces the light and the Moon brights from the Sun's light.
- ✓ Because of the Moon's changing position as it orbits our planet, the Sun's light focus on different parts of it, giving the illusion that the Moon is changing shape over

time.

- ✓ But the fact is that the Moon never changes its shape. The shape of the Moon that appears at night, is the only part of the Moon which is facing us and in sunlight.
- ✓ There are eight total phases of the moon cycle, four primary phases, and four secondary phases.
- ✓ The primary phases are the new moon, first quarter, full moon, and last quarter.
- ✓ The secondary phases are waxing crescent, waxing gibbous, waning crescent, and waning gibbous. The term waxing refers to the growth of the moon's image, while the term waning refers to a shrinking image.
- ✓ The moon changes its shape every day. The day on which the whole of the moon is visible is known as the full moon day. Thereafter every night the size of the bright part of the moon appears to become thinner day by day.
- ✓ On the fifteenth day, the moon is not visible. This day is known as the "new moon day".
- ✓ On most days only a small portion of the moon appears in the sky. This is known as the crescent moon. Then again moon grows larger every day.
- ✓ On the fifteenth day, once again we get a full view of the moon. The time period between one full moon to the next full moon is slightly longer than 29 days (~29.5 days). The various shapes of the bright part of the moon as seen during a month are called phases of the moon.

SEASONS IN SOME PARTS OF THE EARTH

As the earth spins on its axis, producing night and day, it also moves about the sun in an elliptical (elongated circle) orbit that requires about 365 1/4 days to complete. The earth's spin axis is tilted with respect to its orbital plane. This is what causes the seasons. When the earth's axis points towards the sun, it is summer for that hemisphere. When the earth's axis points away, winter can be expected.

Throughout the year, different parts of Earth receive the Sun's most direct rays. So, when the North Pole tilts toward the Sun, it's summer in the Northern Hemisphere. And when the South Pole tilts toward the Sun, it's winter in the Northern Hemisphere.

IMPLICATION OF SEASON ON ACTIVITIES ON EARTH

The season on earth affects the various activities conducted by human beings. This ranges from human activities, agricultural activities and human life. These activities are all affected by the seasons which arise from the changes in seasons.

Item

Discuss the impact and implications of changing seasons to the human and other activities on Earth.

RELATIVE MOTION OF THE SUN AND MOON AND ECLIPSE

The Sun is the largest of the sun, Earth and Moon. The earth rotates about the sun and revolves about its own axis. The moon rotates about the Earth and the sun concurrently. When the Sun, Earth and the Moon are in a straight line, the shadow of the sun is cast either on the Earth or the Moon. This is referred to as an eclipse.

During a solar eclipse, the moon moves between the Earth and the sun and blocks the sunlight. The shadow is formed on Earth.

During a lunar eclipse, the Earth blocks the sun's light from reaching the moon. The shadow is formed on the moon as the Earth blocks light from reaching the moon. Since we are standing on Earth, what we see is that the moon gets dark. Other kinds of eclipses happen too.

CHARACTERISTICS OF INNER AND OUTER PLANETS

Density: *Inner planets are denser than outer planets.*

Composition: *Outer planets are made of gas, ice, and rocks, whereas the inner planets are made of iron, nickel, and silicates.*

Moons: *Inner planets have very few to no moons around them, whereas the outer planets have dozens of moons orbiting them.*

EXPLAIN WHY EARTH IS THE ONLY PLANET THAT SUPPORTS LIFE.

The Earth has the right distance from the Sun; it is protected from harmful solar radiation by its magnetic field. It is also kept warm by an insulating atmosphere, and it has the right chemical ingredients for life, including water and carbon.

Earth is able to support life because it has a suitable temperature for living organisms along with the presence of oxygen and water that is required for the survival of all life forms

The Earth appears to be the only planet in the solar system with living creatures. In the solar system, the planets orbit around the Sun. Earth is the third planet from the Sun. It is one of the inner planets. As far as we know, Earth is also the only planet that has liquid water. Earth's atmosphere has oxygen. The water and oxygen are crucial to life as we know it. Therefore ethe Earth is able to support life in it.

THE ASTEROID BELT AND WHERE IT'S FOUND

The asteroid belt is a region within the solar system occupied by asteroids that are sparsely held together by gravity and occupying a region taking the shape of a gradient ring orbiting the Sun.

Asteroids are small rocky bodies

sometimes composed of iron and nickel, which orbit the Sun. The asteroid belt exists between the orbits of Mars and Jupiter, between 330 million and 480 million kilometers from the Sun.

IS THE ASTEROID BELT A FAILED PLANET?

Astronomers once thought that the asteroid belt was a failed planet that fragmented during the solar system's development. However, this hypothesis has largely been abandoned. Astronomers now believe the asteroid belt never gravitationally accreted into a planet, but was kept from doing so because of the massive gravity from Jupiter's mass.

ORIGIN AND STRUCTURE UNIVERSE

The big-bang theory proposes the universe was formed from an infinitely dense and hot core of the material. The bang in the title suggests there was an explosive, outward expansion of all matter and space that created atoms. Spectroscopy confirms that hydrogen makes up about 74% of all matter in the universe

The universe appears to have an infinite number of galaxies and solar systems and our solar system occupies a small section of this vast entirety. The origins of the universe and solar system set the context for conceptualizing the Earth's origin and early history.

The mysterious details of events prior to and during the origin of the universe are subject to great scientific debate. The prevailing idea about how the universe was created is called the ***big-bang theory***. Although the ideas behind the big-bang theory feel almost mystical, they are supported by Einstein's theory of general relativity.

The big-bang theory proposes the universe was formed from an *infinitely dense and hot core of the material*. The bang in the title suggests there was an explosive, outward expansion of all matter and space that created atoms. Spectroscopy confirms that hydrogen makes up about 74% of all matter in the universe. Since its creation, the universe has been expanding for 13.8 billion years and recent observations suggest the rate of this expansion is increasing.

THE EARTH'S AXIS

The Earth is a rocky planet that rotates in a near circular orbit around the Sun. It rotates on its axis, which is a line through the north and south poles. The axis is tilted at an angle of approximately 23.5° from the vertical. The Earth completes one full rotation (revolution) in approximately 24 hours (1 day). This rotation creates the apparent daily motion of the Sun rising and setting.

Rotation of the Earth on its axis is therefore responsible for the periodic cycle of day and night.

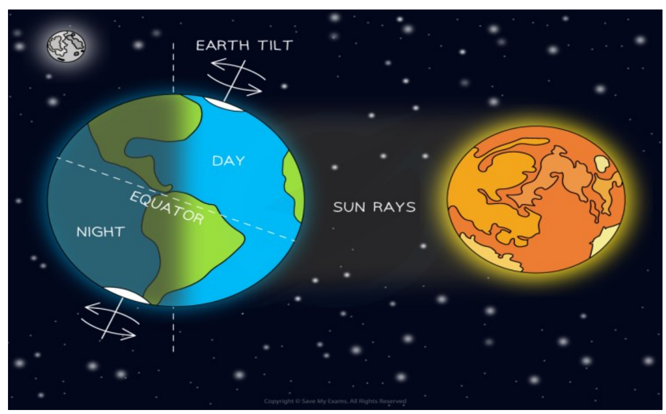
DAY AND NIGHT

The Earth's rotation around its axis creates day and night.

Day is experienced by the half of the Earth's surface that is facing the Sun. Night is the other half of the Earth's surface, facing away from the Sun. *Day and night are caused by the Earth's rotation*

RISING AND SETTING OF THE SUN

The Earth's rotation on its axis makes



the Sun looks like it moves from east to west

At the equinoxes the Sun rises exactly in the east and sets exactly in the west.

Equinox (meaning 'equal night') is when day and nights are approximately of equal length.

However, the exact locations of where the Sun rises and sets change throughout the seasons. In the northern hemisphere (above the equator): In summer, the sun rises north of east and sets north of west

In winter, the sun rises south of east and sets south of west.

The Sun rises in the east and sets in the west. Its approximate area changes throughout the year

The Sun is highest above the horizon at noon (12 pm).

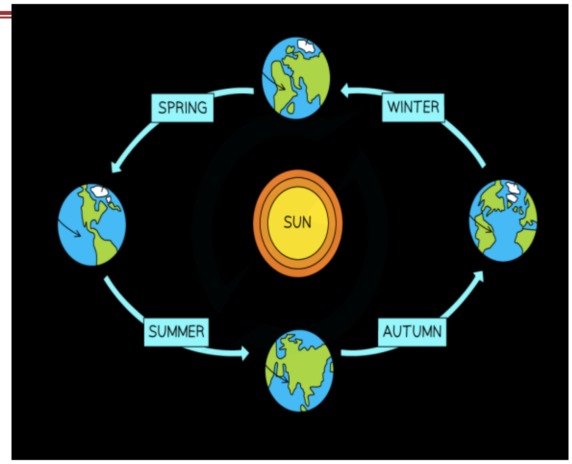
In the northern hemisphere, the daylight hours are longest up until roughly the 21st June.

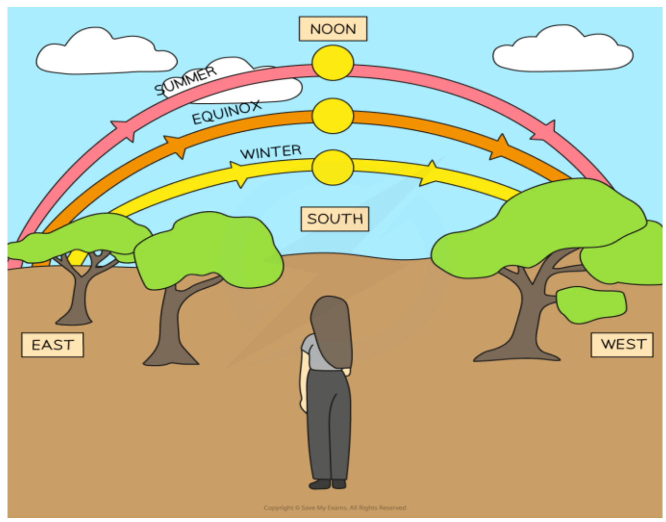
This day is known as the ***Summer Solstice*** and is where the Sun is at its highest point in the sky all year.

The daylight hours then decrease to their lowest around 21st December

This is known the Winter Solstice and is where the Sun is at its lowest point in the sky all year.

THE EARTH'S ORBIT





The Earth orbits the Sun once in approximately 365 days. This is 1 year. The combination of the orbiting of the Earth around the Sun and the Earth's tilt creates the seasons

Seasons in the Northern hemisphere caused by the tilt of the Earth

Over parts B, C and D of the orbit, the northern hemisphere is tilted towards the Sun.

This means daylight hours are more than hours of darkness. This is spring and summer. The southern hemisphere is tilted away from the Sun. This means there are shorter days than night. This is autumn and winter.

Over parts F, G and H of the orbit, the northern hemisphere is tilted away from the Sun. The situations in both the northern and southern hemisphere are reversed. It is autumn and winter in the northern hemisphere, but at the same time it is spring and summer in the southern hemisphere. At C: This is the ***summer solstice***

The northern hemisphere has the longest day, whilst the southern hemisphere has its shortest day

At G: This is the ***winter solstice.***

The northern hemisphere has its shortest day, whilst the southern hemisphere has its longest day. At A and D: Night and day are equal in both hemispheres. These are the equinoxes.

MOON & EARTH

The Moon is a silent satellite around the Earth

It travels around the Earth in roughly a circular orbit once a month

This takes 27-28 days.

The Moon revolves around its own axis in a month so always has the same side facing the Earth. We never see the hemisphere that is always facing away from Earth, although astronauts have orbited the Moon and satellites have photographed it.

The Moon shines with **reflected light from the Sun**; *it does not produce its own light.*

PHASES OF THE MOON

The way the Moon's appearance changes across a month, as seen from Earth, is called its *periodic cycle of phases*

PHASES OF THE MOON AS IT ORBITS AROUND EARTH

In the image above, the inner circle shows that exactly half of the Moon and is illuminated by the Sun at all times. The outer circle shows how the Moon looks like from the Earth at its various positions.

In the New Moon phase:

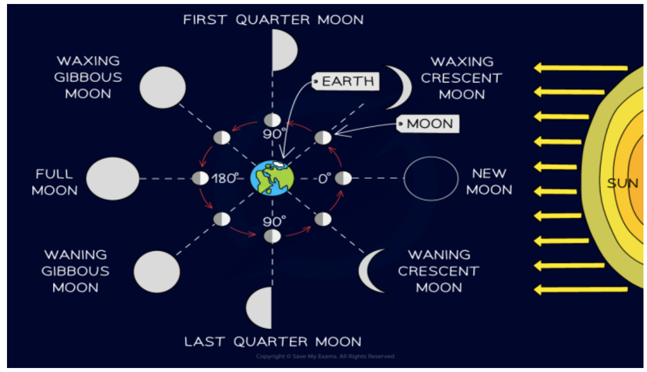
The Moon is between the Earth and the Sun. Therefore, *the sunlight is only on the opposite face of the Moon to the Earth.* This means the Moon is *unlit as seen from Earth, so it is not visible.*

At the Full Moon phase:

The Earth is between the Moon and the Sun. The side of the Moon that is facing the *Earth is completely lit by the sunlight*. This means the Moon is *fully lit as seen from Earth.*

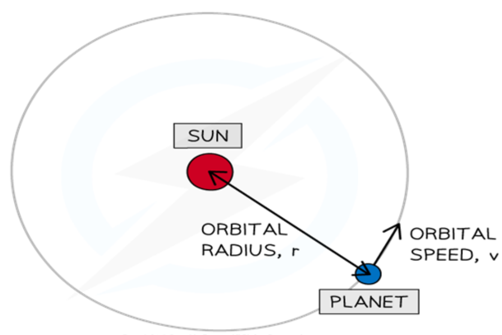
In between, a crescent can be seen where the Moon is partially illuminated from sunlight.

ORBITAL SPEED



When planets move around the Sun, or a moon moves around a planet, they orbit in circular motion. This means that in one orbit, a planet travels a distance equal to the circumference of a circle (the shape of the orbit).

This is equal to $2\pi r$ where r is the radius a circle.



The relationship between speed, distance and time is: the average orbital speed of an object can be defined by the equation: $v = \frac{2\pi r}{T}$

Where:

- ✓ v = orbital speed in metres per second (m/s)
- ✓ r = average radius of the orbit in metres (m)
- ✓ T = orbital period in seconds (s)

This orbital period (or time period) is defined as: The time taken for an object to complete one orbit.

The orbital radius r is always taken from the centre of the object being orbited to the object orbiting.

Orbital radius and orbital speed of a planet moving around a Sun

Worked Assessment

The Hubble Space Telescope moves in a circular orbit. Its distance above the Earth's surface is 560 km and the radius of the Earth is 6400 km. It completes one orbit in 96 minutes.

Calculate its orbital speed in m/s.

Step 1: List the known quantities

Radius of the Earth, R = 6400 km

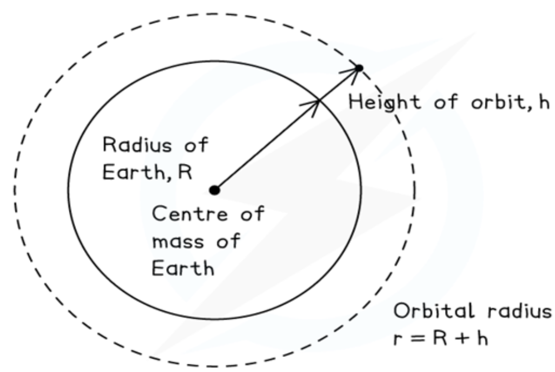
Distance of the telescope above the Earth's surface, h = 560 km

Time period, T = 96 minutes

Step 2: Write the relevant equation

Step 3: Calculate the orbital radius, r

The orbital radius is the distance from the centre of the Earth to the telescope



Step 4: Convert any units

The time period needs to be in seconds

The radius needs to be in metres

Step 5: Substitute values into the orbital speed equation

Assessment Tip

Remember to check that the orbital radius r given is the distance from the centre of the Sun (if a planet is orbiting a Sun) or the planet (if a moon is orbiting a planet) and not just from the surface. If the distance is a height above the surface you must add the radius of the body, to get the height above the centre of mass of the body. This is because orbits are caused by the mass, which can be assumed to act at the centre, rather than the surface.

GRAVITATIONAL EFFECTS ON ORBITS

GRAVITATIONAL FIELD STRENGTH

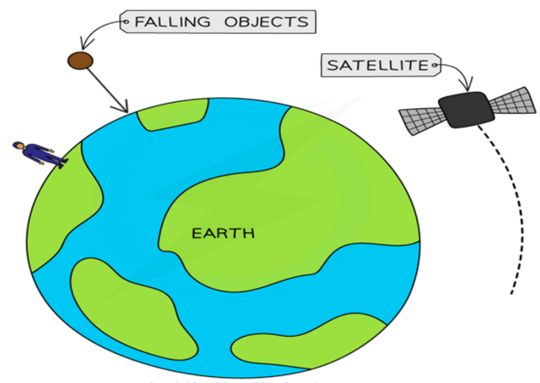
The strength of gravity on different planets affects an object's weight on that planet.

Weight is defined as the force acting on an object due to gravitational attraction.

Planets have strong gravitational fields. Hence, they attract nearby masses with a strong gravitational force.

Because of weight:

- ✓ Objects stay firmly on the ground
- ✓ Objects will always fall to the ground
- ✓ Satellites are kept in orbit



Objects are attracted towards the centre of the Earth due to its gravitational field strength.

Both the weight of any body and the value of the gravitational field strength, g, differs between the surface of the Earth and the surface of other bodies in space, including the Moon because of the planet or moon's mass. The greater the mass of the planet then the greater its gravitational field strength.

Higher gravitational field strength means a larger attractive force towards the centre of that planet or moon, g varies with the distance from a planet, but on the surface of the planet, it is roughly the same.

The strength of the field around the planet decreases as the distance from the planet increases.

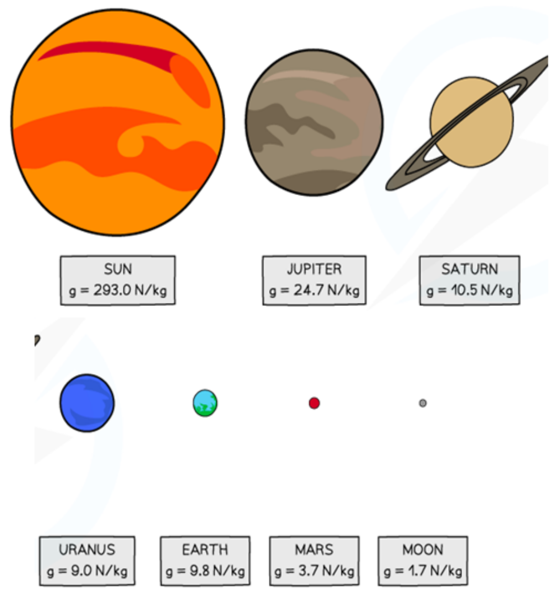
However, the value of g on the surface varies dramatically for different planets and moons. The gravitational field strength (g) on the Earth is approximately 10 N/kg.

The gravitational field strength on the surface of the Moon is less than on the Earth.

This means it would be easier to lift a mass on the surface of the Moon than on the Earth.

The gravitational field strength on the surface of the gas giants (eg. Jupiter and Saturn) is more than on the Earth.

This means it would be harder to lift a mass on the gas giants than on the Earth.

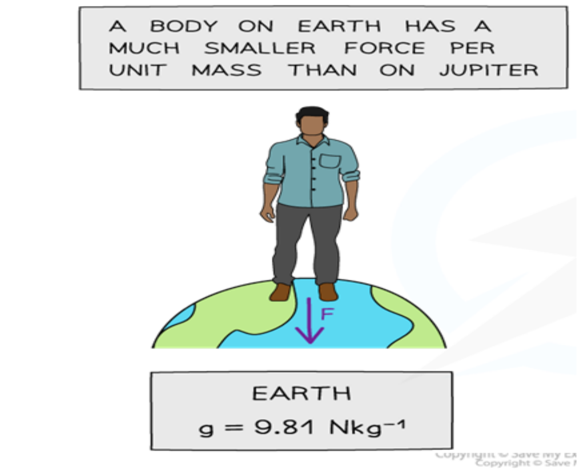


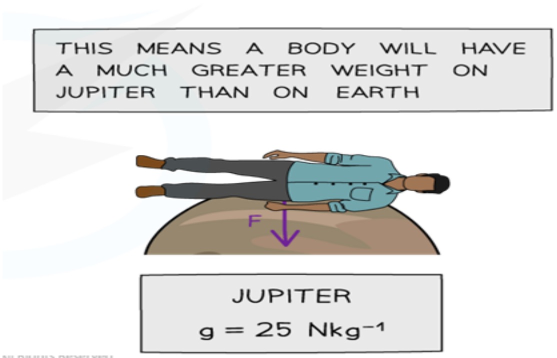
Value for g on the different objects in the Solar System.

On such planets such as Jupiter, an object's mass remains the same at all points in space.

However, their weight will be a lot greater meaning for example; a human will be unable to fully stand up.

A person's weight on Jupiter would be so large a human would be unable to fully stand up.





Assessment Tip

You do not need to remember the value of g on different planets for your Assessment, the value of g for Earth will be given in the Assessment question.

GRAVITATIONAL ATTRACTION OF THE SUN

There are many orbiting objects in our solar system and they each orbit a different type of planetary body.

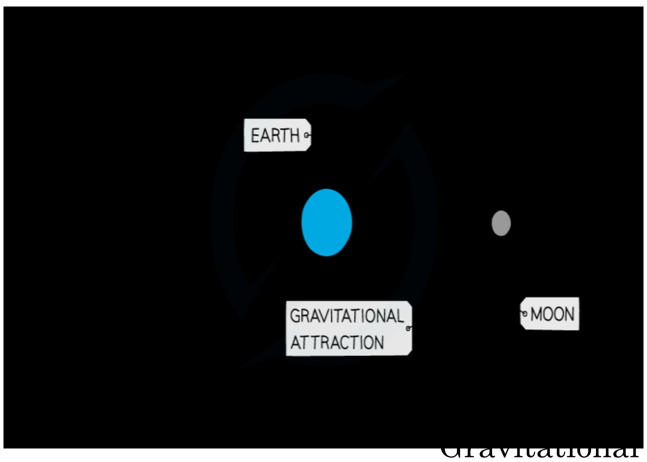
Orbiting Objects or Bodies in Our Solar System Table

A smaller body or object will orbit a larger body.
For example, a planet orbiting the Sun;

Body or Object	What it Orbits
Planet	Sun
Moon	Planet
Comet	Sun
Asteroid	Sun
Artificial satellite	Any object or body in solar system

In order to orbit a body such as a star or a planet, there has to be a force pulling the object towards that body.
Gravity provides this force. Therefore, it is said that the force that keeps a planet in orbit around the Sun is the gravitational attraction of the Sun.
The gravitational force exerted by the larger body on the orbiting object is always attractive. Therefore, the gravitational force always acts towards the centre of the larger body.

Therefore, the force that keeps an object in orbit around the Sun is the gravitational attraction of the Sun and is always directed from the orbiting object to the centre of the Sun. The gravitational force will cause the body to move and maintain in



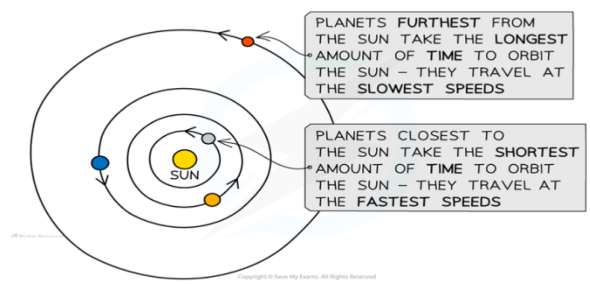
Gravitational attraction causes the Moon to orbit around the Earth.

Sun's Gravitational Field & Distance

As the distance from the Sun increases:

The strength of the Sun's gravitational field on the planet decreases. Their orbital speed of the planet decreases. To keep an object in a circular path, it must have a centripetal force. For planets orbiting the Sun, this force is gravity. *Therefore, the strength of the Sun's gravitational field in the planet affects how much centripetal force is on the planet.*

This strength decreases the further away the planet is from the Sun, and the weaker the centripetal force. The centripetal force is proportional to the orbital speed. *Therefore, the planets further away from the Sun have a smaller orbital speed. This also equates to a longer orbital duration*



How the speed of a planet is affected by its distance from the Sun.

This can be seen from data collected for a planet's orbital distance against their orbital speed. E.g. Neptune travels much slower than Mercury.

Table of Orbital Distance, Speed and Duration

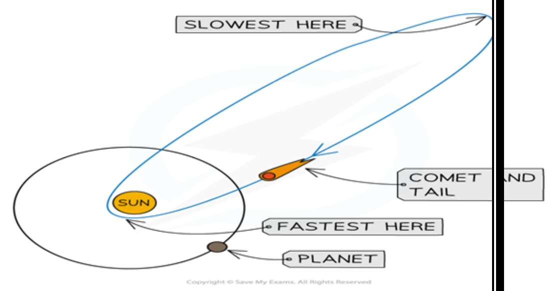
Planet	Orbital distance / million km	Orbital Speed / km/s	Orbital duration / days or years
Mercury	57.9	47.9	88 days
Venus	108.2	35.0	225 days
Earth	149.6	29.8	365 days
Mars	227.9	24.1	687 days
Jupiter	778.6	13.1	11.9 years
Saturn	1433.5	9.7	29.5 years
Uranus	2872.5	6.8	75 years
Neptune	4495.1	5.4	165 years

Assessment Tip

Be careful with your wording in this topic when talking about gravity.

It is important to refer to the force of gravity as 'gravitational attraction', ' strength of the Sun's gravitational field' or 'the force due to gravity'.

Avoid terms such as 'the Sun's gravity' or even more vague, 'the force from the Sun'.



ORBITS & CONSERVATION OF ENERGY

An object in an elliptical orbit around the Sun travels at a different speed depending on its distance from the Sun. Although these orbits are not circular, they are still stable.

For a stable orbit, *the radius must change if the comet's orbital speed changes.*

As the comet approaches the Sun:

- ✓ *The radius of the orbit decreases*
- ✓ *The orbital speed increases due to the Sun's strong gravitational pull*

As the comet travels further away from the Sun:

- ✓ *The radius of the orbit increases*

- ✓ *The orbital speed decreases due to a weaker gravitational pull from the Sun*

Comets travel in highly elliptical orbits, speeding up as they approach the Sun.

CONSERVATION OF ENERGY

Although an object in an elliptical orbit, such as a comet, continually changes its speed its energy must still be conserved.

Throughout the orbit, *the gravitational potential energy and kinetic energy of the comet changes.*

As the comet approaches the Sun:

- ✓ *It loses gravitational potential energy and gains kinetic energy, this causes the comet to speed up*
- ✓ *This increase in speed causes a slingshot effect, and the body will be flung back out into space again, having passed around the Sun.*

As the comet moves away from the Sun:

- ✓ *It gains gravitational potential energy and loses kinetic energy, this causes it to slow down*
- ✓ *Eventually, it falls back towards the Sun once more. In this way, a stable orbit is formed.*

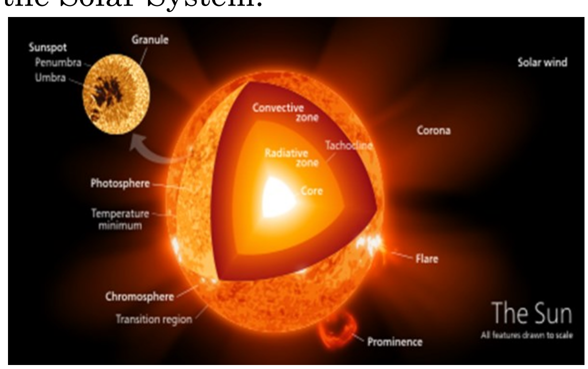
Assessment Tip

Remember that an object's kinetic energy is defined by: $E = \frac{1}{2}mv^2$; where m is the mass of the object and v is its speed.

Therefore, *if the speed of an object increases, so does its kinetic energy. Its gravitational potential energy therefore must decrease for energy to be conserved.*

THE SUN

The Sun is the star at the center of the Solar System.



It is a massive, hot ball of plasma, inflated and heated by energy produced by nuclear fusion reactions at its core.

Part of this energy is emitted from its surface as visible light, ultraviolet, and infrared radiation, providing most of the energy for life on Earth.

The Sun lies at the centre of the Solar System. The Sun is a star which makes up over 99% of the mass of the solar system. The fact that most of the mass of the Solar System is concentrated in the Sun is the reason the smaller planets orbit the Sun. The gravitational pull of the Sun on the planets keeps them in orbit. The Sun is a medium sized star consisting of mainly hydrogen and helium. It radiates most of its energ the infrared, visible and ultraviolet re gions of the electromagnetic spectrum.

OUR SUN

Stars come in a wide range of sizes and colours, from yellow stars to red dwarfs, from blue giants to red supergiants. These can be classified according to their colour. Warm objects emit infrared and extremely hot objects emit visible light as well.

Therefore, *the colour they emit depends on how hot they are.*

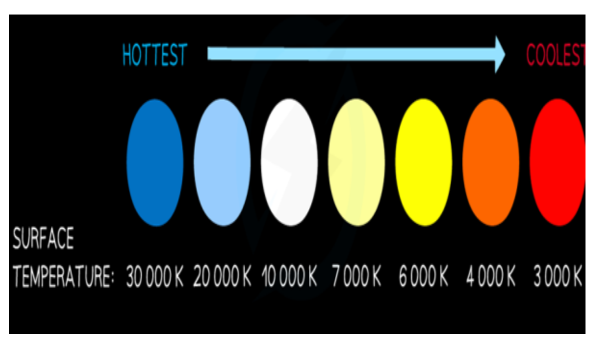
- ✓ *A star's colour is related to its surface temperature.*
- ✓ *A red star is the coolest (at around 3000 K).*
- ✓ *A blue star is the hottest (at around 30 000 K).*
- ✓ *The colour of a star correlates to its temperature.*

Nuclear Fusion in Stars

In the centre of a stable star, hydrogen nuclei undergo nuclear fusion to form helium. The equation for the reaction is

$${}^{2}_{1}H + {}^{3}_{1}H \rightarrow {}^{4}_{2}He + {}^{1}_{0}n$$

shown here:



Deuterium and tritium are both isotopes of hydrogen.

They can be formed through other fusion reactions in the star. A huge amount of energy is released in the reaction.

This provides a pressure that prevents the star from collapsing under its gravity

The fusion of deuterium and tritium to form helium with the release of ener*gy*

THE SOLAR SYSTEM

The Solar System consists of:

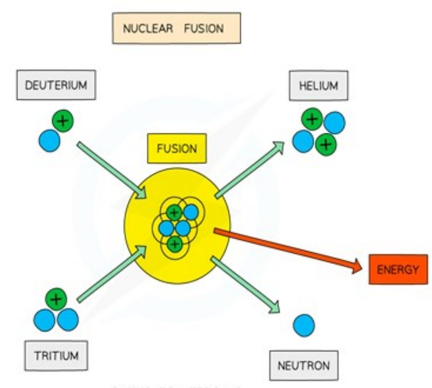
- ✓ The Sun
- ✓ Eight planets
- ✓ Natural and artificial satellites
- ✓ Dwarf planets
- ✓ Asteroids and comets

THE SUN & THE PLANETS

The Sun lies at the centre of the Solar System. The Sun is a star that makes up over 99% of the mass of the solar system. There are eight planets and an unknown number of dwarf planets which orbit the Sun.

The gravitational field around planets is strong enough to have pulled in all nearby objects with the exception of natural satellites. The gravitational field around a dwarf planet is not strong enough to have pulled in nearby objects.

The 8 planets in our Solar System in ascending order of the distance from the Sun are:



1. Mercury,2. Venus, 3. Earth, 4. Mars, 5. Jupiter,6. Saturn, 7. Uranus, and 8. Neptune

SATELLITES

There are two types of satellite:

- ✓ Natural
- ✓ Artificial

Some planets have moons which orbit them.

- ✓ ***Moons are an example of natural satellites***
- ✓ ***Artificial satellites are man-made and can orbit any object in space***

The International Space Station (ISS) orbits the Earth and is an example of an artificial satellite.

ASTEROIDS & COMETS

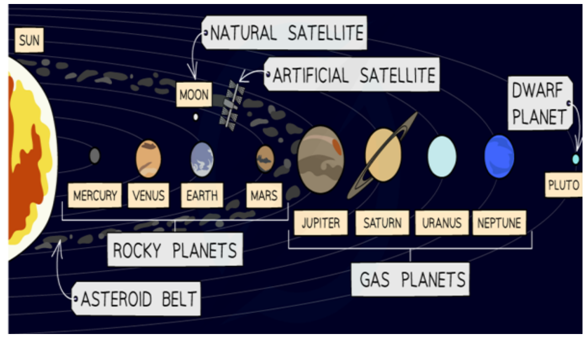
Asteroids and comets also orbit the sun.

An asteroid is a small rocky object which orbits the Sun.

The asteroid belt lies between Mars and Jupiter.

Comets are made of dust and ice and orbit the Sun in a different orbit to those of planets.

The ice melts when the comet approaches the Sun and forms the comet's tail.



The objects in our solar system

Assessment Tip

You need to know the order of the 8 planets in the solar system. The following mnemonic gives the first letter of each of the planets to help you recall them:

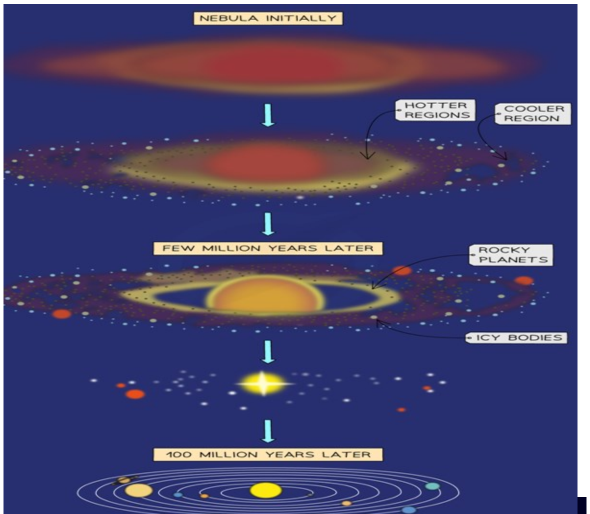
My Very Excellent Mother Just Served Us Noodles

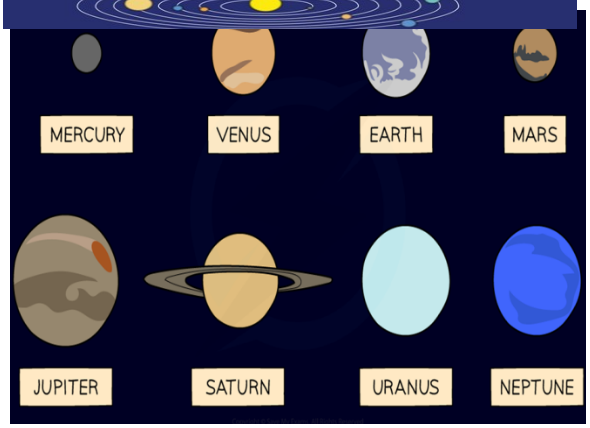
(Mercury, Venus, Earth, Mars, Jupiter, Saturn, Uranus, Neptune)

Accretion Model of the Solar System

There are 4 rocky and small planets: Mercury, Venus, Earth and Mars. These are the nearest to the Sun.

There are 4 gaseous and large planets: Jupiter, Saturn, Uranus and Neptune. There are the furthest from the sun





THE EIGHT PLANETS OF OUR SOLAR SYSTEM

The differences in the types of planets are defined by the accretion model for Solar System formation.

The Sun was thought to have formed when gravitational attraction pulled together clouds of hydrogen dust and gas (called nebulae).

The Solar System then formed around 4.5 billion years ago.

The planets were formed from the remnants of the disc cloud of matter left over from the nebula that formed the Sun.

These interstellar clouds of gas and dust included many elements that were created during the final stages of a star's lifecycle (a previous supernova).

Gravity collapsed the matter from the nebula in on itself causing it to spin around the Sun.

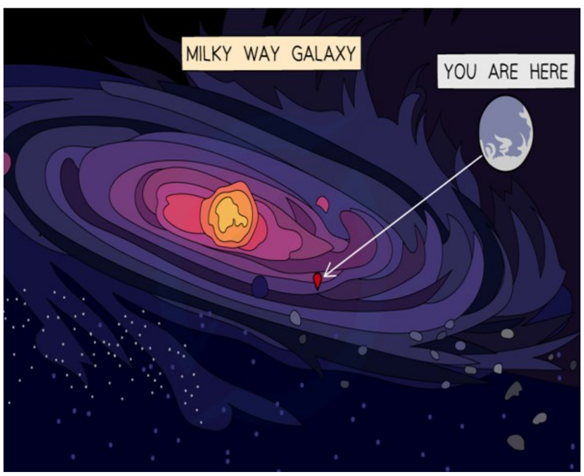
The gravitational attraction between all the small particles caused them to join together and grow in an accretion process. A rotating accretion disc is formed when the planets emerged.

The accretion model of the creation of the Solar System

As the Sun grew in size it became hotter, where the inner planets were forming near the Sun, *the temperature was too high for molecules such as Hydrogen, Helium, water and Methane to exist in a solid state*.

Therefore, *the inner planets are made of materials with high melting temperatures such as metals (e.g. iron).*

Only 1% of the original nebula is composed of heavy elements, so the inner, rocky planets could not grow much and stayed as a small size, solid and rocky. The cooler regions were further away from the Sun, and temperature was low enough for the light molecules to exist in a solid state. The outer planets therefore could grow to a large size up and include even the lightest element, Hydrogen. These planets are large, gaseous and cold.



THE MILKY WAY

Galaxies are made up of billions of stars.

The Universe is made up of many different galaxies.

The Sun is one of billions of stars in a galaxy called the Milky Way.

Other stars in the Milky Way galaxy are much further away from Earth than the Sun is. Some of these stars also have planets which orbit them.

Our solar system is just one out of potentially billions in our galactic neighborhood, the Milky Way. There are estimated to be more than 100 billion galaxies in the entire universe.

ASTRONOMICAL DISTANCES

Astronomical distances such as the distances between stars and galaxies are so large that physicists use a special unit to measure them called ***the light-year.***

One light-year *is defined as* ***the distance travelled by light through (the vacuum of) space in one year***.

The speed of light is the *universal speed limit*; nothing can travel faster than the speed of light.

But over astronomical distances, light actually travels pretty slowly.

The diameter of the Milky Way is approximately 100 000 light-years.

This means that light would take 100 000 years to travel across it.

One light year is equal to 9.5×10^{12} km, or 9.5×10^{15} m

STAR FORMATION

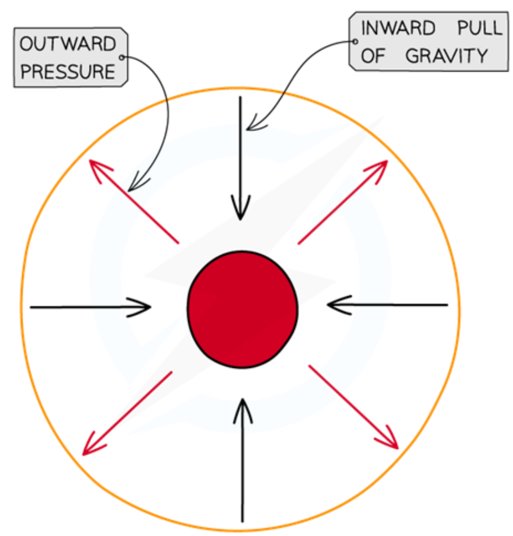
1. **Nebula**: All-stars' form from a giant interstellar cloud of hydrogen gas and dust called *a nebula*

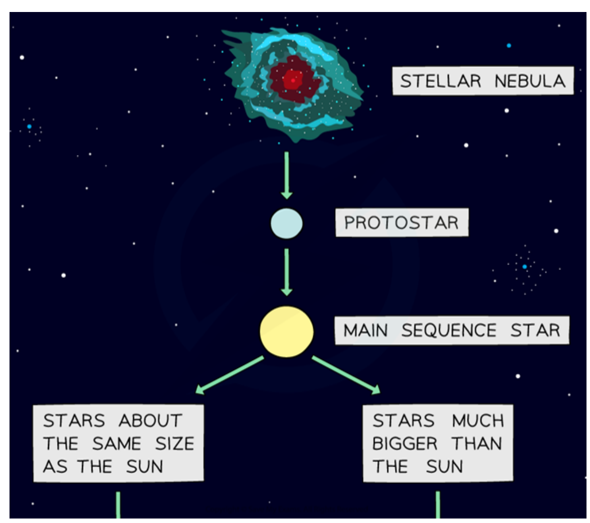
2. **Protostar**: The force of gravity within a nebula pulls the particles closer together until it forms a hot ball of gas, known as a *protostar.* As the particles are pulled closer together the density of the protostar will increase. This will result in more frequent collisions between the particles which causes the temperature to increase.

3. **Main Sequence Star**: Once the protostar becomes hot enough, nuclear fusion reactions occur within its core. The hydrogen nuclei will fuse to form helium nuclei. Every fusion reaction releases heat (and light) energy which keeps the core hot

Once a star initiates fusion, it is known as a main-sequence star

During the main sequence, the star is in equilibrium and said to be stable. The inward force due to gravity is equal to the outward pressure force from the fusion reactions.

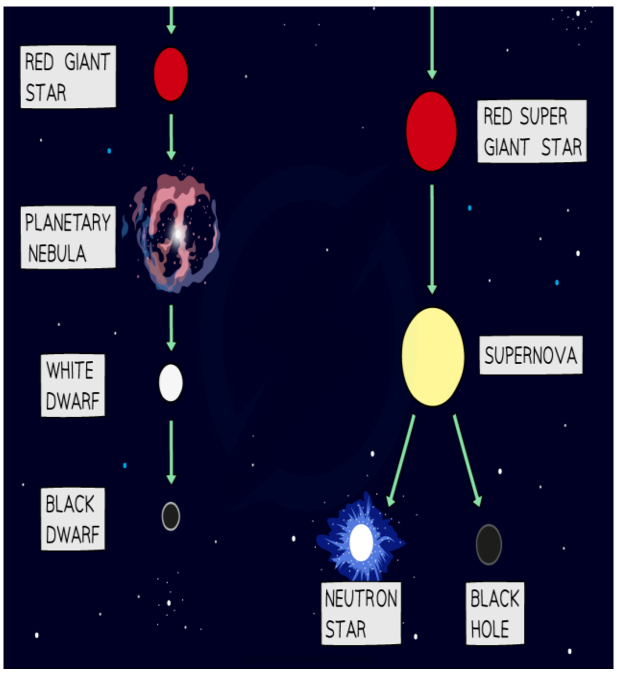




The outwards and inwards forces within a star are in equilibrium. The centre red circle represents the star's core and the orange circle represents the star's outer layers

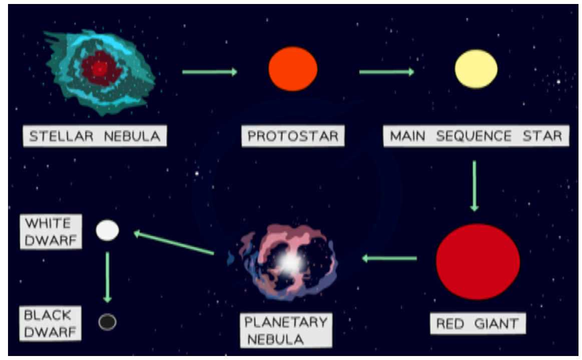
Once a protostar is formed, its life cycle will depend on its mass.

The different life cycles are shown below;



Flow diagram showing the life cycle of a star, which is the same size as the Sun (solar mass) and the lifecycle of a star which is much more massive than the Sun.

LIFE CYCLE OF LOW MASS STARS



A low-mass star will go through the following stages

The lifecycle of a low-mass star:

4. **Red Giant:** After several billion years the hydrogen causing the fusion reactions in the star will begin to run out. Once this happens, the fusion reactions in the core will start to die down. This causes the core to shrink and heat up.

The core will shrink because the inward force due to gravity will become greater than the outward force due to the pressure of the expanding gases as the fusion dies down.

A new series of reactions will then occur around the core, for example, helium nuclei will undergo fusion to form beryllium.

These reactions will cause the outer part of the star to expand. A low-mass star that is up to 8 times the mass of the Sun or smaller will become a red giant. It is red because the outer surface starts to cool.

5. Planetary Nebula

Once this second stage of fusion reactions have finished, the star will become unstable and eject the outer layer of dust and gas. The layer of dust and gas which is ejected is called a *planetary nebula.*

6. White Dwarf

The core which is left behind will collapse completely, due to the pull of gravity, and the star will become a white dwarf. The white dwarf will be cooling down and as a result, the amount of energy it emits will decrease.

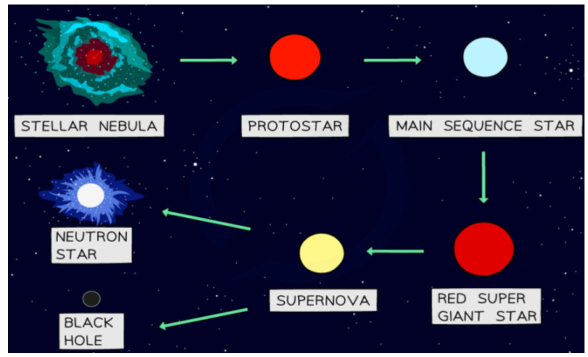
7. Black Dwarf

Once the star has lost a significant amount of energy it becomes a black dwarf. It will continue to cool until it eventually disappears from sight.

LIFE CYCLE OF HIGH MASS STARS:

A high-mass star will go through the following stages

Lifecycle of a high-mass star



8. Red Supergiant

After several million years, the hydrogen causing the fusion reactions in the star will begin to run out.

A high-mass star (one more than 8 times the mass of the Sun) will become a red supergiant.

Similar to a low-mass star, the fusion reactions in the core will start to die down. The core will go through a series of periods of shrinking and heating up. As a result, the outer parts of the star will expand and contract. This time, fusion reactions will form elements all the way up to iron. Fusion reactions cannot continue once iron is formed.

9. Supernova

Once the fusion reactions inside the red supergiant cannot continue, the core of the star will collapse suddenly and cause a gigantic explosion. This is called a *supernova.* At the centre of this explosion a dense body, called a neutron star will form.

The outer remnants of the star will be ejected into space during the supernova explosion, forming new clouds of dust and gas (nebula)

The nebula from a supernova may form new stars with orbiting planets.

10. Neutron Star (or Black Hole)

In the case of the biggest stars, the neutron star that forms at the centre will continue to collapse under the force of gravity until it forms a black hole.

A black hole is an extremely dense point in space that not even light can escape from.

GALAXIES & REDSHIFT

Usually, when an object emits waves, the wave fronts spread out symmetrically. If the wave source moves, the waves can become squashed together or stretched out.

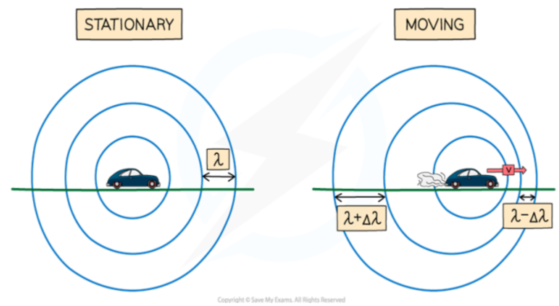


Diagram showing the wave fronts produced from a stationary object and a moving object.

A moving object will cause the wavelength, λ, (and frequency) of the waves to change:

- ✓ *The wavelength of the waves in front of the source decreases and the frequency increases*
- ✓ *The wavelength behind the source increases and the frequency decreases*

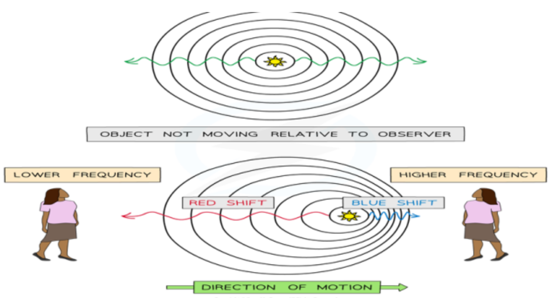
This effect is known as the *Doppler effect.*

Doppler effect: The apparent change in the frequency of the wave when there is relative motion between the observer and the source of the waves.

The Doppler effect also affects light.

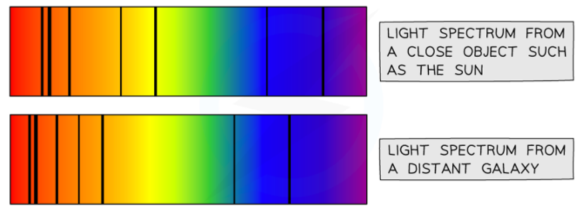
If an object moves away from an observer the wavelength of light increases. This is known as ***redshift*** as the light moves towards the red end of the spectrum.

Redshift is an increase in the observed wavelength of electromagnetic radiation emitted from receding stars and galaxies.



Light from a star that is moving *towards an observer will be blue shifted* and light from a star *moving away from an observer will be redshifted.* The observer behind observes a red shift.

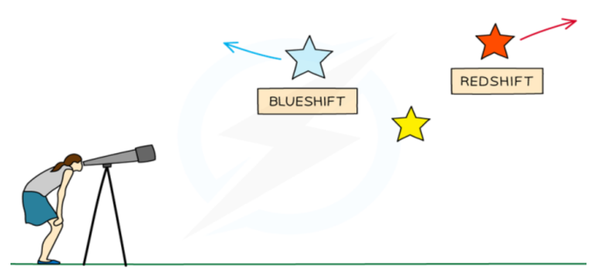
Light emitted from distant galaxies appears redshifted when compared with light emitted on Earth. The diagram below shows the light coming to us from a close object, such as the Sun, and the light coming to us from a distant galaxy



Comparing the light spectrum produced from the Sun and a distant galaxy

The diagram also shows that the light coming to us from distant galaxies is redshifted. The lines on the spectrum are shifted towards the red end. This indicates that the galaxies are moving away from us. *If the galaxies are moving away from us it means that the universe is expanding.* The observation of redshift from distant galaxies supports the Big Bang theory.

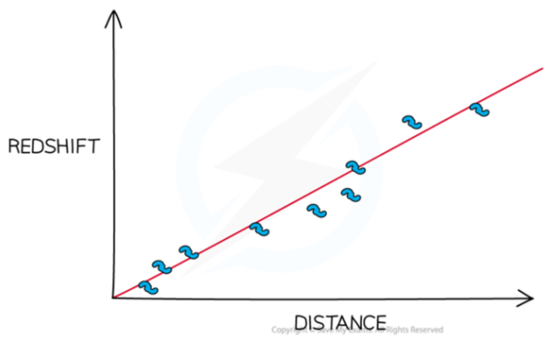
Another observation from looking at the light spectrums produced from



distant galaxies is that

the greater the distance to the galaxy, the greater the redshift. *This means that the further away a galaxy, the faster it is moving away from us.*

Graph showing the greater the distance to a galaxy, the greater the redshift



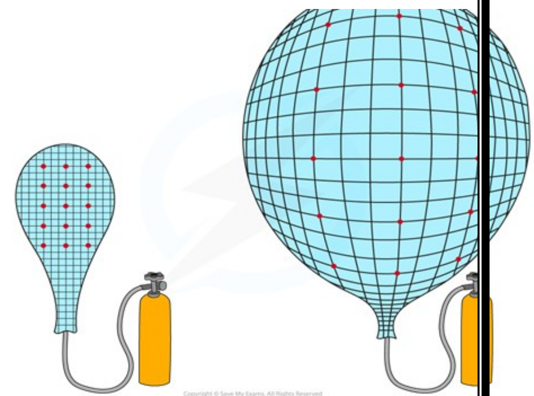
THE BIG BANG

Around 14 billion years ago, the Universe began from a very small region that was extremely hot and dense.

Then there was a giant explosion, which is known as the *Big Bang.*

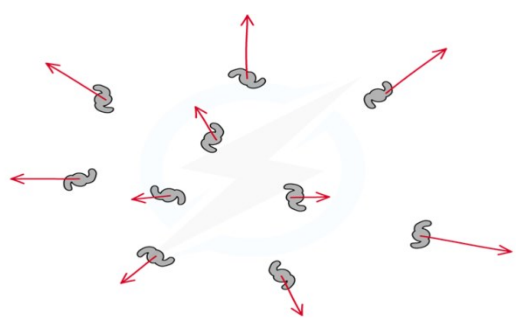
This caused the universe to expand from a single point, cooling as it does so, to form the universe today. Each point expands away from the others.

This is seen



from galaxies moving away from each other, and the further away they are the faster they move.

Redshift in the light from distant galaxies is evidence that the *Universe is expanding* and supports the Big Bang Theory, As a result of the initial explosion, the Universe continues to expand.



All galaxies are moving away from each other, indicating that the universe is expanding.

An analogy of this is points drawn on a balloon where the balloon represents space and the points as galaxies.

When the balloon is deflated, all the points are close together and an equal distance apart.

As the balloon expands, all the points become further apart by the same amount. This is because the space itself has expanded between the galaxies.

A balloon inflating is similar to the stretching of the space between galaxies

REDSHIFT AND CMBR

The Big Bang theory is very well supported by evidence from a range of sources

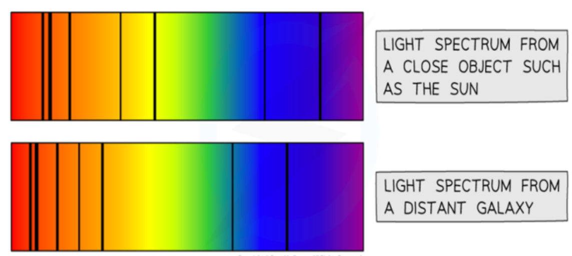
The main pieces of evidence are;

- ✓ Galactic red-shift,
- ✓ Cosmic Microwave Background Radiation (CMBR),
- ✓ Evidence from Galactic Red-Shift,

Galactic redshift provides evidence for the Big Bang Theory and the expansion of the universe.

The diagram below shows the light coming to us from a close object, such as the Sun, and the light coming to the Earth from a distant galaxy.

Comparing the light spectrum



produced from the Sun and a distant galaxy

Red-shift provides evidence that the Universe is expanding because:

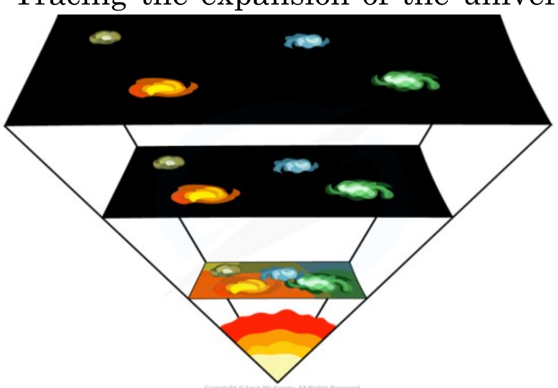
Red-shift is observed when the spectral lines from the distant galaxy move closer to the red end of the spectrum, this is because light waves are stretched by the expansion of the universe so the wavelength increases (or frequency decreases). This indicates that the galaxies are moving away from us.

Light spectrums produced from distant galaxies are red-shifted more than nearby galaxies.

This shows that the greater the distance to the galaxy, the greater the redshift.

This means that the further away a galaxy is, the faster it is moving away from the Earth. These observations imply that the universe is expanding and therefore support the Big Bang Theory.

Tracing the expansion of the universe



back to the beginning of time leads to the idea the universe began with a "big bang"

EVIDENCE FROM COSMIC MICROWAVE BACKGROUND (CMB) RADIATION

The discovery of the CMB (**Cosmic Microwave Background**) radiation led to the Big Bang theory becoming the currently accepted model.

The CMB is a type of electromagnetic radiation which is a remnant from the early stages of the Universe.

It has a wavelength of around 1 mm making it a microwave, hence the name Cosmic Microwave Background radiation.

In 1964, Astronomers discovered radiation in the microwave region of the electromagnetic spectrum coming from all directions and at a generally uniform temperature of 2.73 K.

They were unable to do this any earlier since microwaves are absorbed by the atmosphere.

Around this time, space flight was developed which enabled astronomers to send telescopes into orbit above the atmosphere.

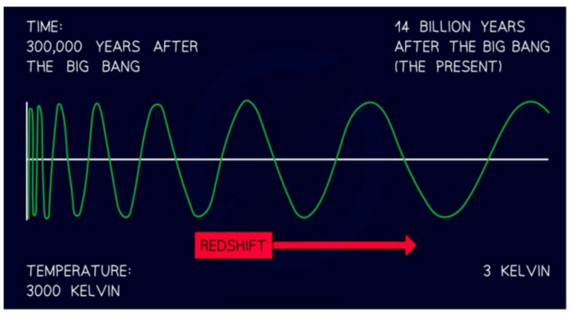
According to the Big Bang theory, the early Universe was an extremely hot and dense environment.

As a result of this, it must have

emitted thermal radiation. The radiation is in the microwave region.

This is because over the past 14 billion years or so, the radiation initially from the Big Bang has become redshifted as the Universe has expanded. Initially, this would have been high energy radiation, towards the gamma end of the spectrum.

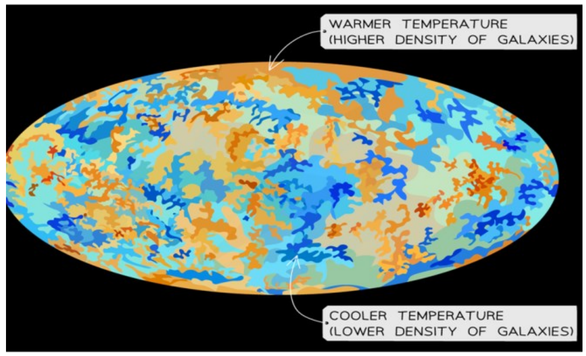
As the Universe expanded, the wavelength of the radiation increased Over time, it has increased so much that it is now in the microwave region of the spectrum.



The CMB is a result of high energy radiation being redshifted over billions of years.

The CMB radiation is very uniform and has the exact profile expected to be emitted from a hot body that has cooled down over a very long time. This phenomenon is something that other theories (such as the Steady State Theory) cannot explain.

The CMB is represented by the following map:



The CMB map with areas of higher and lower temperature. Places with higher temperature have a higher concentration of galaxies, Suns and planets. This is the closest image to a map of the observable Universe.

The different colours represent different temperatures. The red / orange / brown regions represent warmer temperature indicating a higher density of galaxies.

The blue regions represent cooler temperature indicating a lower density of galaxies.

The temperature of the CMB radiation is mostly uniform; however, there are minuscule temperature fluctuations (on the order of 0.00001 K). This implies that all objects in the Universe are more or less uniformly spread out.

MEASURING GALACTIC SPEED & DISTANCE

USING REDSHIFT OBSERVATIONS TO MEASURE THE UNIVERSE

The change in wavelength of the galaxy's starlight due to redshift can be used to find the velocity, v, with which a galaxy (or any distant object) is moving away from Earth.

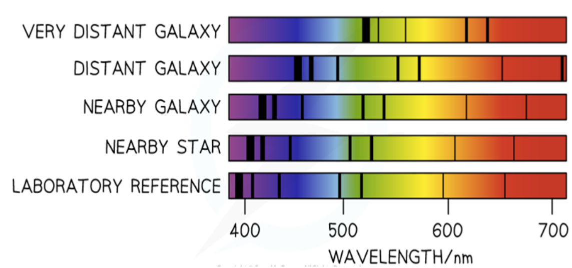
Using an equation to compare the ratio of the expected wavelength with the observed wavelength, the velocity can be found; This equation will not be directly examined but the idea that the velocity of distant objects can be found from the redshift seen in easily observed wavelengths is an important one.

MEASURING DISTANCE USING SUPERNOVAE

- ✓ Redshift and CMB radiation allow various measurements of the Universe to be accurately made.
- ✓ Measuring distance is done using different methods.
- ✓ A key method is the use of standard candles, including supernovae.
- ✓ Supernovae are exploding stars.

Certain types have the same peak level of brightness (absolute magnitude), making them extremely useful in measuring the distance to remote stars and galaxies.

Type 1a supernovae are so bright that they can be seen clearly even though they may be deep inside their parent galaxy. This allows the distance to the galaxy to be calculated.



Hubble Constant Calculations

In 1929, the astronomer Edwin Hubble showed that the universe was expanding.

He did this by observing the absorption line spectra produced from the light of distant galaxies.

He discovered that the light was shifted towards the red end of the spectrum. *This Doppler shift in the wavelength of the light is evidence that distant galaxies are moving away from the Earth.*

Hubble also observed that light from more distant galaxies was more red-shifted than the light from nearer galaxies. *This observation showed that galaxies or stars which are further away from the Earth are moving faster than galaxies which are closer.*

Examples of redshifted line spectra for galaxies at different distances from the Earth compared to a laboratory sample.

HUBBLE'S LAW

Hubble's law states that the recessional velocity v of a galaxy is proportional to its distance from Earth.

Hubble's law can be expressed as an equation:

$$V = HOd$$

Where:

HO = Hubble constant (per second)

v = recessional velocity of an object, the velocity of an object moving away from an observer (km/s)

d = distance between the object and the Earth (km)

As the equation shows, the Hubble Constant,

H0 is defined as the ratio of the speed at which the galaxy is moving away from the Earth, to its distance from the Earth.

The accepted value of the Hubble constant is H0 = 2.2×10^{-18} per second

Assessment Tip

Make sure to learn the currently accepted value of the Hubble constant.

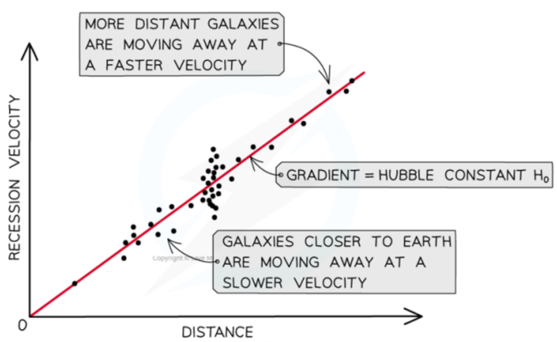
You will be expected to know that the current estimate for H0 is 2.2×10^{-18} per second

AGE OF THE UNIVERSE

Since Hubble's Law states that

$$V = H0d$$

It can be rearranged to show that, Hubble's law shows that the further away a star is from the Earth, the faster it is moving away from us.



A key aspect of Hubble's law is that the furthest galaxies appear to move away the fastest.

The gradient of the graph can be used to find the Age of the Universe,

When the distance equals zero, this represents all the matter in the Universe being at a single point. *This is the singularity that occurred at the moment of the Big Bang.*

The units of the gradient are per second (the same as the units of the Hubble Constant).

By taking the reciprocal, or, the units will become seconds.

Therefore the reciprocal of the gradient represents time and gives the amount of time which the Universe has been expanding for.

Astronomers have used this formula to estimate the age of the Universe at about 13.7 billion years.

Worked Activity

A distant galaxy is 20 light-years away from Earth.

Use Hubble's Law to determine the velocity of the galaxy as it moves away from Earth. (The Hubble constant is currently agreed to be 2.2×10^{-18} s^{-1}, 1-light year ≈ 9.5×10^{15} m)

Step 1: List the known quantities:

d = 20 light years

Ho = 2.2×10^{-18} s^{-1}

Step 2: Convert 20 light-years to m:

1 ly ≈ 9.5×10^{15} m

So, 20 ly = 20 x (9.5×10^{15}) = 1.9×10^{17} m

Step 3: Substitute values into Hubble's Law:

From the data booklet: v ≈ H0d

So, v ≈ (2.2×10^{-18}) x (1.9×10^{17}) = 0.418 m s^{-1}

Step 4: Confirm your answer:

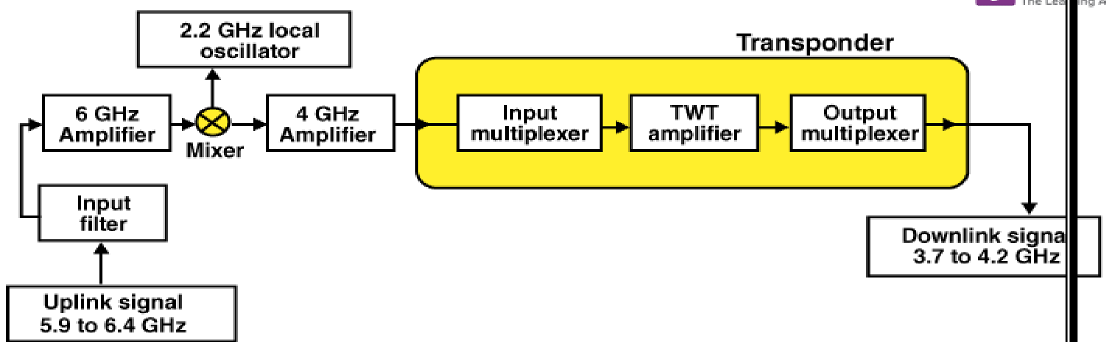
The velocity of the galaxy as it moves away from Earth 0.42 m s^{-1}

SATELLITE COMMUNICATION

Satellite communication is transporting information from one place to another using a communication satellite in orbit around the Earth. Watching the English Premier League every weekend with your friends would have been impossible without this.

A communication satellite is an artificial satellite that transmits the signal via a transponder by creating a channel between the transmitter and the receiver at different Earth locations.

Telephone, radio, television, internet, and military applications use satellite communications. Believe it or not, more than 2000 artificial satellites are hurtling around in space above your heads.



Satellite Communication Block Diagram

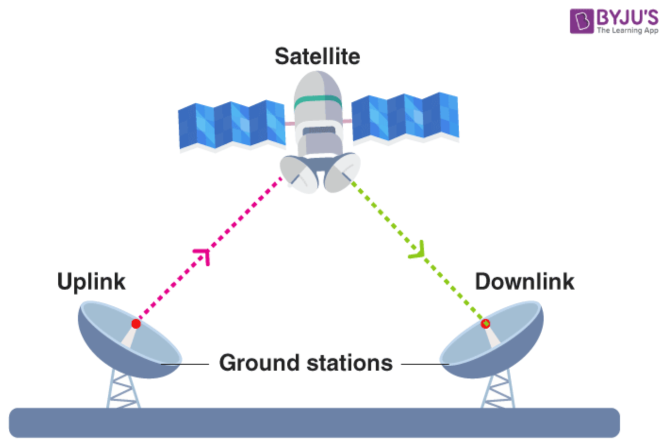
How Satellite Communications Work?

The communication satellites are similar to the space mirrors that help us bounce signals such as radio, internet data, and television from one side of the earth to another. Three stages are involved, which explain the working of satellite communications. These are:

- ✓ Uplink
- ✓ Transponders
- ✓ Downlink

Consider an example of signals from a television. In the first stage, the signal from the television broadcast on the other side of the earth is first beamed up to the satellite from the ground station on the earth. This process is known as *uplink*.

The second stage involves transponders such as radio receivers, amplifiers, and transmitters. These transponders boost the incoming signal and change its frequency so that the outgoing signals are not altered. Depending on the incoming signal sources, the transponders vary.



The final stage involves a downlink in which the data is sent to the other end of the receiver on the earth. It is important to understand that usually, there is one uplink and multiple downlinks.

Satellite Communications in India

It's interesting to know that the Indian National Satellite (INSAT) system is one of the largest domestic communication systems that is placed in the geo-stational orbit. There are more than 200 transponders in the INSAT system and are used for various purposes such as telecommunications, weather forecasting, television broadcasting, disaster warning, search and rescue operations, and satellite newsgathering.

Below is the list of communication satellites along with their applications:

Satellite name	Launch date	Application
GSAT-30	Jan 17, 2020	Communication
GSAT-31	Feb 06, 2020	Communication
GSAT-15	Nov 11, 2015	Communication and navigation
GSAT-10	Sep 29, 2012	Communication and navigation
INSAT-3A	Apr 10, 2003	Communication and climate and environment
KALPANA-1	Sep 12, 2002	Communication and climate and environment

The need for satellite communication becomes evident when we want to transmit the signal to far-off places, where the Earth's curvature comes into play. This obstruction is overcome by putting communication satellites in space to transmit the signals across the curvature. Satellite communication uses two types of artificial satellites to transmit the signals:

- ✓ **Passive Satellites:**

If you put a hydrogen balloon that has a metallic coating over it up in the air, it technically becomes a passive satellite. Such a balloon can reflect microwave signals from one place to another. The passive satellites in space are similar. These satellites just reflect the signal back towards the Earth without amplification. Since the satellite orbit height can range from 2000 to 35786 km, attenuation due to the atmosphere also comes into play, and due to this, the received signal is often very weak.

- ✓ **Active Satellites:**

Active Satellites, unlike passive satellites, amplify the transmitted signals before re-transmitting it back to Earth, ensuring excellent signal strength. Passive satellites were the earliest communication satellite, but now almost all the new ones are active satellites.

To avoid mixing up and interference signals, every user is allocated a specific frequency for transmitting.

The International Telecommunication Union does this frequency allocation. Geosynchronous satellites are of note here. Geostationary orbit is present at 35786 km above Earth's surface. If you can spot such a satellite with a telescope from Earth, it will appear stationary to you. The satellite's orbital period and the Earth's rotational rate are in sync.

Some More Information About Geostationary Orbits

These were some typical orbits. Apart from these, we also have orbits that address particular problems. The Russians faced one such issue. GEO satellites worked perfectly for the equatorial regions, but they had a very weak coverage near the Poles. The Russians designed an orbit with a very high inclination to address this problem. The inclination is the angle between the satellite's orbit and the equator. This orbit was called the Molniya orbit. The orbit had excellent coverage of the North Pole for a short time. Molniya had a period of 24 hours, but out of that, it would be close to Earth only for 6-9 hours. Russia launched more satellites in the same orbit and soon had uninterrupted coverage.

Satellite Communication Services

There are two categories in which satellite communication services can be classified:

- One-way satellite communication
- Two- way satellite communication

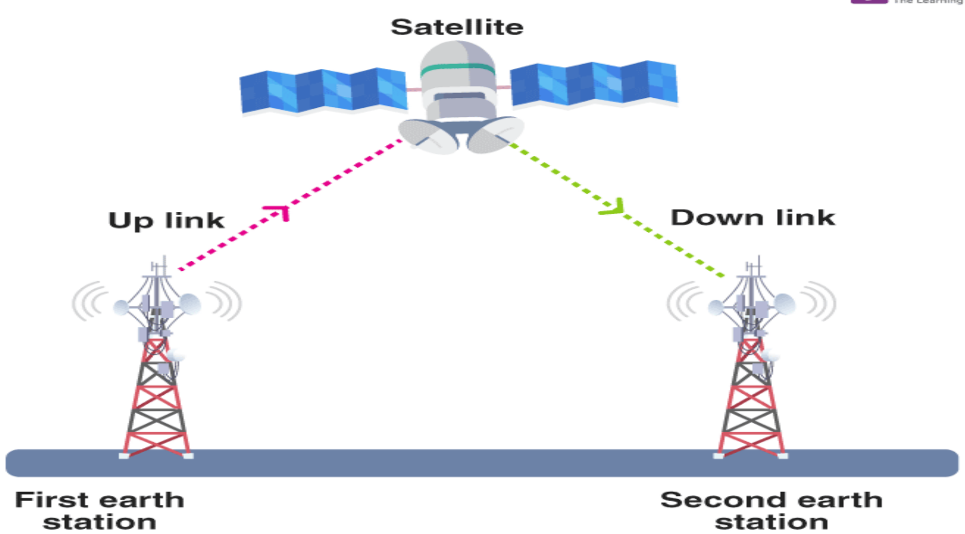
One-way Satellite Communication

In one-way satellite communication, the communication usually takes place between either one or multiple earth stations through the help of a satellite. The communication takes place between the transmitter on the first earth satellite to the receiver which is the second earth satellite. The transmission of the signal is unidirectional. Some common one-way satellite communication is:

- Position location services are provided by the radio

- Tracking is a part of space operations services
- Internet services take place with broadcasting satellites

Following is the figure which explains the one-way satellite communication:

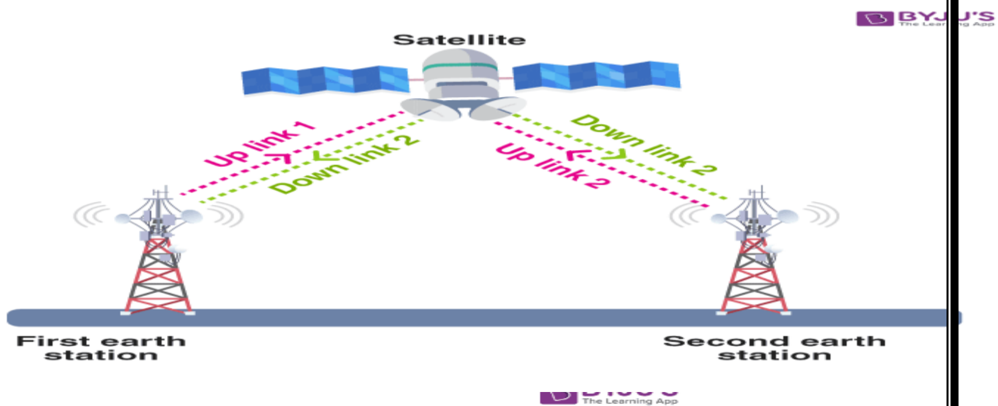


Two-Way Satellite Communication

In two-way satellite communication, the information is exchanged between any two earth stations. It can be said that there is a point to point connectivity.

The signal is transmitted from the first earth station to the second earth station such that there are two uplinks and two downlinks between the earth stations and the satellite.

Following is the figure for the two-way satellite communication:



Advantages of Satellite Communication

The following are the advantages of satellite communication:

- Installments of circuits are easy.
- The elasticity of these circuits is excellent.
- With the help of satellite communication, every corner of the earth can be covered.
- The user fully controls the network.

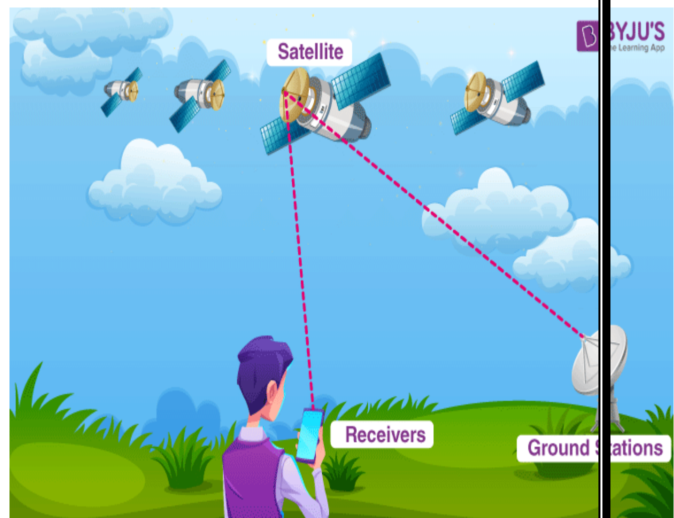
Disadvantages of Satellite Communication

The following are the disadvantages of satellite communication:

- Initial expenditure is expensive.
- There are chances of blockage of frequencies.
- Propagation and interference.

Applications of Satellite Communication

- Telephone
- Television
- Digital cinema
- Radio broadcasting
- Amateur radio
- Internet access
- Military
- Disaster Management



Global Positioning System-GPS

In ancient times, humans relied on the skies for navigation. We depended on objects in the sky to deduce where we were and how to get to other places. Ancient sailors used the constellations in the night sky to assess where they were. Compasses, maps and astrolabes are among the early tools used by ocean navigators. In the modern era, technological and electronic equivalents have predominantly replaced these tools. Now we only need a simple hand-held GPS (short for Global Positioning System) receiver to comprehend precisely where we are in the world.

What is GPS?

Global Positioning System (GPS): *It is a radio navigation system used on land, sea, and air to determine the exact location, time and velocity irrespective of weather conditions.*

The US military first used it in the year 1960.

Components of a GPS system

GPS is a system and it is made up of three parts: satellites, ground stations, and receivers.

Following are the functionalities of each of these parts:

- ✓ Satellites act like the stars in constellations, and we know where they are because they invariably send out signals.
- ✓ The ground stations make use of the radar to make sure the satellites are actually where we think they are.
- ✓ A receiver is a device that you might find in your phone or in your car and it constantly seeks for the signals from the satellites. The receiver figures out how far away they are from some of them. Once the receiver calculates its distance from four or more satellites, it knows exactly where you are.

How does GPS Work?

There are at least 4 GPS satellites in the line of sight of a receiver on the earth. The transmitter GPS sends information about the position and time to the receiver GPS at fixed intervals. The signals that are sent to the receiver devices are radio waves. By finding the difference in time between the signal sent from the GPS satellite to the time the GPS receivers, the distance between the GPS receiver and the satellite can be calculated. Using the trilateration process, the receiver locates its position as the signals are obtained from at least three satellites.

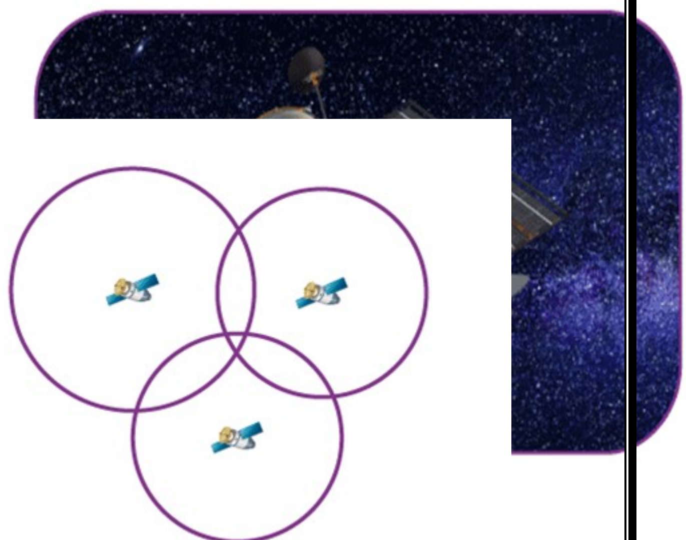
For a GPS to calculate a 2-D position, which includes the latitude and longitude, a minimum of 3 satellites are required. For a 3-D position that provides latitude, longitude, and altitude, a minimum of 4 satellites are needed.

GPS is a system of 30+ navigation satellites orbiting the Earth. We know their location precisely because they invariably send out signals. The GPS receiver in your phone receives these signals. Once the receiver calculates its distance from four or more GPS satellites, it can figure out exactly where you are.

What Is Trilateration?

Trilateration is defined as the process of determining the location based on the intersections of the spheres.

The distance between the satellite and the receiver is calculated by considering a 3-D sphere such that the satellite is located at the centre of the sphere. Using the same method, the distance for all the 3 GPS satellites from the receiver is calculated.



Following are the parameters that are calculated after trilateration:

- ✓ Time of sunrise and the sunset
- ✓ Speed
- ✓ Distance between the GPS receiver to the destination

GPS systems are remarkably versatile and can be found in almost any industry sector. They can be used to map forests, help farmers harvest their fields and navigate aeroplanes on the ground or in the air.

How does GPS work?

By finding the difference in time between the signals sent from the GPS satellite to the time the GPS receivers, the distance between the GPS receiver and the satellite can be calculated. Using the trilateration process, the receiver locates its position as the signals are obtained from at least three satellites.

Hubble Space Telescope (HST)

We have studied various optical instruments like microscopes, telescopes, and many more in our previous sessions. Depending on the requirement to view nearby or distant objects, these instruments are used. The lens used in these instruments also varies accordingly. Telescopes are mainly used to view celestial objects clearly. In this session let us learn in brief about the Hubble space telescope and its applications.

The Hubble Space Telescope

Some logics and creations are hard to understand until we find a proper way to explore them. Likewise, when the formation of galaxies and planets could not be easily understood, the Hubble space telescope came in handy to discover and conclude celestial evidence.

The Hubble Space Telescope is also referred to as HST or Hubble.

It is a space telescope, and the first sophisticated optical observatory to be placed into orbit around Earth.

It is the largest and most versatile telescope on which many research papers have been written. Hubble has made over 1.4 million observations, and has aided to track the interstellar and celestial bodies present in space.

Invention of Hubble Space Telescope

The HST is named after the American astronomer Edwin P. Hubble who has made notable contributions to the field of astronomy and cosmology. The Hubble was built by the National Aeronautics and Space Administration (NASA) of the United States along with the European Space Agency (ESA).

The project Hubble was funded in the year 1970 and was to be planned to be launched in the year 1983. However, after overcoming various technical and financial challenges, Hubble was all set for launch in the year 1990. Hubble Space Telescope is a large space telescope launched in 1990 and is still operational. It was launched in John F. Kennedy space center in Florida. It is expected to decay by 2030-2040. This telescope is operated by NASA, ESA, and Space Telescope Science Institute (STScI). It is one of the significant contributions in studying the reason for the cosmic revelations.

Specifications of Hubble Space Telescope

Hubble measures 13.2 meters i.e., 43.5 feet wide with a maximum diameter of 14 feet (4.2 m). It would approximately weigh 11,110 kilograms (24,500 pounds) on the Earth.

This solar-powered telescope orbits about 340 miles (547 kilometers) above the Earth, on a path, inclined 28.5 degrees to the equator.

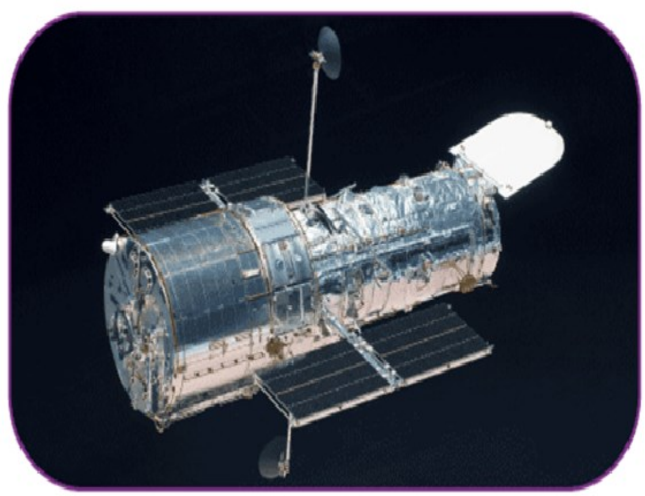
It is a reflecting telescope that features a large mirror that collects light from celestial objects and directs it into two cameras and two spectrographs.

HST contains a 94-inch primary mirror, a smaller secondary mirror, along various recording instruments to detect ultraviolet, visible, and infrared light.

To capture the detailed and high-resolution images, a wide-field planetary camera is placed.

Hubble features three interferometers known as fine guidance sensors which are helpful in calculating positions of stars as well as the brightnesses.

Hubble has the capacity to transfer 120 gigabytes of data every week.



Hubble Space Telescope

Observations of Hubble Space Telescope

Some of the prominent observations made by the HST are as given below:

The Hubble space telescope is the main instrument in discovering the moons (hydra and nix) around the planet Pluto.

It made observations of six galaxies merging together,

HST found small concentrations of black holes.

The Hubble Space Telescope could find infrared radiations too.

Hubble's constant was determined after HST observed the Cepheid variables in nearby galaxies. Hubble has recorded the birth of stars through turbulent clouds of gas and dust. Hubble is the main reason behind discovering dusty disks and stellar nurseries although the Milky Way. Using Hubble, the presence of black holes is proved.

INTERNATIONAL SPACE STATION

The International Space Station (ISS) is a huge spacecraft orbiting around our planet. It revolves around the Earth with a consistent speed and direction. It acts as an all-in-one place where astronauts can live and conduct

International Space Station

experiments. The space station is a unique science laboratory where a broad spectrum of experiments is carried out. Many nations are involved with the maintenance of the craft. Since its launch, the space station has been extended with newer modules and equipment. Astronauts are deployed to assemble and disassemble parts. Overall it took forty-two space flights to attach the main parts of the space station.

The International Space Station (ISS)

The International Space Station is an interchangeable and modular spacecraft travelling in low Earth orbit. It is also a habitable spacecraft where astronauts can live for many months. It is regulated by a public association of multiple space research organizations: NASA (United States of America), ESA (Europe), Roscosmos (Russia), CSA(Canada) and JAXA(Japan).

The ownership of the space station is regulated under intergovernmental agreements and treaties.

It revolves around the Earth at a mean altitude of about 402 km. The average speed is about 17,500 mph. Therefore, it completes one full revolution around the Earth in 90 minutes.

The station acts as a microgravity research lab for astronomy, physics, astrobiology, meteorology, etc. The ISS is used for the trials of spaceship equipment and systems that are needed for Mars and Moon missions.

NASA predominantly uses the station to understand the effects of working and living in space. Such invaluable information will further demystify the conditions necessary for humans to survive on other planets.

Launch of the International Space Station

In November 1998, the first module of ISS was launched into orbit. Zarya (control module) was launched by a Russian rocket. The U.S. Unity Node module was attached to Zarya two weeks later. The space shuttle Endeavour carried and docked the Unit node to the existing module.

More parts were attached over the next 24 months. After deploying all necessary modules, the first crew reached the station on November 2, 2000. The construction of the full version of the space station was completed in 2011. Apart from these central installations, thousands of repairs and updates have been done frequently.

Size of the International Space Station

The International Space Station is 109 meters from end to end.

It has the volume of two Boeing 747 jets.

It is almost the size of a full-length American football ground. It weighs around 0.45 million kilograms on Earth. It has about 932 cubic meters of space. Approximately 13 km of wire links the entire space station's electric circuit system. Almost one-third of the area is taken by storage and equipment. The remaining portion is habitable. It can accommodate a crew of six people and a few visitors.

Essential Parts of the International Space Station

The International Space Station has a huge array of modules and equipment. The early Russian modules had basic systems required for the smooth operation of the station. They also had primary living space for the crew.

Nodes are modules that connect individual parts of the space station. Solar arrays extend out from the main structure. It is used to accumulate solar energy for generating electricity. The arrays are joined to the space station with the help of an extended truss. In fact, there are radiators on the truss, which helps to regulate the station's temperature.

Robotic arms are attached outside the station. They were used to build the whole space station. Robotic arms also help to move astronauts during spacewalks. Other than these use cases, such automated arms are extensively used in laboratory science experiments.

Docking ports are another crucial part of the entire space station. They enable the station to connect external spacecraft and satellites for various purposes. New visitors and crew members enter through the docking ports. Supplies are also delivered through docking ports.

Important Modules of International Space Station

Important Modules of International Space Station

Zarya	Harmony	Tranquility	Columbus	Kibō
Poisk	Unity	Zvezda	Destiny	Quest
Cupola	Rassvet	MLM	Nauka	Prichal
Bigelow Expandable Activity Module	International Docking Adapters	Bishop Airlock Module		

Uses of International Space Station

- ✓ *The ultimate goal of the International Space Station is to facilitate long-term space exploration and create useful inventions for the goodness of humanity.*
- ✓ *There are six cutting-edge laboratories enabling premium research projects in various fields of science and technology.*
- ✓ *Complex and volatile experiments can be easily conducted in microgravity spaces. Especially in medicine, we are witnessing revolutionary research projects that were impossible to perform in earthly conditions.*
- ✓ *Studies on hyper and microgravity help understand the effects of alien conditions on the human body.*

- ✓ *Cultivating protein crystals in space could help scientists develop better treatment solutions for many diseases that have no cure. In addition, there are numerous innovative space research projects that are designed to study celestial bodies.*

The International Space Station acts as a doorway to new horizons in space exploration. It is a place where we can learn and experiment on living and surviving on alien planets. The long-term consequences of weightlessness and radiation on the human body are the most crucial research areas, which will allow us to prepare astronauts for crewed interplanetary missions.

Important Facts about International Space Station

It is an international collaboration of five space agencies. Fifteen countries control the International Space Station.

NASA Astronaut Bill Shepherd and cosmonauts Sergei Krikalev and Yuri Gidzenko were the first humans to live on the space station.

A crew of seven people work while moving at a speed of 8 km/s, circling the Earth about every 1.5 hours.

In a day, the station completes sixteen orbits around the Earth, moving through sixteen sunsets and sunrises.

The living area in the station is bigger than a six-bedroom apartment.

The International Space Station has software that monitors about 350,000 sensors, tracking the station and crew members.

About fifty computers administer the systems on the station.

About 3 million lines of software codes on the ground assist around 1.5 million lines of flight software codes.

In the U.S. section, there are about 1.5 million lines of software codes (flight) running on 44 computers. These communicate through 100 data networks delivering 4,00,000 signals. Such signals are responsible for valve positions, temperature or pressure estimations, etc.

The crew members do physical exercises at least two hours a day to counter the loss of muscle and bone density in the human body.

Astronauts frequently do spacewalks for station maintenance and upgrades.

The solar array wingspan is much longer than the world's biggest passenger airliner (the Airbus A380).

The bigger modules and other space station parts were brought on 42 different flights. Thirty-seven parts were brought by U.S. space shuttles and five by Russian Proton/Soyuz rockets.

Eight miles of wire links the electrical system on the space station.

The 55-foot robotic arm Canadarm2 has seven joints and two hands. It is used to manoeuvre large modules, conduct experiments and carry spacewalking astronauts.

Eight spacecraft could be attached to the station at one instance.

On average, a spacecraft arrives at the space station four hours after being dispatched from the Earth.

The main cargo spaceships were SpaceX's Dragon, Northrop Grumman's Cygnus, the Russian Progress and JAXA's HTV.

They were used to deliver essential goods to the space station.

The microgravity laboratory (Expedition 60) has anchored approximately 3,000 research projects from more than 108 countries.

About twenty research payloads can be functional outside the space station at once.

The International Space Station travels the distance to the Moon and back every 24 hours.

The Water Recovery System efficiently regulates the dependence on water supplied by cargo spacecraft by 65 percent.

Significant Contributions of International Space Station

The International Space Station is aiding in the research of water purification technology. In the space station, scientists are able to conduct advanced experiments which are not possible on the Earth. In space, the external variables are significantly less compared to the Earth. Fewer constraints mean less probability of errors.

- ✓ High-quality protein crystals are being developed in the space station. *Space has the perfect conditions to examine these structures.*

- *Microgravity is conducive to the optimal cultivation of rare and complex protein crystal structures. These are some of the crucial substances in medical diagnosis. Hematopoietic prostaglandin D synthase was developed here, an essential component in diagnosing muscular dystrophy.*
- *Space station ultrasound technology.*
- *Eye surgery methods with space station hardware and tools (helmet feeding highly efficient image-processing chips).*
- *Robotic arms can be used to operate complex tumours.*
- *Research on the characteristics of various fluids to improve existing medical devices.*
- *They are developing fine-tuned diets and exercises for preventing bone loss or degradation.*
- *Practical experiences in the space station help better understand osteoporosis development.*
- *The International Space Station gives excellent opportunities for students to conduct their own scientific experiments in space.*
- *It helps to monitor water quality.*
- *It also enables us to monitor and predict natural calamities from space.*

There have been projects for developing optimal methods for cultivating crops in space. In turn, it also helps to find solutions for mould prevention in medical labs, homes and large-scale food storage.

FUNDAMENTALS OF DIGITAL ELECTRONICS

POTENTIAL DIVIDER

A potential divider is a simple circuit that uses resistors (or thermistors / LDR's) to supply a variable potential difference.

A potential divider is widely used in circuits. It is based on the principle that the potential drop across a segment of a wire of uniform cross-section carrying a constant current is directly proportional to its length.

It is used in the volume control knob of music systems. Sensory circuits using light-dependent resistors and thermistors also use potential dividers.

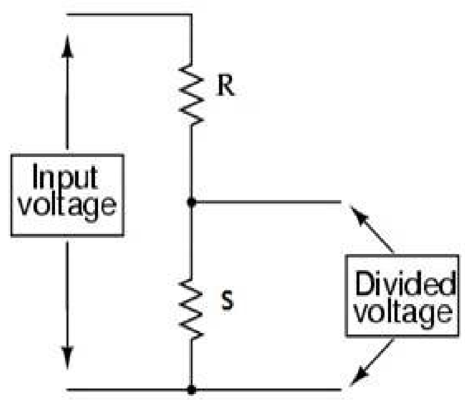
They can be used as audio volume controls, to control the temperature in a freezer or monitor changes in light in a room.

Two resistors divide up the potential difference supplied to them from a cell. The proportion of the available p.d. that the two resistors get depends on their resistance values.

- V_{in} = p.d. supplied by the cell
- V_{out} = p.d. across the resistor of interest
- R_1 = resistance of resistor of interest R_1
- R_2= resistance of resistor R_2

POTENTIAL DIVIDER

A potential divider consists of two resistors (R_1 and R_2=S) in series. The current I through both the resistors are the same. The potential across resistor R_1 is V_1 and R_2=S is V_2. The potential difference across the resistors can be mathematically written using Ohm's law.



$$V_1 = IR_1 \text{ and } V_2 = IR_2$$

Dividing V_1 by V_2,

$$\frac{V_1}{V_2} = \frac{R_1}{R_2}$$

Figure 1: Potential Divider

Using the above equation, it can be understood that the total potential difference (V) is divided between the two resistors according the ratio of their resistances. By choosing the appropriate resistor values, the potential difference across the resistances can be varied.

Resistance

The resistance of a uniform conductor depends upon:

- Its length, l
- Its cross-sectional area, A
- The resistivity of the material, ρ

The resistivity is different for different materials and varies greatly with temperature. It is measured in Ωm. The relationship between resistance and the three quantities can be represented using mathematical equation as shown,

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

From the above equation of resistance, it can be noted that the value of resistance increases with increase in the length of the conductor.

Variable Resistor

A variable resistor (rheostat) can be used to control current in a circuit. A variable resistor consists of a length of resistance wire and an adjustable sliding contact. Without switching off the circuit, the resistance can be varied using a sliding contact. The symbol for a variable resistor is given in the diagram below.

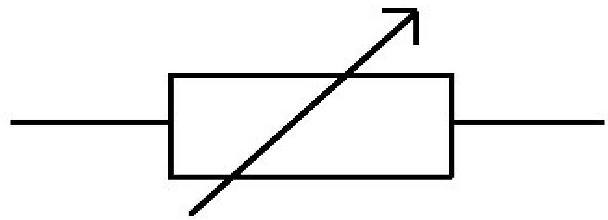


Figure 2: Circuit Symbol of Variable Resistor

A rheostat is made using a resistance wire, which is wound around circular insulation. A sliding contact is placed in the wire to change the length of the resistor. An end of the wire and sliding contact is connected to the circuit. As the length of the resistance wire is changed, the resistance also changes. The resistance can be set to any value from nearly zero to the total resistance of the wire in the variable resistor. A rheostat is used in car lighting systems to change the brightness of the lights.

Potentiometer

The design of a potentiometer is similar to that of a variable resistor. All the three points, both the ends of resistance wire and the adjustable contact, are connected to the circuit.

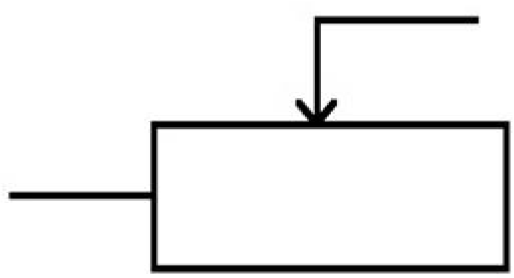


Figure 3: Circuit Symbol for Potentiometer

Two terminals and the contact are connected to the circuit. The length of the wire can be changed by the sliding contact. The resistance increases as the length of the wire increases. The resistance can be set to any value from zero to the total resistance of the wire. Potentiometers are often used, for example, to change the volume in a speaker system.

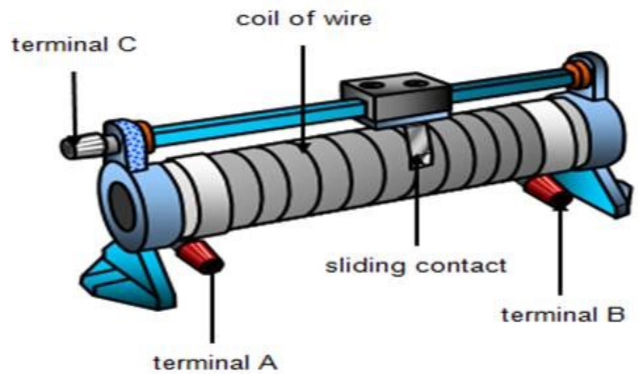


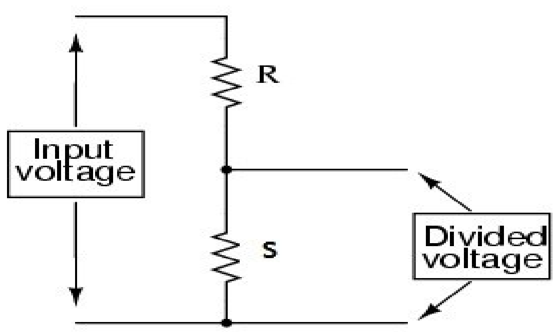
Figure 4: A Potentiometer

Application of Potential Dividers

Potential dividers are widely used in sensory circuits. The change in the physical property of a sensor has to be processed before it can be displayed or measured. Light-dependent resistors and thermistors are two examples of sensory devices whose resistances vary with light and temperature respectively. The resistance of a light-dependent resistor decreases as the light intensity increases. The resistance of the thermistor decreases with rise in temperature. A potential divider can be used to process the information obtained from these sensory devices.

Let us consider a potential divider circuit as shown in *Figure 1*. A sensory device can be placed in the position of R2.

Figure 5: Potential Divider in Sensory Circuits



The voltage across sensory device (Vs) can be mathematically written as:

$$V_s = \frac{S}{S+R} \times Input\ voltage$$

The magnitude of Vs depends on the relative resistance of R and S.

We can note that, as the resistance of sensory device (S) increases, the voltage also increases.

Example

A potential divider circuit can be used inside a refrigerator to switch on the cooling circuit when the temperature is high (more than 3°C).

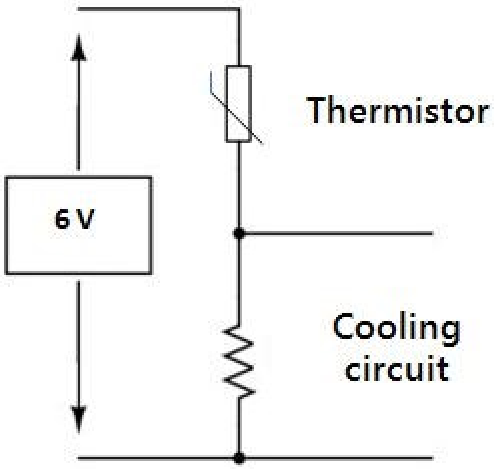


Figure 6: Potential Divider Using a Thermistor

The characteristics of the thermistor are given in the table below. Let the voltage across the cooling circuit be VCC and the resistance of cooling circuit is 5kΩ. In order for the cooling circuit to operate, it needs a potential difference of 5 V or more.

Let us check what happens if the temperature is above 3°C. Let the resistance of thermistor be R_t.

$$Vcc = \frac{6\times5000}{5000+R_t}$$

At 2°C,

$$Vcc = \frac{6\times5000}{5000+1500} = 4.6\ V$$

So the cooling circuit is off.

At 3°C,

$$Vcc = \frac{6\times5000}{5000+1000} = 5.0\ V$$

The cooling circuit is on. This condition holds true when the temperature increases more than 3°C.

Temperature	Resistance of Thermistor
2°C	1500 Ω
3°C	1000 Ω
4°C	500 Ω

Hence, this potential divider meets the requirements of the refrigerator. These circuits can be further modified to suit different applications. For example: switching off a heater when the temperature is above a certain temperature. This circuit can also be used for switching off lights in the daytime and switching them on at night (using LDR).

Summary

Two resistors in series act as a **potential divider**, where $\frac{V_1}{V_2} = \frac{R_1}{R_2}$.

- If V is the input voltage, the divided voltage across the output can be given by the equation $V_{out} = \frac{VR_1}{R_1+R_2}$.
- A **potentiometer** is a variable resistor connected as a potential divider to give a continuously variable output voltage.

Digital electronics is a type of electronics that deals with the digital systems which processes the data/information in the form of binary (0s and 1s) numbers, whereas analog electronics deals with the analog systems which processes the data/information in the form of continuous signals.

Continuous signals

A Continuous signal is function f(t), whose value is defined for all time 't' in other words.

Continuous signal a varying quantity with respect to independent variable time. Example: Figure 1.1(a) shows the continuous signal.

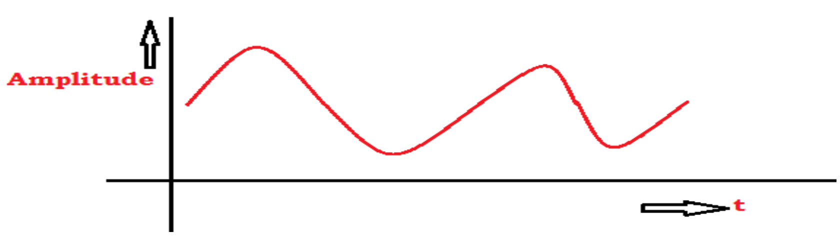


Figure 1.1(a):

Continuous signals.

Digital signals

A digital signal is a quantized discrete time signal. Example: Figure 1.1(b) shows the discrete and digital signals.

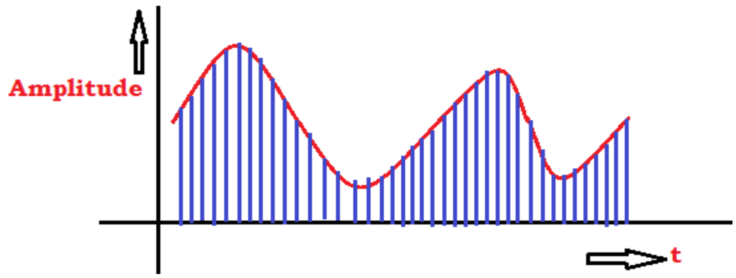
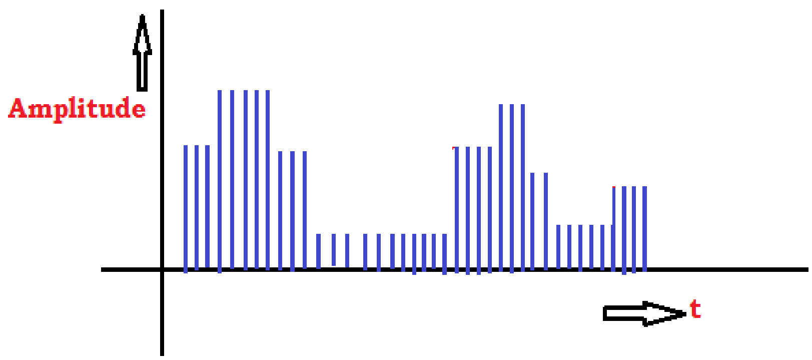


Figure 1.1(b1): *Discrete signal.*

Figure 1.1(b2): Digital signal



Boolean algebra

Boolean algebra is a branch of Algebra (Mathematics) that deals with operations on logical values with Boolean variables; Boolean variables are represented as binary numbers which takes logic 1 and logic 0 values. *Hence, the Boolean algebra is also called two-valued logic, Binary Algebra or Logical Algebra.* The Boolean algebra was introduced by great mathematician George Boole in 1847. The Boolean algebra is a fundamental for the development of digital electronic systems, and is provided for in all programming languages.

Set theory and statistics fields also use Boolean algebra for the representation, simplification and analysis of mathematical quantities.

Classifications of Logic levels

1. *Positive logic*

   Logic 0 = False, 0V, Open Switch, OFF

   Logic 1= True, +5V, Closed Switch, ON

2. *Negative logic*

   Logic 0 = True, +5V, Closed Switch, ON

   Logic 1= False, 0V, Open Switch, OFF

Boolean algebra differs from normal or elementary algebra. Latter deals with numerical operations such as, addition, subtraction, multiplication and division on decimal numbers.

And former deals with the logical operations such as conjunction (OR), disjunction (AND) and negation (NOT). In present context, ***positive logic has been used for the entire discussion, representation and simplification of Boolean variables.***

Boolean Algebra Rules and properties

1. *Boolean variables take only two values, logic 1 and logic 0, called binary numbers.*
2. *Basic operations of Boolean algebra are complement of a variable, ORing and ANDing of two or more variables.*
3. *Mathematical description of Boolean operations using variables is called* ***Boolean expression.***
4. *Complement of variable is represented by an over-bar (-),* $Y = \bar{A}$
5. *ORing of variables is represented by a plus symbol (+), A+B=Y (output)*
6. *ANDing of variables is represented by a dot symbol (.), A.B=Y (Output)*
7. *Boolean operations are different from binary operations.*

A	$Y = \bar{A}$
0	1

Example: 1+1=10 in Binary Addition, 1+1=1 in Boolean algebra.

1	0

Table 1.1, shows the complement operation of a variable, table 1.2 summarized the OR operation and table 1.3, summarized the AND operation of two variables.

Table 1.1:

Complement of variable A

Table 1.2: OR operation on A and B

A	B	Y=A+B
0	0	0
0	1	1
1	0	1
1	1	1

Table 1.3: AND operation on A and B

A	B	Y=A.B
0	0	0
0	1	0
1	0	0
1	1	1

The present chapter deals with the simplification of Boolean expressions and representation using sum of product form and product of sum forms.

Boolean Laws:

Law-1: Commutative law

The sequence of changing the variables does not effect on the result even after changing their sequence while performing OR, or AND operations of Boolean expression.

i. e. , A. B = B. A and A + B = B + A

Law-2: Associative law

The order of operations on variables is independent.

A.(B. C) = (A. B). C and A + (B + C) = (A + B) + C

Logic Gates realization of Boolean Expressions

Logic gate is the basic building block of any digital circuits. The logic gates may have one or more inputs and only one output. The relationship between input and output is based on a certain logic, which is same as Boolean operations, such as **AND, OR** and **NOT**.

Based on the Boolean operations, the gates are named as **AND** gate, **OR** gate and **NOT** gate. These *three gates are called basic gates*, and some more gates can be derived by using the basic gates, they are named as *NAND gate, NOR gate, EXOR gate and XNOR gate. NAND* and *NOR gates are called universal gates*, because by using only the *NAND gates /NOR* gates we can realize all basic gates even all Boolean expression.

Logic gates, its truth table, expression and symbols are summarized in the table 1.7 as follows.

Logic Gates

Logic gates are the fundamental components of all digital circuits and systems. In digital electronics, there are seven main types of logic gates used to perform various logical operations. A logic gate is basically an electronic circuit designed by using components like diodes, transistors, resistors, capacitors, etc., and capable of performing logical operations. In this article, we will study the definition, truth table, and other related concepts of logic gates. So let's start with the basic introduction of logic gates.

LOGIC GATE

A logic gate is an electronic circuit designed by using electronic components like diodes, transistors, resistors, and more. As the name implies, a logic gate is designed to perform logical operations in digital systems like computers, communication systems, etc.

Therefore, we can say that the building blocks of a digital circuit are logic gates, which execute numerous logical operations that are required by any digital circuit. A logic gate can take two or more inputs but only produce one output. The output of a logic gate depends on the combination of inputs and the logical operation that the logic gate performs.

Logic gates use Boolean algebra to execute logical processes. Logic gates are found in nearly every digital gadget we use on a regular basis. Logic gates are used in the architecture of our telephones, laptops, tablets, and memory devices.

Types of Logic Gates

A logic gate is a digital gate that allows data to be manipulated. Logic gates, use logic to determine whether or not to pass a signal. Logic gates, on the other hand, govern the flow of information based on a set of rules.

The logic gates can be classified into the following major types:

1. **Basic Logic Gates**

There are three basic logic gates:

a) **AND Gate,**
b) **OR Gate, and**
c) **NOT Gate**

2. Universal Logic Gates

In digital electronics, the following two logic gates are considered as universal logic gates:

NOR Gate and NAND Gate

3. Derived Logic Gates

The following two are the derived logic gates used in digital systems:

- ✓ ***XOR Gate,***
- ✓ ***XNOR Gate, and***
- ✓ ***AND Gate***

In digital electronics, the **AND** gate is one of the basic logic gate that performs the logical multiplication of inputs applied to it. It generates a high or logic 1 output, only when all the inputs applied to it are high or logic 1. Otherwise, the output of the **AND** gate is *low or logic 0.*

Properties of AND Gate:

The following are two main properties of the AND gate:

AND gate can accept two or more than two input values at a time, when all of the inputs are logic 1; the output of this gate is logic 1.

The operation of an AND gate is described by a mathematical expression, which is called the Boolean expression of the AND gate.

For two-input AND gate, the Boolean expression is given by, Y=$A.\ B$

Y=A.B, where, A and B are inputs to the AND gate, while Y denotes the output of the AND gate.

We can extend this expression to any number of input variables, such as, Y=A.B.C. D…

Truth Table of AND Gate:

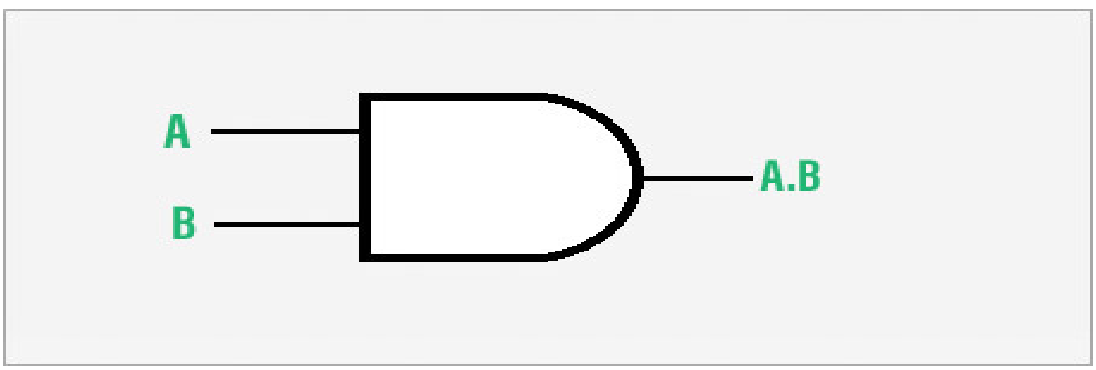
The truth table of a two input AND gate is given below:

Input		**Output=A.B**
A	B	A AND B

Input		Output=A.B
0	0	0
0	1	0
1	0	0
1	1	1

Symbol of AND Gate:

The logic symbol of a two input AND gate is shown in the following figure.



Symbol of Two-Input AND Gate

OR Gate

In digital electronics, there is a type of basic logic gate which produces a low or logic 0 output only when it's all inputs are low or logic 0. For all other input combinations, the output of the OR gate is high or logic 1. This logic gate is termed as ***OR gate***.

An OR gate can be designed to have two or more inputs but only one output.

The primary function of the *OR gate is to perform the logical sum operation.*

Properties of OR Gate:

An OR gate have the following two properties:

It can have two or more input lines at a time.

When all of the inputs to the OR gate are low or logic 0, the output of it is low or logic 0.

The operation of an OR gate can be mathematically described through a mathematical expression called *Boolean expression of the OR gate*.

The Boolean expression for a two input OR gate is given by,

Y = A + B

The Boolean expression for a three-input OR gate is, Y= A + B + C

Here, A, B, and C are inputs and Y is the output variables. We can extend this Boolean expression to any number of input variables.

Truth Table of OR Gate:

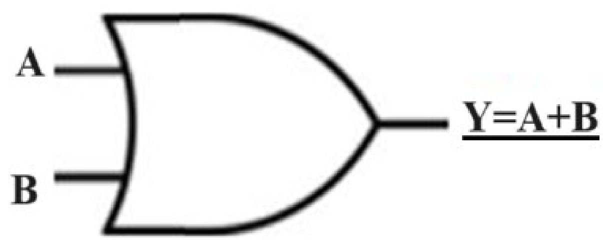
The truth table of an OR gate describes the relationship between inputs and output. The following is the truth table for the two-input OR gate:

Input		**Output,Y**
A	B	A OR B
0	0	0
0	1	1
1	0	1

Input		Output,Y
1	1	1

Symbol of OR Gate:

The logic symbol of a two-input OR gate is shown in the following figure.



Symbol of Two-Input OR Gate

NOT Gate

In digital electronics, the NOT gate is another basic logic gate used to perform compliment of an input signal applied to it. It takes only one input and one output. The output of the NOT gate is complement of the input applied to it. Therefore, if we apply a low or logic 0 outputs to the NOT gate is gives a high or logic 1 output and vice-versa.

The NOT gate is also known as inverter, as it performs the inversion operation.

Properties of NOT Gate:

The output of a NOT gate is complement or inverse of the input applied to it. NOT gate takes only one output.

The logical operation of the NOT gate is described by its Boolean expression, which is given by $Y = \bar{A}$

The bar over the input variable A represents the inversion operation.

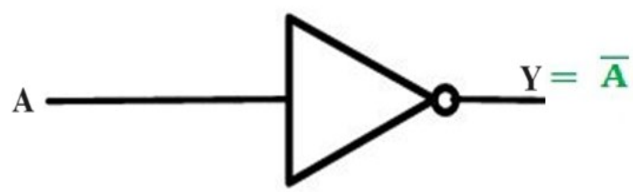
Truth Table of OR Gate:

The truth table describes the relationship between input and output. The following is the truth table for the NOT gate:

Input	Output, $Y = \bar{A}$
A	**NOT A**
0	1
1	0

Symbol of NOT Gate

The logic circuit symbol of a NOT gate is shown in the following figure. Here, A is the input line and Y is the output line.



Symbol of NOT the Gate

NOR Gate

The NOR gate is a type of universal logic gate that can take two or more inputs but one output. It is basically a combination of two basic logic gates i.e., OR gate and NOT gate. Thus, it can be expressed as,

NOR Gate = OR Gate + NOT Gate

In other words, a NOR gate is an OR gate followed by a NOT gate.

Neither properties of NOR Gate:

The following neither are two important properties of NOR gate:

A NOR gate can have two or more inputs and gives an output.

A NOR gate gives a high or logic 1 output only when it's all inputs are low or logic 0.

Similar to basic logic gates, we can describe the operation of a NOR gate using a mathematical equation called Boolean expression of the NOR gate.

The Boolean expression of a two did not input NOR is gate given below:

$C = \overline{A + B}$

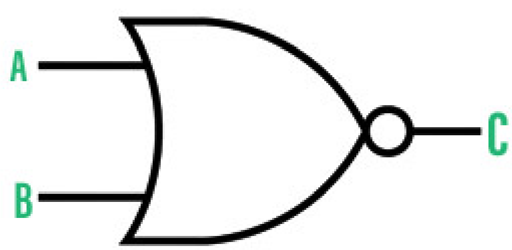
We can extend this expression to any number of input variables.

In the above Boolean expressions, the *variables A and B are called input variables while the variable C is called the output variable*.

Truth Table of NOR Gate:

The following is the truth table of a two-input NOR gate showing the relationship between its inputs and output:

Input		Output
A	B	A NOR B
0	0	1
0	1	0
1	0	0
1	1	0



Symbol of the NOR Gate

NAND Gate

In digital electronics, the NAND gate is another type of universal logic gate used to perform logical operations. The NAND gate performs the inverted operation of the

AND gate. Similar to NOR gate, the NAND gate can also have two or more input lines but only one output line.

The NAND gate is also represented as a combination of two basic logic gates namely, *AND gate* and *NOT gate*.

Hence, it can be expressed as **NAND Gate = AND Gate + NOT Gate**

Properties of NAND Gate:

The following are the two key properties of NAND gate:

NAND gate can take two or more inputs at a time and produces one output based on the combination of inputs applied.

NAND gate produces a low or logic 0 outputs only when it's all inputs are high or logic 1.

We can describe the expression of NAND gate through a mathematical equation called its Boolean expression.

The Boolean expression of a two input NAND gate, $\boldsymbol{C=\overline{AB}}$

In this expression, A and B are the input variables and C is the output variable. We can extend this relation to any number of input variables like three, four, or more.

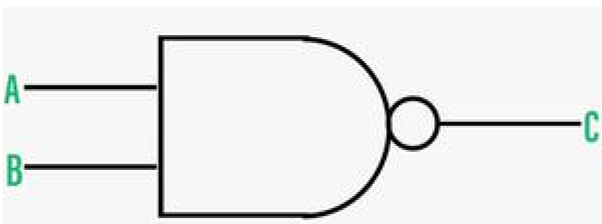
Truth Table of NAND Gate:

The truth table is a table of inputs and output that describes the operation of the NAND gate and shows the logical relationship between them:

Input		Output $\boldsymbol{C=\overline{AB}}$
A	**B**	**A NAND B**
0	0	1
0	1	1

Input		Output $C=\overline{AB}$
1	0	1
1	1	0

Symbol of NAND Gate: The logic symbol of a NAND gate is represented as a AND gate with a bubble on its output end as depicted in the following figure. It is the symbol of a two-input NAND gate.



Symbol of NAND Gate

XOR Gate

In digital electronics, there is a specially designed logic gate named, ***XOR gate,*** *which is used in digital circuits to perform modulo sum*. It is also referred to as **Exclusive OR gate or Ex-OR gate**. The XOR gate can take only two inputs at a time and give an output.

The output of the XOR gate is high or logic 1 only when its two inputs are dissimilar.

Properties of XOR Gate:

The following two are the main properties of the XOR gate:

It can accept only two inputs at a time. There is nothing like a three or more input XOR gate.

The output of the XOR gate is logic 1 or high, when its inputs are dissimilar.

The operation of the XOR gate can be described through a mathematical equation called its Boolean expression. The following is the Boolean expression for the output of the XOR gate. **Y=**$A \oplus B$

Here, Y is the output variable, and A and B are the input variables.

This expression can also be written as follows:$Y = A\bar{B} + A\bar{B}$

Truth Table of XOR Gate:

The truth table is a table of inputs and output that describe the relationship between them and the operation of the XOR gate for different input combinations. The truth table of the XOR gate is given below:

Input		**Output, $\boldsymbol{Y = A\bar{B} + \bar{A}B}$**
A	**B**	**A XOR B**
0	0	0
0	1	1
1	0	1
1	1	0

Symbol of XOR Gate: The logic symbol of an XOR gate is shown in the following figure.

Symbol of XOR Gate

XNOR Gate

The XNOR gate is another type of special purpose logic gate used to implement exclusive operation in digital circuits. It is used to implement the Exclusive NOR operation in digital circuits. It is also called *the Ex-NOR or Exclusive NOR gate.*

It is a combination of two logic gates namely, XOR gate and NOT gate. Thus, it can be expressed as, **XNOR Gate = XOR Gate + NOT Gate**

The output of an XNOR gate is high or logic 1 when it's both inputs are similar. Otherwise the output is low or logic 0.

Hence, the *XNOR gate is used as a similarity detector circuit.*

Properties of XNOR Gate:

The following are two key properties of XNOR gate:

XNOR gate takes only two inputs and produces one output.

The output of the XNOR gate is high or logic 1 only when it has similar inputs.

The operation of XNOR gate can be described through a mathematical equation called the Boolean expression of XNOR gate. Here is the Boolean expression of the XNOR gate, $\boldsymbol{Y=A\odot B}$

We can also write this expression as follows: $\boldsymbol{Y = AB + \overline{AB}}$

Here, the A and B are inputs and Y is the output.

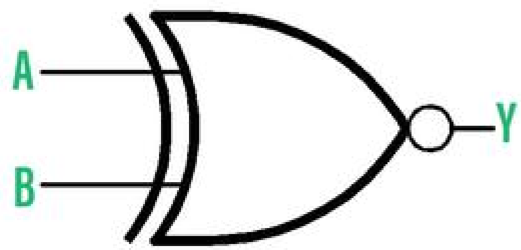
Truth Table of XNOR Gate:

The truth table of the XNOR gate is given below. This truth table is describing the relationship between inputs and output of the XNOR gate.

Input		Output
A	B	A XNOR B
0	0	1
0	1	0
1	0	0
1	1	1

Symbol of XNOR Gate:

The logic symbol of XNOR gate is shown in the following figure. Here, A and B are inputs and Y is the output.



Applications of Logic Gates

Logic gates are the fundamental building blocks of all digital circuits and devices like computers.

Here are some key digital devices in which logic gates are utilized to design their circuits:

- ✓ *Computers*
- ✓ *Microprocessors*
- ✓ *Microcontrollers*
- ✓ *Digital and smart watches*
- ✓ *Smartphones, etc.*

Logic gates:

Logic gates are digital circuits that conduct logical operations on the input provided to them and produce appropriate output.

Universal gates: *To accomplish a specific logical process, universal gates are created by merging two or more fundamental gates.*

Universal gates are NAND and NOR gates.

What is the output of a NOT gate when input 0 is applied?

Because NOT gate is an inverter. As a result, if 0 is used as an input, the output will be 1.

Which logic gate is known as the "invertor"?

An inverter is also known as a NOT gate. The obtained output is the inverse of the input.

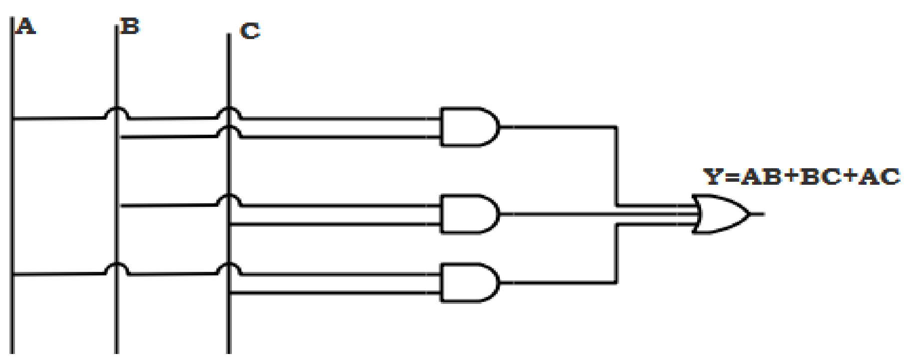
What is the Boolean expression for OR gate?

If A and B are the input, then the OR gate output can be given as *Y=A+B.*

What is the Boolean expression for the XNOR gate?

If A and B are the input, then the XNOR gate output can be given as Y=A.B+A'B'.

LOGIC DIAGRAM

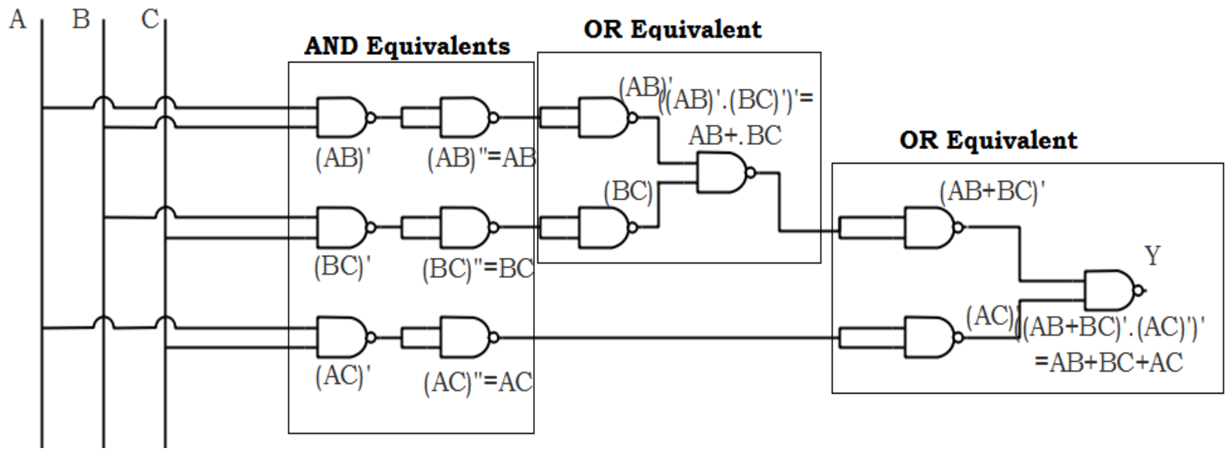


Realize the following Boolean expression using only NAND gates.

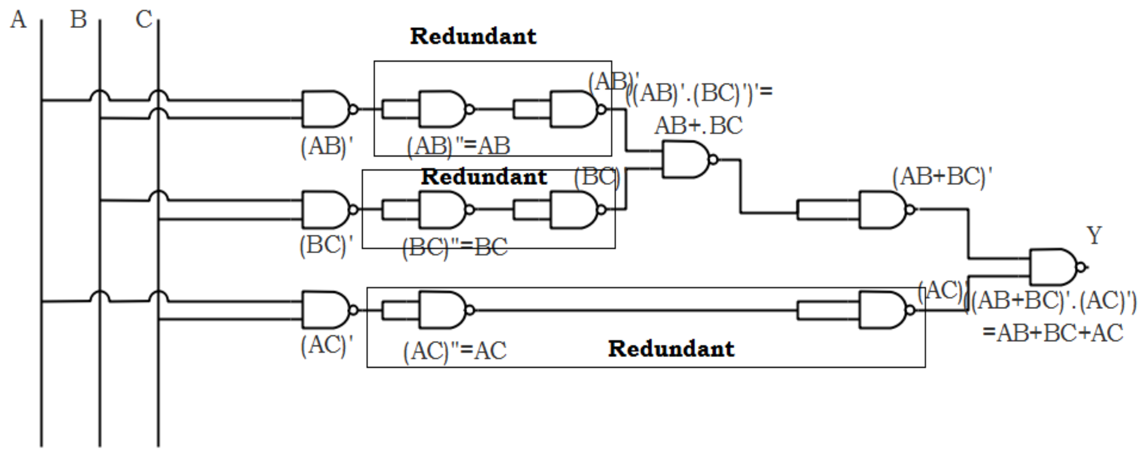
Y = AB + BC + AC

Logic diagram

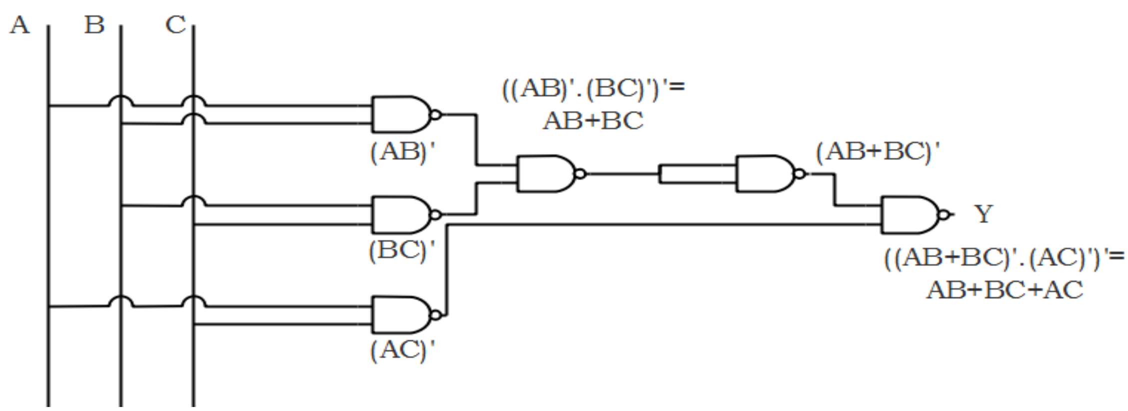
Step-1: Replace basic gates by NAND equivalents



Step-2: Eliminate two single inputs NAND gates are connected in series.



Step-3: Draw the resultant logic circuit.



BISTABLE CIRCUITS

A Bistable is a digital circuit that has two inputs and a digital output.

The SET input makes the output Logic 1 (HIGH) and the output will stay in this state until forced to change. The RESET input makes the output Logic 0 (LOW) and the output will also stay in this state until forced to change. The output of a Bistable circuit is stable in both states - it can remain as either Logic 1 or Logic 0 indefinitely until either the SET or RESET initiate a change of state. The name means that the circuit has two stable states.

The terms *Bistable, Latch and Flip-Flop* are sometimes used interchangeably to describe Bistable circuits. However, each of these terms does have a specific meaning.

1) *A bistable circuit is the most basic circuit with SET and RESET inputs and the output immediately responds to a change in the inputs.*
2) *A latch is very similar to the basic bistable circuit but includes an ENABLE to control the state of the output.*
3) *A flip-flop is a bistable circuit where the output changes on the rising (usually) edge of a clock pulse.*

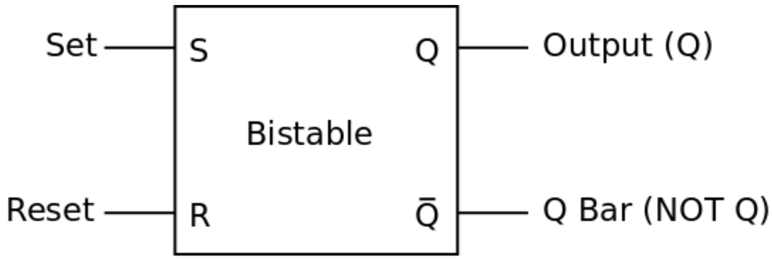
BISTABLE BASICS

A Bistable has two inputs called **Set (S)** and **Reset (R)**.

The output is called **Q**. There is often a second output which is the opposite of Q or, in logic terms, **NOT Q**.

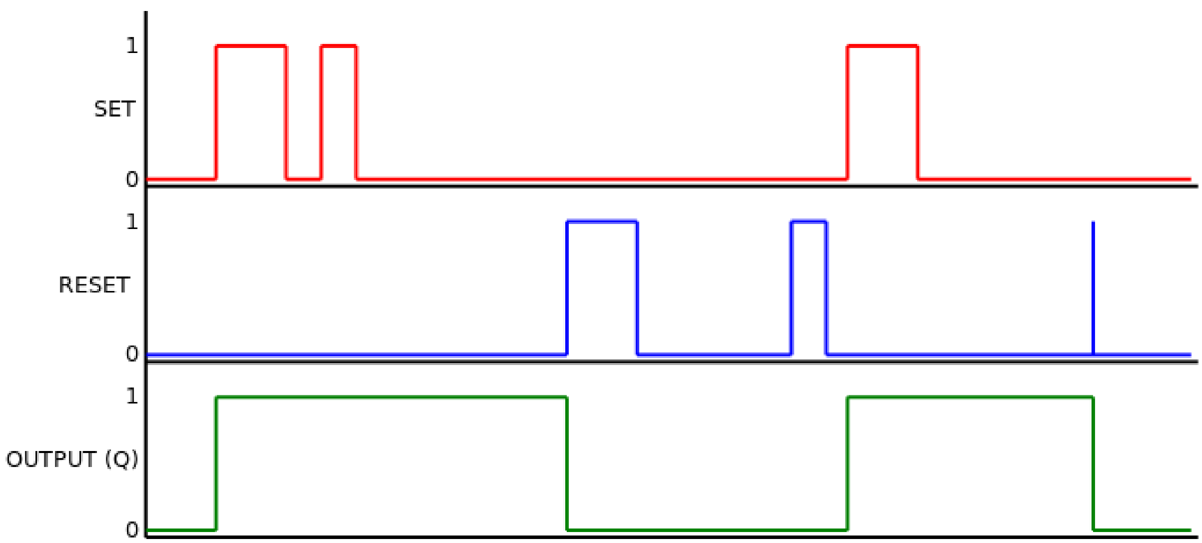
The NOT Q output is written as $\bar{Q}$ and pronounced "Q-bar"

In the most common bistables, Set and Reset are usually LOW and must go HIGH to change the output.



NOTE

1. In normal operation, SET and RESET are usually both held LOW
2. Q is always the opposite of $\overline{Q}$
3. SET and RESET should not both be high at the same time - if they are the state of the outputs is undecided
4. There are also bistables where SET and RESET are usually HIGH and go LOW to change the output.



The timing diagram shows how the SET and RESET inputs cause Q and $\overline{Q}$ to change

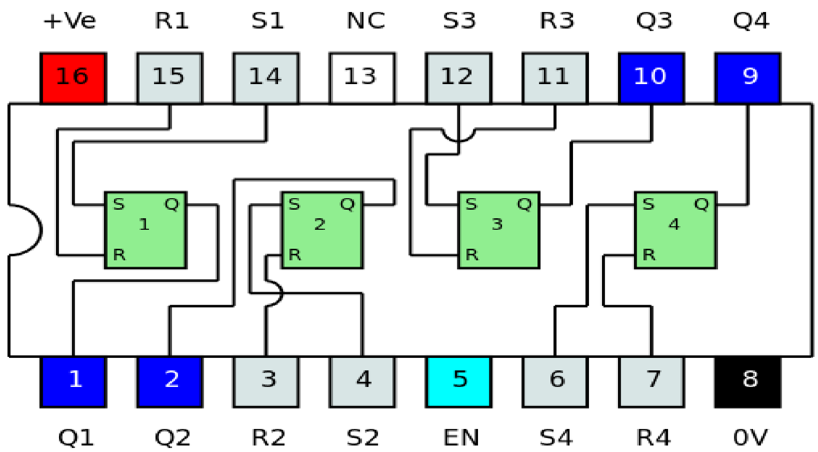
The first time SET (Red line) goes HIGH it makes the OUTPUT (Green line) go HIGH. Making the SET go HIGH again has no further effect - the OUTPUT stays HIGH.

Making the RESET (Blue line) go HIGH makes the OUTPUT go LOW. Making the RESET go HIGH again has no further effect - the OUTPUT stays LOW.

The SET and RESET pulses can be momentary pulses as shown by the final RESET pulse which is just a very narrow, short pulse.

A bistable is particularly useful in an alarm circuit where one input (the sensor or detector) will SET the alarm ringing and a different input (the security officers key) will RESET the alarm to silent.

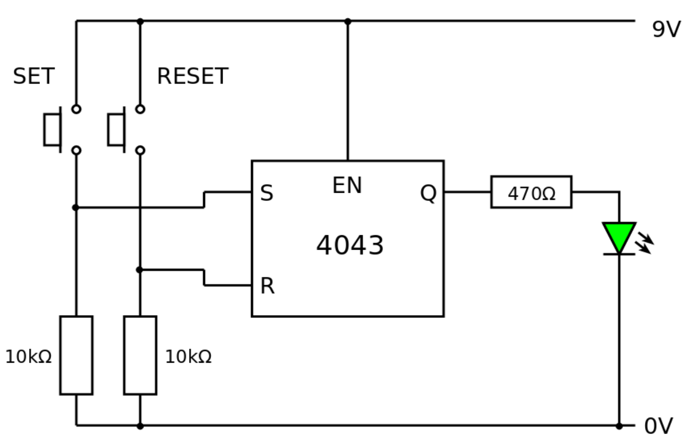
4043 Bistable IC



A basic bistable can be built from logic gates but is also available on a dedicated IC such as the 4043

The 4043 IC contains four separate bistables each with a SET, a RESET and a single output. As shown in the pin layout, only output Q is available. There is no Q-bar output.

SET is normally LOW, making SET go HIGH forces the output Q HIGH. RESET is normally LOW, making RESET go HIGH forces the output Q LOW.



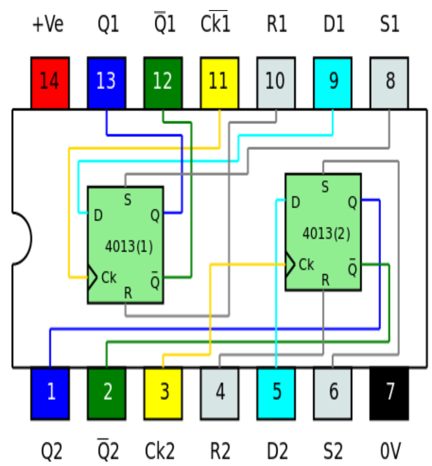
Making both SET and RESET HIGH at the same time is a disallowed state - in this case the output Q goes HIGH with the final state being determined by which input goes LOW first.

The 4043 IC also has an ENABLE input. This input controls the tristate output of all four bistables together.

When the ENABLE is HIGH, the outputs of each bistable are either HIGH or LOW as expected. When the enable is LOW the outputs are not connected to the bistables and simply float to any value.

A simple test circuit is shown with the ENABLE connected HIGH and two inputs provided by push buttons.

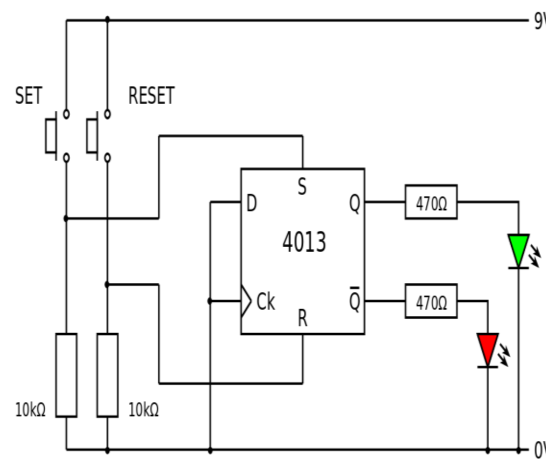
Using 4013 as a Bistable



A bistable can easily be built from a 4013 D-type flip-flop IC. The 4013 has a SET and RESET as expected and also has outputs Q and Q making it preferable to the 4043 IC in some cases.

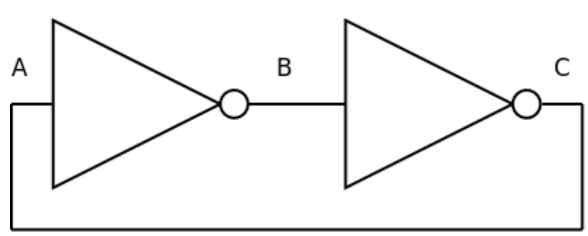
There are two other inputs called **CLOCK (CK)** and **DATA (D)** that are not used and must be connected to ground when the 4013 is used as a simple bistable.

The 4013 IC contains two separate flip-flops and so can be used to provide two separate bistables that operate completely independently.



SET is normally LOW, making SET go HIGH forces the output Q HIGH and Q LOW. RESET is normally LOW, making RESET go HIGH forces the output Q LOW and Q HIGH.

Making both SET and RESET HIGH at the same time is a disallowed state - in this case the outputs Q and Q both go HIGH with the final state being determined by which input goes LOW first.



The diagram shows a simple test circuit with CK and D connected to ground.

Simple logic gate Bistable

At the heart of a bistable circuit are two inverting logic gates.

The output of each logic gate is connected to the input of the other logic gate. Such a circuit has two states where it is stable.

The most basic logic gate bistable is made from two **NOT gates** as shown in the diagram.

Situation 1:

Assume A = 0 and therefore B = 1. B = 1 and therefore C = 0 ... C is connected to A, and so A = 0 as required.

Situation 2:

Assume A = 1 and therefore B = 0. B = 0 and therefore C = 1 ... C is connected to A, and so A = 1 as required.

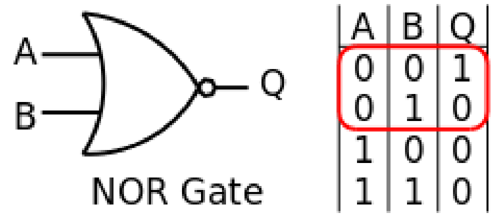
Whether A = 0 or A = 1, the circuit works in both cases. To make this circuit a bistable simply make one of the NOT gate outputs Q and the other$\bar{Q}$.

This is not a good circuit. To SET or RESET the bistable requires input A or input B to be forced into either a HIGH or LOW state - but the inputs are also the outputs of the other logic gates and forcing the outputs of logic gates to be either HIGH or LOW can lead to problems.

If we assume situation 1 where A = 0 and we force A to be HIGH so that A = 1 then the output C will try and stay LOW so is A HIGH or LOW? An indeterminate state can result and the bistable will either fail to work or be unreliable or, in the worst case scenario, the logic gates will be damaged by having their outputs forced HIGH or LOW. All together not good.

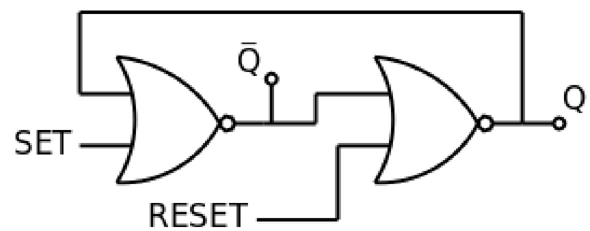
NOR gate Bistable

Consider the function of the NOR gate. When A = 0 (as shown circled in red) then the NOR gate acts like a NOT gate with B and Q being opposite in both cases.



Therefore the NOR gate can replace the NOT gate in the simple logic bistable. However, when A = 1, Q = 0 irrespective of the state of B therefore A is acting like a RESET.

This is an excellent bistable circuit.



When SET and RESET are both LOW the NOR gates act as NOT gates and the bistable has two stable states.

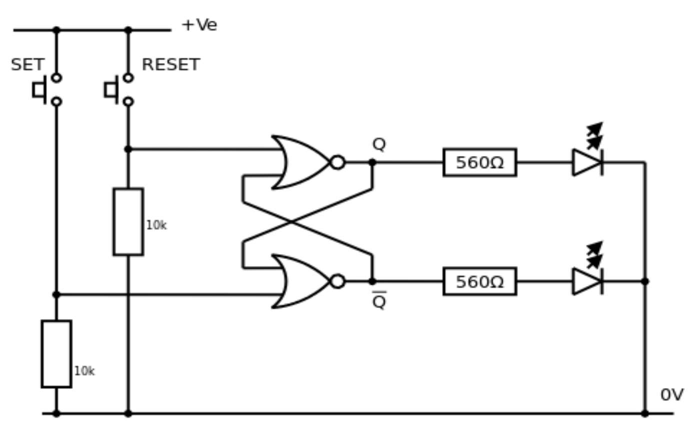
SET and RESET can safely be made HIGH as they are not directly connected to the output of the NOR gates - they are only inputs.

Situation 1:

Consider SET = 0, RESET = 0, Q = 0 and therefore $\bar{Q}$ = 1. Making SET = 1 forces $\bar{Q}$ = 0. Both inputs to the right do not hand NOR gate are now LOW and so Q = 1. The feedback ensures that at least one of the inputs of the left hand NOR gate is now HIGH and so $\bar{Q}$ = 0. Therefore, making SET = 1 forces Q = 1 as required.

Situation 2:

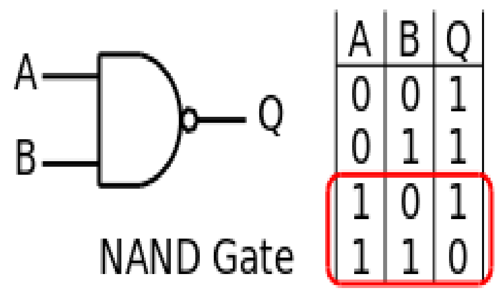
Consider SET = 0, RESET = 0, Q = 1 and therefore $\bar{Q}$ = 0. Making RESET = 1 forces Q = 0. Both inputs to the left hand NOR gate are now LOW and so $\bar{Q}$ = 1. The feedback ensures that at least one of the inputs of the right hand NOR gate is now HIGH and so Q = 0. Therefore, making RESET = 1 forces Q = 0 as required.



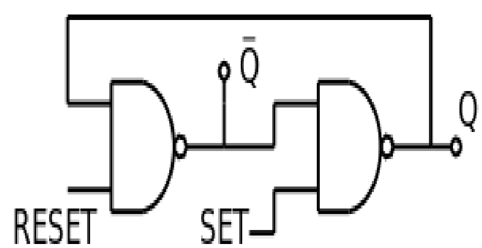
Logic circuits or devices where the inputs are normally LOW and go HIGH to make something happen are not often referred to as having "NOR gate logic" or "NOR logic" because in the NOR gate bistable SET and RESET are normally LOW.
Note that the 4043 and 4013 ICs Kemploy NOR gate logic.

The NOR gate bistable circuit is shown - with suitable inputs and outputs - and is equivalent to the circuit described above but is drawn differently. You have to convince yourself it is the same circuit!
Pull down resistors ensure SET and RESET are normally LOW and go HIGH when the buttons are pressed (NOR Logic).

NAND gate Bistable



Consider the function of the NAND gate. When A = 1 (as shown circled in red) then the NAND gate acts like a NOT gate with B and Q being opposite in both cases. Therefore the NAND gate can replace the NOT gate in the simple logic bistable if A is held HIGH. However, when A = 0, Q = 1 irrespective of the state of B therefore A is acting like a SET.
When SET and RESET are both HIGH the NAND gates act as NOT gates and the bistable has two stable states as before.



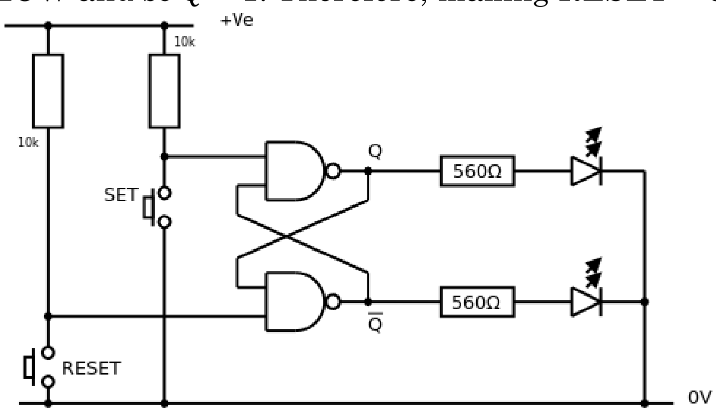
SET and RESET can safely be made LOW as they are not directly connected to the output of the NAND gates - they are only inputs.
Note that in this case the SET and RESET inputs are normally HIGH and must go LOW to cause a change to happen - this type of logic is called "NAND gate logic" or "NAND logic". Having the normal state of the inputs as HIGH does not seem obvious at first but this is very similar to the monostable circuit where the trigger is held HIGH and goes LOW to start the monostable. NAND gate logic is quite common in more advanced digital circuits.

Situation 1:

Consider SET = 1, RESET = 1, Q = 0 and therefore $\overline{Q}$ = 1. Making SET = 0 forces Q = 1. Both inputs to the left hand NAND gate are now HIGH and so $\overline{Q}$ = 0. The feedback ensures that at least one of the inputs of the right hand NAND gate is now LOW and so Q = 1. Therefore, making SET = 0 forces Q = 1 as required.

Situation 2:

Consider SET = 1, RESET = 1, Q = 1 and therefore $\overline{Q}$ = 0. Making RESET = 0 forces $\overline{Q}$ = 1. Both inputs to the right hand NAND gate are now HIGH and so Q = 0. The feedback ensures that at least one of the inputs of the right hand NAND gate is now LOW and so $\overline{Q}$ = 1. Therefore, making RESET = 0 forces Q = 0 as required.



The 4044 IC is functionally equivalent to the 4043 described above except that it uses NAND Logic and the pin layout is slightly different.

The NAND gate bistable circuit is shown - with suitable inputs and outputs - and is equivalent to the circuit described above but is drawn differently. You have to convince yourself it is the same circuit!

Pull up resistors ensure SET and RESET are normally HIGH and go LOW when the buttons are pressed (NAND Logic).