PRINCIPLES OF PHYSICS

THE NEW EXPECTATIONS FOR LEARNING

The **NEW LOWER SECONDARY CURRICULUM** sets new expectations for learning, with a shift from Learning Outcomes that focus mainly on knowledge to those that focus on skills and deeper understanding.

These new **Learning Outcomes** require a different approach to assessment. The "**Learning Outcomes**" in the manuscript are set out in terms of **Knowledge**, **Understanding**, **Skills**, **Values**, and **Attitudes**. This is what is referred to by the letters **k, u, s, v/a**.

Knowledge(K)	The retention of information.
Understanding(U)	Putting knowledge into a framework of meaning – the development of a 'concept'.
Skills(S)	The ability to perform a physical or mental act or operation.
Values (V)	The inherent or acquired behaviours or actions that form a character of an individual.
Attitudes(A)	A set of emotions, beliefs or behaviours toward a particular object, person, thing or event.

Note: *Due to the nature of the assessment and different curriculum need with emphasis on strategy, this gives a learner the opportunity to show the extent to which s/he has achieved the Learning Outcomes; the book has put into consideration and hence forth no examples have been taken care of. Learners should engage in group discussions to get the outcomes of the different set activities in the book along different themes.*

The new lower secondary curriculum being implemented in Uganda marks a significant shift towards competency-based learning, emphasizing the application of knowledge, skills, and problem-solving abilities. The focus is no longer just on memorizing formulas and concepts but on nurturing students' ability to apply Physics in real-life contexts. This curriculum fosters the development of essential competencies such as analytical reasoning, creativity, and collaboration. Physics, as a core scientific discipline, offers learners the tools to explore and understand the fundamental principles governing the natural world, from forces and motion to energy transformations and the properties of matter. By engaging in hands-on experiments, collaborative projects, and practical problem-solving tasks, students will be encouraged to investigate real-world challenges, thereby developing the skills necessary for lifelong learning and future careers in science and technology.

Ultimately, this learner-centered approach aims to equip students with not only knowledge of physics but also the capacity to tackle complex societal problems with innovative solutions, ensuring they contribute meaningfully to Uganda's socio-economic development.

Senior One

1.1 Introduction to Physics

Learning Outcomes

a) Understand the meaning of physics, its branches and why it is important to study Physics (u,v/a))
b) Understand why it is important to follow the laboratory rules and regulations (u, v/a)

Definition of Physics

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

Basic Laboratory Rules

The laboratory is a facility designed and equipped for conducting scientific research, experiments and measurements.

An average laboratory has electrical energy supply, water and gas piping systems, workbenches and cabinets for storage of equipment and chemicals. Some of the chemicals and equipment are particularly dangerous. An individual working in a typical laboratory will be exposed to a number of dangers including poisons, flammable materials, explosive materials, extreme temperature, moving machinery and high voltage electricity.

The following precautions must, therefore, be taken when working in the laboratory:

(i) Proper dressing must be put on. Shirts and blouses must be tucked in and long hair tied up. Closed shoes must be worn. This is to avoid loose clothing or body parts such as hair getting accidentally tangled up in moving machinery. In addition, safety glasses or face shields must be worn when working with hazardous or poisonous materials. Shorts and sandals must never be worn in the laboratory, and lab coats, if in use should always be buttoned.

(ii) The locations of electricity switches, fire-fighting equipment, First Aid kit, gas supply and water supply systems must be noted. These will be extremely useful in case of any emergency within the laboratory. Access to all these facilities must remain unobstructed, this includes emergency showers and eye washes, where these are available in the laboratory.

(iii) While working in the laboratory, windows and doors should be kept open. This is to prevent inhalation of dangerous materials or gases and also to allow for easy escape/evacuation in case of an emergency. Similarly, corridors or pathways within the laboratory should not be used as working or storage areas.
(iv) Any instructions given must be followed carefully. Never attempt anything while in doubt. In case of any doubt or queries, consult your teacher or the Laboratory assistant. Additionally, if any equipment fails to function, this should be reported immediately to the teacher or the laboratory technician. Never try to fix a problem on your own as this could cause a serious accident or damage to the equipment
(v) Never taste, eat or drink anything in the laboratory. Food should also never be stored in the laboratory. This is to avoid the risk of consuming dangerous or poisonous materials or substances. Related to this, never pipette anything by mouth (a bulb should be used instead). Smelling of gases is also highly discouraged.
(vi) Ensure that all electrical switches, gas and water taps are turned off when not in use. This is to avoid wastage in addition to averting the risk of fire or other hazards.
(vii) When handling electrical apparatus, hands must be dry. Do not splash water where electrical sockets are located. Water to some extent is an electrical conductor and when in contact with exposed power cables, can cause severe electric shock.
(viii) Never plug foreign objects into electrical sockets. Apart from damaging the socket, this can also cause an electric shock.
(ix) Keep floors and working surfaces dry. Any spillage should be wiped off immediately. Liquid on the floor surface can cause skidding, resulting in serious injuries. Some corrosive liquids will damage the floor or working surfaces.
(x) All apparatus must be cleaned and returned to the correct location of storage after use. This facilitates easy re-use of the apparatus, apart from ensuring good order in the laboratory.
(xi) Laboratory equipment should not be taken out of the lab. This is to minimise the risk of damage to the equipment, or even loss.
(xii) Any waste after an experiment must be disposed of appropriately. This is because waste from certain experiments can be quite hazardous to the body and to the environment.
(xiii) Hands must be washed before leaving the laboratory.

Experiments should never be left unattended. Similarly, the Bunsen burner should be adjusted to give a luminous flame, or turned off, when not in use. Never should an open flame be left unattended. This is to minimize the risk of fire or other serious accidents.
Volatile and flammable compounds should only be used in the fume cupboard. The same applies to procedures that should result in hazardous fumes or any inhalable material.
One should never look directly down into the liquid being heated in a test-tube. The tube should also not be pointed towards anyone nearby.
Corrosive chemicals should be kept separately. This is to prevent damage to other laboratory appliances especially the metallic type.

First Aid Measures

Accidents or emergencies are prone to occur any time and it is, therefore, the user's responsibility to be conversant with the safety and fire alarm posters strategically positioned within the laboratory premises. These must be followed strictly during an emergency. The locations of vital emergency equipment such as fire extinguisher must be known and easily accessible to all, and users must be continually reminded of building evacuation procedures.

In case of injuries in the laboratory, the teacher in charge or the laboratory technician must be immediately informed and necessary action taken without delay. Common laboratory injuries include burns, cuts and bruises (sometimes resulting in bleeding), poisoning and foreign matter in the eyes. These cases should be handled in the following way. (Those offering first aid should ensure they are in the first place safe from the danger).

Cuts
These may result from poor handling of glass apparatus or cutting tools like razors and scalpels.
In case the cut results in bleeding, pressure or direct compression should be applied directly to the wound and proper dressing applied as medical assistance is sought.

Burns
Burns may result from naked flames or even splashes of concentrated acids and bases.

Burns should generally be treated by flushing cold water over the affected area. Acid burns could alternatively be treated with sodium hydrogen carbonate (baking soda), and base burns with boric acid or vinegar.

Poisoning

This may result from inhaling poisonous fumes or swallowing of poisonous chemicals or materials. In case this happens, the poisoning agent should be noted while urgent medical assistance is sought. For a poison ingested through the mouth, the recommended antidote should be given to the victim, and vomiting should not be induced unless recommended by a medical practitioner. If the poison is in form of a gas, the first step should be to remove the victim from the area and take him/her to an area with fresher air. If the poison is corrosive to the skin, the victim's clothing should be removed from the affected area, and cold water run over the area for at least 30 minutes. If the poison gets to the eye, the same should be flushed with clean water for at least 15 minutes, and the patient advised not to rub the eyes.

Electric Shock

This may result from touching exposed wires or using faulty electrical appliances.

Without getting in contact with the victim, the first thing to do is to cut off the current causing the shock by:

(i) Turning off the current at the main switch, or,

(ii) Using a non-conducting object, such as wooden rod, to move the victim away from the conductor.

In the meantime, urgently seek medical assistance. If the victim has a pulse but is not breathing, offer mouth to mouth resuscitation as you awaits assistance.

If for some reason a laboratory user faints or loses consciousness, he/she should be promptly and gently moved to an area with fresh air and placed in a recovery position (with the head slightly lower than the rest of the body). If necessary, mouth to mouth resuscitation should be offered.

Matter

Matter is anything that occupies space and has weight

Basic fundamental quantities of physics: These are physical quantities which cannot be obtained from any other physical quantities. On the other hand, there are other quantities obtained by multiplication or division of basic physical quantities. These are called *derived quantities*, for example, area, volume and density.

These are some of the basic fundamental quantities measured in physics, namely and their Units of measurements.

i) Length (metre-m)
ii) Mass (kilogram-kg)
iii) Time(second-s)
iv) Electric current (ampere-A)
v) Amount of substance (mole-mol)
vi) Thermodynamic temperature (Kelvin-K)
vii) Luminous intensity (candela-cd)

1.2 Measurements in Physics

Learning Outcomes

a) Understand how to estimate and measure physical quantities: length, area, volume, mass, and time (u, s, g,s)
b) Explain how they choose the right measuring instrument and units; explain how to use the instruments to ensure accuracy (u,s)
c) Appreciate that the accuracy of measurements may be improved by making several measurements and taking an average value (gs,v/a)
d) Identify potential sources of error in measurement and devise strategies to minimize them (u, s,v/a)
e) Understand the scientific method and explain the steps used in relation to the study of physics(u)
f) Know that practical investigations involve a ‘fair test’, analysis, prediction and justification of results, and observations, and apply learning in practice (k,s)
g) Record data in graphs and charts and look for trends (u,s)
h) Understand and be able to use scientific notation and significant figures (u,s)
i) Understand density and its application to floating and sinking(u)
j) Determine densities of substances and relate them to purity (u, s,gs)
k) Understand the global nature of ocean currents and how they are driven by changes in water density and temperature (u,s)

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 a measure of distance between two points. Breadth, width, height, radius, depth and diameter are all lengths. 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; 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.

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:

i) Engineer's calipers,

ii) 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.

Activity

1. James found that the perimeter of his farming plot was approximately 200 strides. His stride was 0.75m long. What was the perimeter of the plot?
2. Estimate the width of your desk, classroom window and the classroom by counting how using the ruler or any possible measuring instrument in S.I units.
3. Suggest a method you can use to estimate the width of a page of your book.

MEASUREMENT OF AREA OF AN OBJECT

Area is the quantity that expresses the extent of a given surface on a plane. It is a derived quantity of length. The SI unit of area is the square metre, written as m^2. It can also be measured in multiples and sub-multiples of m^2, for example, cm^2 and km^2.

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 of the object.
Name the different objects you know around you and establish their areas.

Importance and Applications of area.

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.

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:

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

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).

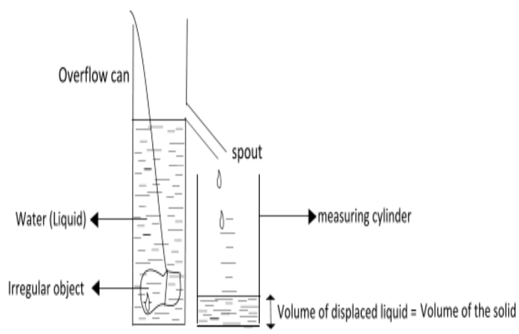
Dosage of liquid medications, blood transfusions, and intravenous fluids are often calculated based on volume.

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

Volume of irregular Shaped Objects

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

Procedure



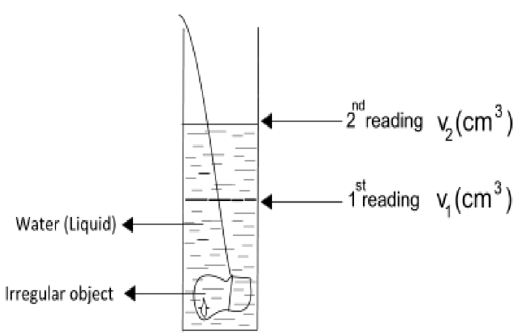
An over flow can is filled with water

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,

V= Volume of 2nd reading - Volume 1st reading

Therefore, $V = V_2 - V_1$

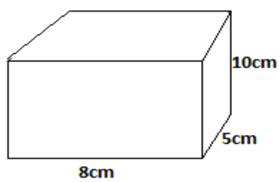
Volume of liquids

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

Activity:

1. Use the rectangular box below to answer questions that follow.

Find the volume;



(i) in cm^3

Volume = L x W x H

V= 8cm x 5cm x 10cm

V= **$400cm^3$**

(ii) In m^3

Volume in m^3

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

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

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

Solution

V=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.

Volume = $\pi r^2 h$

= x 7cm x 7cm x10cm

= **$1540cm^3$**

(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 = 7^2xh

∴ h = 0.078 cm

MASS

*Mass is t*he property of a body that is a measure of its inertia, and that is commonly taken as a measure of the amount of matter 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.

Characteristics of Mass:

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.

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.

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 of mass:

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.
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.
Accurate measurement and control of mass are crucial in designing and manufacturing products, from small electronic components to large structures like buildings and bridges.
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:
Time is often perceived as moving in a linear fashion from the past to the present and into the future.
Time can be measured using various units and instruments, with seconds being the base unit in the International System of Units (SI).
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 of time

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

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

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.

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).

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

Significant figures are the digits in a number that carry meaning contributing to its measurement accuracy. This includes all the non-zero digits, any zeros between them, and any trailing zeros in a decimal number.

Importance in Measurements

Significant figures reflect the precision of a measurement. When recording measurements, the number of significant figures indicates how accurate the measurement is.

The more significant figures in a number, the more precise the measurement is.

Rules for Determining Significant Figures

Non-Zero Digits: Always significant.

Example: 123.45 has five significant figures.

Leading Zeros: Not significant; they only indicate the position of the decimal point.

Example: 0.0032 has two significant figures.

Captive (or trapped) Zeros: Zeros between non-zero digits are significant.

Example: 1002 has four significant figures.

Trailing Zeros:

With a Decimal Point: Significant.

Example: 2.300 has four significant figures.

Without a Decimal Point: Not significant unless explicitly indicated.

Example: 2300 has two significant figures, but if written as 2300. (With a decimal), it has four significant figures.

Significant Figures in Calculations:

Addition and Subtraction:
The result should be reported with the same number of decimal places as the number with the fewest decimal places.
Example: 12.11 + 1.2 = 13.3 (one decimal place, matching the least precise term).

Multiplication and Division: The result should have the same number of significant figures as the number with the fewest significant figures in the calculation.
Example: 2.5 × 3.42 = 8.6 (two significant figures).

Rounding Rules:
When rounding a number to a certain number of significant figures:
Look at the digit immediately after the last significant figure.
If it's 5 or greater, round up the last significant figure.
If it's less than 5, keep the last significant figure as it is.
Exact Numbers:
Numbers that are counted (e.g., 3 apples) or defined quantities (e.g., 1 inch = 2.54 cm) have an infinite number of significant figures and do not limit the precision of calculated results.
Use in Reporting Scientific Data:
In scientific publications and data reports, using the correct number of significant figures ensures that the data is not over-interpreted and reflects the actual precision of the measurement instruments.

Common Mistakes
Overestimating the precision by reporting too many significant figures. Misinterpreting leading or trailing zeros.
Example:
If you measure a length as 0.00456 meters, the significant figures are 456, giving three significant figures. This indicates that the measurement instrument can measure to the nearest ten-thousandth of a meter.
Understanding significant figures is critical in maintaining the integrity of scientific calculations and reporting. It helps in avoiding the illusion of precision where there is none, ensuring the accuracy and reliability of scientific results.
Activity

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:

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.

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.

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:

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

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.

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

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 has a standard density of 1 g/cm^3 at 4°C. This property is often used as a reference point.
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 has a high density of about 19.32 g/cm^3, which is why gold objects feel heavy for their size.
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}.

$$\begin{aligned}\text{Density} &= 1.0gm^{-3}\\ &= 1.0 \times 1000kgm^{-3}\\ &= 1000kgm^{-3}.\end{aligned}$$

1. A piece of steel has a volume of $12cm^3$ and a mass 96g.Find its density.
   (a) In g/cm^3
   (b) Density $8g/cm^3$
   (b) $8g/cm^3$ to kg/m^3
   = 8 x 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.
3. Volume of one water drop = $0.1cm^3$
   Volume of 50 water drops = $0.1x\ 50cm^3$ = $5cm^3$

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 OBJECTS

The mass of the solid is obtained 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, and then substitutes the dimensions into the known formula of determining the volume.

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 obtained using displacement method.

The density is then obtained from, density = $\frac{mass}{volume}$

Density of liquids

i) The volume V of the liquid is measured using a measuring cylinder.
ii) The liquid is poured into the beaker of known mass, M_O.
iii) The mass M of the beaker containing the liquid is obtained using a beam balance.
iv) The density of the liquid will be
v) Density = $\frac{M-M_O}{V}$

Density of Air

i) A round bottomed flask is weighed when full of air and its weighed again after removing air with a vacuum pump.

ii) The difference gives the mass of air.
iii) The volume of air is obtained by putting water in the same flask and measures its volume using a measuring cylinder.
iv) The volume of water will be the volume of air
v) 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

= 10 x10 x (12-10) = 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 x 10 x 12) cm^3

= 1200cm^3

Volume of water displaced

$V= V_2 – V_1$

= (1200 – 1000) cm^3 = 200cm^3

a) Calculate the density of the rock

Density = 3g/cm^3

2. A Perspex box having 6cm square base contains water to a height of 10cm. 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

3. 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

= $V_2 - V_1$

= $468 - 360cm^3$

= $108\ cm^3$

(ii) Calculate the density of the stone.

Density = $1.11\ g/cm^3$

4. A steel box of dimensions 100cm by 20cm by 40cm has a mass of 560g
   Find its density
   (i) In g/cm^3
   (ii) In kg/m^3

Volume = L x W x H

= $(100 \times 40 \times 20)\ cm^3$

= $80,000cm^3$

Density = $0.007g/cm^3$

(i) In kg/m^3

Density = 0.007×1000

Density = $7kg/m^3$

DENSITY OF MIXTURES

Suppose two substances are mixed as follows:

Substance	**Mass**	**Volume**	**Density**
X	M_1	V_1	$d = \frac{m_1}{v_1}$
Y	M_2	V_2	$d = \frac{m_2}{v_2}$

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 = $0.8 \times 100gcm^3 = 80g$

(ii) The mass of liquid

Density x Volume = $1.5 \times 300 = 450g$

Density of a mixture $= \frac{450+80}{300+100} = 1.325gcm^{-3}$

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/cm^3 (or 1000 kg/m^3) at 4°C.

Characteristics of relative density

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

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 substance.

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

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:

a) Helps in identifying materials and verifying their purity. For example, the relative density of pure gold is about 19.3.
b) Used in industries like mining, oil, and chemicals to assess material properties.
c) Determines whether an object will float or sink in a fluid. An object with an RD less than 1 will float in water.
d) Used in quality control processes to ensure consistency and standards in manufacturing.

Examples:

a) The relative density of water is 1, as it is the reference substance.
b) Ethanol has a relative density of about 0.79, meaning it is less dense than water and will float on it.

c) 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
Suppose you have a liquid with a density of 850 kg/m³. To find its relative density, compare it with to water:
This means the liquid has a relative density of 0.85 and is less dense than water.

Importance of R.D in Different Fields:

a) Used to determine the concentration of solutions and the purity of substances.
b) Helps in studying the stratification of lakes and oceans where water density varies with temperature and salinity.
c) Essential in designing systems involving fluid flow, such as pipelines and hydraulics.

Ocean Currents and Water Density
Ocean currents are a critical component of Earth's climate system, influenced by various factors, including changes in water density. Ocean currents are large-scale movements of water within the oceans, driven by various forces such as wind, Earth's rotation (Coriolis Effect), temperature gradients, salinity differences, and tides.
Density-Driven Currents (Thermohaline Circulation):

Ocean water density is primarily influenced by temperature and salinity:
Temperature: Colder water is denser than warmer water.
Salinity: Water with higher salinity is denser than water with lower salinity.
Thermohaline circulation, also known as the "global conveyor belt," is a density-driven ocean circulation system. It plays a key role in distributing heat and regulating climate across the globe.
Cold, salty water in the Polar Regions sinks due to its higher density, driving deep ocean currents. As this water moves along the ocean floor, it eventually warms and rises, creating a global circulation pattern.

Role of Water Density in Ocean Currents:

In the Polar Regions, where water is cold and salty, the increased density causes the water to sink, initiating deep ocean currents that travel across the globe.

Changes in water density also affect surface currents. For instance, when surface water becomes denser, it can sink, driving vertical currents that impact surface water movement.

Upwelling occurs when deeper, colder, and nutrient-rich water rises to the surface, often driven by wind patterns and changes in water density. Downwelling occurs when surface water sinks due to increased density, often due to cooling or increased salinity.

Impact of Ocean Currents on the Warming of the North Atlantic Due to Climate Change:

Climate Change and the North Atlantic:

The North Atlantic region is particularly sensitive to changes in ocean currents, especially the Atlantic Meridional Overturning Circulation (AMOC), a key component of the global conveyor belt.

AMOC is responsible for transporting warm, salty water from the tropics northward, where it cools, sinks, and returns southward as a deep current.

Warming of the North Atlantic:

Climate change is causing accelerated melting of polar ice, particularly in Greenland. This influx of freshwater into the North Atlantic reduces the salinity of seawater, decreasing its density and potentially disrupting the sinking of water that drives the AMOC.

A reduction in the density of North Atlantic waters can weaken the AMOC, leading to a slowdown in the circulation. A weakened AMOC could reduce the transport of warm water to the North Atlantic, potentially leading to regional cooling in Europe and North America, despite global warming.

Ocean currents play a vital role in distributing heat across the planet. If the AMOC weakens, it could lead to significant changes in weather patterns, sea level rise, and more extreme weather events in the North Atlantic region.

Potential Impacts of a Weakened AMOC:

Paradoxically, while the planet warms, regions like Northern Europe and the eastern United States could experience cooler temperatures if the AMOC weakens and less warm water is transported northward.

A weakened AMOC could lead to a rise in sea levels along the North Atlantic coast due to changes in ocean circulation patterns.

Changes in ocean currents can alter atmospheric circulation, potentially leading to more intense storms and hurricanes in the North Atlantic region.

Changes in ocean currents and temperature can impact marine life, including fish populations and migratory patterns, affecting ecosystems and human activities like fishing.

As polar ice melts, it reduces the reflective surface area, causing more sunlight to be absorbed by the ocean, further increasing temperatures and accelerating ice melt. This feedback loop can further weaken ocean currents by altering water density.

Increased freshwater input from melting ice can further reduce the salinity and density of ocean water, amplifying the weakening of the AMOC and potentially leading to more pronounced climate impacts.

The monitoring of ocean salinity, temperature, and currents is crucial for predicting changes in the AMOC and understanding the potential impacts on the North Atlantic and global climate.

Advanced climate models are used to simulate the impact of changing ocean currents on global and regional climates. These models help predict potential scenarios and inform climate policy and adaptation strategies.

Coastal regions in the North Atlantic may need to implement adaptation strategies to cope with the potential impacts of a weakened AMOC, including sea level rise and changing weather patterns.

Reducing greenhouse gas emissions is critical to slowing the rate of climate change and its impact on ocean currents. Global efforts to limit temperature rise can help mitigate the risks associated with the disruption of ocean circulation patterns.

Ocean currents, driven by changes in water density, are integral to the global climate system. The potential weakening of the AMOC due to climate change could have profound effects on the North Atlantic region, including alterations in temperature, sea level, and weather patterns. Understanding these dynamics is crucial for developing strategies to address and mitigate the impacts of climate change on ocean currents and the broader environment.

1.3 States of matter

Learning Outcomes

a) Understand the meaning of matter(u)b. Understand that atoms are the building blocks from which all matter is made; appreciate that the states of matter have different properties (k,u)
b) Apply the particle theory to explain diffusion and Brownian motion and their applications(s)
c) Understand how the particle theory of matter explains the properties of solids, liquids and gases, changes of state, and diffusion(u)
d) Understand the meaning and importance of plasma in physics (u, v/a)

CHAPTER 3: STRUCTURE OF MATTER

Matter is the substance that constitutes the physical universe, encompassing everything that has mass and occupies space. It forms the basis of all objects, living or non-living, and exists in various states: solid, liquid, gas, and plasma. Composed of tiny particles called atoms and molecules, matter interacts through physical and chemical processes, giving rise to the diverse materials and phenomena we observe in the world around us. Understanding the nature and properties of matter is fundamental to the study of physics and other sciences, as it helps explain the behavior of objects and the forces that govern them.
Matter is anything that occupies space and has weight. It exists in different forms/states of small items called atoms.

STRUCTURE OF MATTER

Matter is fundamentally defined as anything that occupies space and has mass. This definition encompasses all physical substances, from the smallest particles to the largest structures in the universe. Below are the key reasons why this definition holds:

Matter has a physical presence, meaning it takes up space in the universe. Whether it's a solid, liquid, gas, or plasma, matter displaces a volume in space, which is a key characteristic of its existence.

Mass is a measure of the amount of matter in an object. It is an intrinsic property of matter that does not change regardless of the object's location in the universe. Mass gives matter inertia, the resistance to changes in motion, and is directly related to the gravitational force an object experiences.

The Particle Theory of Matter

The particle theory of matter, also known as the kinetic theory of matter, is a scientific theory that explains the properties and behavior of matter in terms of small, discrete particles.

The key principles:

Whether an object is a solid, liquid, or gas, it is composed of tiny particles (atoms, molecules, or ions).

The particles of matter are always moving. The speed of their movement depends on the state of matter:

In solids, particles vibrate in fixed positions.

In liquids, particles move freely but stay close together.

In gases, particles move rapidly and are widely spaced.

The particles attract each other:

There are forces of attraction between particles that vary in strength depending on the state of matter: Strongest in solids, Weaker in liquids., and Weakest in gases.

Energy and temperature affect particle movement: As temperature increases, the particles gain energy and move faster. This energy is known as kinetic energy.

How matter exists in different states and common examples

Matter can exist in several different states, primarily as solids, liquids, gases, and plasma. The state of matter is determined by the arrangement and energy of its particles.

Solids:

In solids, particles are closely packed together in a fixed arrangement. They vibrate but do not move freely. Solids have a definite shape and volume. Solids

have a tightly packed and orderly arrangement of particles called **lattice**. Strong intermolecular forces hold the particles together.
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).
Metals (like iron, copper), minerals (like quartz, diamond), ice, wood, and plastics are common solids, and glass.
Solids find extensive use in construction (building materials), manufacturing (machinery parts), electronics (semiconductor materials), and daily objects (furniture, utensils).

Liquids:
In liquids, particles are close together but can move past each other. They have weaker intermolecular forces compared to solids. Liquids take the shape of their container. They have a fixed volume that remains constant. Liquids flow and can be poured. Liquids can be compressed slightly compared to gases.
Liquids are formed when solids melt or when gases condense. They can also be created through chemical reactions that produce liquid products.
Water, oil, milk, and alcohol are common liquids.
Liquids are crucial in industries such as food and beverage (processing and packaging), pharmaceuticals (drug formulations), automotive (engine lubricants), and cosmetics (lotions, creams).

Gases
Gas particles are widely spaced and move freely. They have weak intermolecular forces and no fixed arrangement. Gases take the shape of their container. They expand to fill the available space. Gases can be compressed significantly under pressure. Gases mix readily with each other. Gases are formed when substances vaporize (evaporate from liquids), sublimate (turn from solids directly into gases), or when gases are released during chemical reactions. Oxygen, nitrogen, hydrogen, and carbon dioxide are common gases.
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).

In liquids, particles are closely packed but not in a fixed position, allowing them to move freely. Liquids take the shape of their container but have a definite volume. Water, oil, milk, and alcohol are the common liquids.

In gases, particles are far apart and move rapidly in all directions. Gases do not have a definite shape or volume and expand to fill their container.
Examples: Oxygen, nitrogen, carbon dioxide, and steam.

Plasma:
Plasma consists of ionized particles positively charged ions and free electrons due to high energy levels. Plasma conducts electricity and responds to magnetic fields. The presence of ions and free electrons distinguishes plasma from gases. Plasma is often at high temperatures. Plasma is formed when gases are heated to extremely high temperatures or subjected to strong electromagnetic fields, causing ionization of particles. Examples: Lightning, auroras, stars (like the sun), and fluorescent lights, neon signs, and plasma TVs are examples of natural and artificial plasmas.
Plasma finds applications in technologies like plasma cutting and welding, fluorescent lighting, plasma TVs, semiconductor manufacturing, and experimental fusion reactors.
Plasma is a state of matter similar to gas but with ionized particles, meaning the electrons are separated from atoms. This creates a mixture of positively charged ions and free electrons. Plasma is electrically conductive and responds to magnetic fields.

The nature of plasma and why it is described as the fourth state of matter

Plasma is often referred to as the fourth state of matter because it has distinct properties that set it apart from solids, liquids, and gases:
Plasma is created when a gas is energized to the point where electrons are stripped away from atoms, resulting in a soup of free electrons and positively charged ions. Unlike gases, plasma is a good conductor of electricity due to the presence of free-moving charged particles. Plasma can be influenced by magnetic fields, which can cause it to move or change shape. Plasma is the most common state of matter in the universe, found in stars, including our Sun, and interstellar space. Plasma has much higher energy levels than the other states of matter, which is why it requires significant energy input (such as heat or electrical discharge) to form.

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.

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.

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).

Particle theory to explain states of matter
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.
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.
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.

Changes of State of Matter: Water and Ice

When water and ice undergo changes in their state of matter due to heating and cooling, they demonstrate the fundamental principles of phase transitions. These processes include melting, boiling, condensing, and freezing. Understanding these transitions, helps explain the energy changes involved, specifically why heat is absorbed or released.

Melting: Ice to Water
Melting occurs when solid ice is heated, causing it to change into liquid water.
Molecular Explanation:
Ice is a solid where water molecules are arranged in a fixed, crystalline structure, held together by strong hydrogen bonds. As heat is added to ice, the energy causes the water molecules to vibrate more vigorously. When the temperature reaches 0°C (32°F), the vibrations are strong enough to break

some of the hydrogen bonds, allowing the molecules to move more freely. This marks the transition from solid to liquid.

Energy Involvement:
Heat Absorption: During melting, ice absorbs heat from the surroundings. This energy is used to break the intermolecular bonds between water molecules, rather than increasing the temperature. This absorbed energy is known as the latent heat of fusion. The temperature of the substance remains constant at 0°C until all the ice has melted, after which the temperature of the liquid water begins to rise.

Boiling: Water to Steam
Boiling occurs when liquid water is heated to its boiling point, turning it into steam (water vapor).
Molecular Explanation:
In liquid water, molecules are close together but can move around each other freely. As heat is added, the molecules move faster, increasing the kinetic energy of the water. When the temperature reaches 100°C (212°F) at standard atmospheric pressure, the energy is sufficient to overcome the intermolecular forces completely, allowing the molecules to escape into the air as steam.

Energy Involvement:
Heat Absorption: During boiling, water absorbs a significant amount of heat, which is used to break the bonds that hold the molecules in the liquid state. This energy is known as the latent heat of vaporization. Like melting, the temperature remains constant at 100°C during the phase change until all the water has boiled off.

Condensation: Steam to Water
Condensation is the reverse of boiling, where steam (water vapor) cools down and changes back into liquid water.
Molecular Explanation:
As steam cools, the kinetic energy of the water molecules decreases. At a certain point, the molecules slow down enough that the intermolecular forces can pull them back together, forming liquid water. This occurs at the condensation point, which is the same temperature as the boiling point (100°C under standard conditions).

Energy Involvement:

During condensation, steam releases the latent heat of vaporization to the surroundings. This released energy is the same amount that was absorbed during boiling. The temperature remains constant during condensation until all the steam has converted back into liquid water.

Freezing: Water to Ice
Freezing occurs when liquid water is cooled and changes into solid ice.
Molecular Explanation:
As liquid water-cools, the molecules lose kinetic energy and move more slowly. At 0°C, the water molecules begin to arrange themselves into a crystalline structure, forming ice. The hydrogen bonds that were partially broken during melting are reformed, holding the molecules in a fixed position.

Energy Involvement:
During freezing, water releases the latent heat of fusion, the same energy that was absorbed during melting. This energy is released into the surroundings as the water molecules settle into the solid structure. The temperature remains constant at 0°C during the phase change until all the water has frozen.

Why heat is taken in and given out during phase changes

Melting and Boiling (*Heat Absorption*):
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. When a substance melts or boils, energy is required to break the intermolecular bonds that hold the particles in a solid or liquid state. This energy does not increase the temperature but is instead used to change the state of the substance. This is why heat is absorbed during melting and boiling.

Condensing and Freezing (*Heat Release*):
When a substance condenses or freezes, the intermolecular bonds are reformed. The energy that was absorbed during melting or boiling is now released back into the surroundings. This release of energy explains why heat is given out during condensation and freezing.

Importance of Changes of State in Everyday Life

Changes of state such as melting, freezing, condensation, and evaporation—are essential in many everyday processes. They play crucial roles in maintaining life, influencing weather patterns, and supporting various practical activities.

Control of Body Temperature in Mammals

Sweating and Evaporation:

Mammals, including humans, rely on the evaporation of sweat to regulate body temperature. When the body overheats, sweat glands produce sweat, which is mostly water. As the sweat evaporates from the skin's surface, it absorbs heat from the body, cooling it down. This process is crucial for maintaining a stable internal temperature, especially in hot environments or during physical exertion.

Breathing and Heat Exchange:

Mammals also lose heat through the process of respiration. When air is exhaled, it often carries moisture from the lungs. The evaporation of this moisture helps cool the body. The balance between heat production (through metabolism) and heat loss (through evaporation and radiation) is vital for homeostasis.

Rain and the Water Cycle

Evaporation: The water cycle is driven by changes in the state of water. The sun's heat causes water from oceans, lakes, and rivers to evaporate, turning it into water vapor (gas) that rises into the atmosphere.

Condensation: As the water vapor rises and cools, it condenses into tiny droplets, forming clouds. This change of state from gas to liquid is crucial in cloud formation.

Precipitation: When the droplets in clouds combine and grow large enough, they fall to the Earth as precipitation (rain, snow, sleet, or hail). This process returns water to the surface, replenishing water bodies and supporting life on land.

Freezing and Melting in the Water Cycle:

In colder regions, precipitation can fall as snow or ice. This frozen water eventually melts during warmer periods, feeding rivers and lakes, contributing to the continuous cycle of water.

Cooling Drinks with Ice

Melting Ice: Adding ice to a drink cools it down through the process of melting. As the ice absorbs heat from the drink, it changes from a solid to a liquid, lowering the temperature of the drink. The melting process requires energy, known as the latent heat of fusion, which is absorbed from the drink, thus cooling it effectively.

Practical importance:

This is a practical application of phase change that people use daily, especially in warm weather, to keep beverages at a refreshing temperature.

Making Ice Cream

Freezing: The process of making ice cream involves freezing a mixture of cream, sugar, and flavorings. As the liquid mixture cools, it undergoes a phase change from liquid to solid. To achieve the right texture, ice cream is churned during freezing to prevent the formation of large ice crystals. This results in a smooth, creamy consistency.

Use of Salt in Ice Cream Making: Often, salt is added to ice surrounding the ice cream mixture to lower the freezing point of water. This allows the ice cream mixture to freeze at a lower temperature, speeding up the process and improving texture.

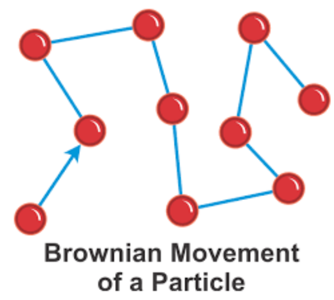
Importance: Understanding the freezing process is crucial in producing ice cream with the desired consistency and flavor, making it a popular treat worldwide.

Brownian motion

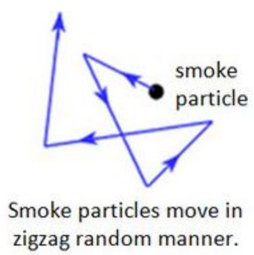
Brownian motion is the random movement of particles suspended in a fluid (liquid or gas) as they collide with the fast-moving molecules of the fluid. **"Brownian motion refers to the random movement displayed by small particles that are suspended in fluids. It is commonly referred to as Brownian movement"**. This motion is a result of the collisions of the particles with other fast-moving particles in the fluid.

It is a direct observation of the kinetic theory of matter. Brownian motion is named after the **Scottish Botanist Robert Brown**, who first observed that pollen grains move in random directions when placed in water.

An illustration describing the random movement of fluid particles (caused by the collisions between these particles) is provided below. The random motion is caused by the uneven and continuous bombardment of the suspended particles by the molecules of the surrounding fluid, which are in constant motion. Brownian motion provided evidence for the existence of atoms and molecules and supported the kinetic theory of matter, which posits that matter is made up of small particles in constant motion.



Brownian motion experiment



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.

Brownian motion is fundamental to understanding processes such as diffusion, where particles spread from areas of higher concentration to lower concentration, and is used in various scientific fields to study particle dynamics and fluid behavior.

Causes Brownian motion

The size of the particles is inversely proportional to the speed of the motion, i.e. Small particles exhibit faster movements. This is because the transfer of momentum is inversely proportional to the mass of the particles. Lighter particles obtain greater speeds from collisions. The speed of the Brownian motion is inversely proportional to the viscosity of the fluid. The lower the viscosity of the fluid, the faster the Brownian movement. Viscosity is a quantity that expresses the magnitude of the internal friction in a liquid. It is the measure of the fluid's resistance to flow.

Effects of Brownian motion

Brownian movement causes the particles in a fluid to be in constant motion. This prevents particles from settling down, leading to the stability of colloidal solutions. A true solution can be distinguished from a colloid with the help of this motion. Albert Einstein's paper on Brownian motion was vital evidence on the existence of atoms and molecules. The kinetic theory of gases , which explains the pressure, temperature, and volume of gases, is based on the Brownian motion model of particles.

Diffusion

Diffusion is the process by which particles (such as molecules or ions) spread out from an area of high concentration to an area of low concentration. This movement occurs until the particles are evenly distributed, reaching a state of equilibrium. Diffusion is a fundamental concept in chemistry, physics, and biology, describing how substances move within liquids, gases, and even across cell membranes. Diffusion occurs down a concentration gradient, which means particles move from a region where they are more concentrated to a region where they are less concentrated. The steeper the concentration gradient (the greater the difference in concentration between the two areas), the faster the rate of diffusion.

Particles in liquids and gases are in constant, random motion due to their kinetic energy. This random movement is what drives diffusion, as particles naturally spread out to occupy all available space.

Diffusion continues until there is no net movement of particles, meaning the concentration of particles is the same throughout the space. At this point, dynamic equilibrium is achieved, where particles continue to move, but there is no overall change in concentration.

Diffusion in Gases: When you open a bottle of perfume, the scent molecules diffuse through the air. Initially, the concentration of perfume molecules is high near the bottle, but they gradually spread out and can be smelled throughout the room.

Diffusion in Liquids: If you drop a dye into a glass of water, the dye molecules will diffuse throughout the water until the color is evenly distributed. The dye moves from an area of high concentration (where it was dropped) to areas of lower concentration.

Biological Diffusion: In living organisms, diffusion is crucial for processes such as gas exchange in the lungs, where oxygen diffuses from the alveoli (where its concentration is high) into the blood (where its concentration is low), while carbon dioxide diffuses in the opposite direction.

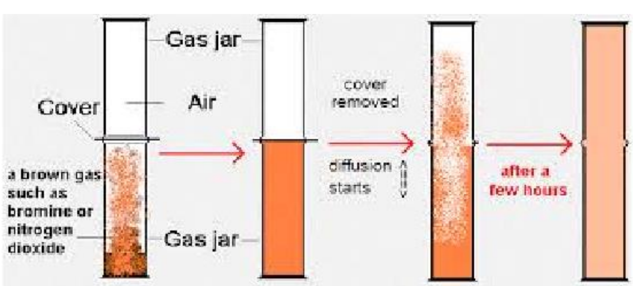
Importance of Diffusion

Diffusion is vital for transporting substances within cells, including nutrients, gases, and waste products. Diffusion helps maintain homeostasis in organisms by ensuring that essential molecules like oxygen and glucose are evenly distributed where needed.

Diffusion is utilized in various industries, such as in the purification of gases, separation processes, and in creating concentration gradients for chemical reactions.

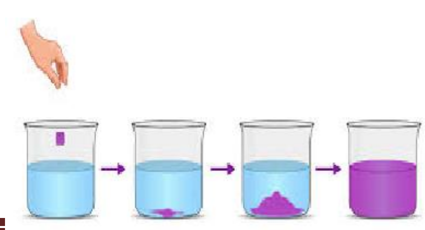
In summary, diffusion is a passive, natural process driven by the random motion of particles, allowing substances to move from areas of high concentration to areas of low concentration until they are evenly distributed. This process is essential in both natural and industrial systems, playing a key role in everything from cellular function to the distribution of scents in a room.

Demonstration of Diffusion in Gases;



Two Gas jars, one full of nitrogen dioxide / bromine and the other gas full of air.
When the gas cover is removed, and the gases mix up, the whole become filled with the brown gas (Nitrogen dioxide). The lighter gas diffuses faster than the heavier gas.

Demonstration of diffusion in liquids:
Half fill a glass beaker with water



Gently and slowly, pour potassium permanganate crystals down the tube.
After some time, the purple colour spreads throughout the beaker. This is due to diffusion of liquid molecules.
The rate of diffusion increases when temperature is increased.

Factors that affect the rate of diffusion in fluids
Diffusion is the process by which particles spread from areas of high concentration to areas of low concentration, occurring in both liquids and gases. The rate of diffusion in fluids is influenced by several factors:
Temperature: Higher temperatures increase the kinetic energy of particles, causing them to move more rapidly. This increased movement accelerates the rate of diffusion. In contrast, at lower temperatures, particles move more slowly, and the rate of diffusion decreases.
Concentration Gradient: The concentration gradient is the difference in concentration between two regions. The greater the concentration difference, the faster the rate of diffusion. Diffusion occurs more rapidly when there is a steep concentration gradient, as particles move quickly to balance concentrations.
Molecular Size: Smaller molecules diffuse faster than larger molecules because they encounter less resistance and can move more easily through the fluid. Larger molecules move more slowly, reducing the rate of diffusion.
Medium of Diffusion: The rate of diffusion is also affected by whether the medium is a liquid or a gas. Gases typically allow faster diffusion due to the greater distance between particles, which leads to fewer collisions.
In liquids, particles are closer together, leading to more frequent collisions and slower diffusion.
Viscosity of the Fluid: Viscosity refers to the "thickness" or resistance to flow in a fluid. Higher viscosity fluids (e.g., honey) slow down the diffusion process because particles move more slowly through the dense medium. Lower viscosity fluids (e.g., water) allow for faster diffusion because particles can move more freely.
Nature of the Diffusing Substance: The chemical nature of the diffusing substance can also impact the rate of diffusion. For instance, substances that are more soluble in the fluid will diffuse faster. Polar substances may diffuse more slowly in non-polar solvents and vice versa.
Surface Area: The rate of diffusion increases with the surface area over which diffusion can occur. Larger surface areas provide more space for particles to move and spread out.

Comparison of Diffusion in Liquids and Gases

Speed of Diffusion:

Gases: Diffusion occurs much faster in gases than in liquids. This is because gas particles are further apart, with more kinetic energy and fewer collisions between particles, allowing them to spread quickly.

Liquids: In liquids, particles are closer together and move more slowly due to intermolecular forces, leading to slower diffusion rates.

Molecular Interaction:

Gases: In gases, the interaction between molecules is minimal because the particles are far apart, leading to a less frequent but faster spread of particles.

Liquids: In liquids, molecules interact more frequently due to closer proximity, which hinders the free movement of particles and slows down diffusion.

Density and Medium Resistance:

Gases: The lower density of gases means there is less resistance to the movement of particles, which facilitates faster diffusion.

Liquids: The higher density and viscosity of liquids create more resistance, slowing down the diffusion process.

Linking diffusion to biological processes: Transpiration and Osmosis

Transpiration:

Transpiration is the process by which water vapor diffuses from plant leaves into the atmosphere through stomata.

The rate of transpiration depends on factors similar to diffusion, such as temperature, humidity, and the concentration gradient between the inside of the leaf and the surrounding air.

In this process, water molecules move from areas of high concentration inside the leaf (where water is abundant) to low concentration outside the leaf (in the air), driven by diffusion.

Osmosis:

Osmosis is a special type of diffusion involving the movement of water molecules across a semi-permeable membrane from an area of lower solute concentration to an area of higher solute concentration.

In biological systems, osmosis is crucial for maintaining cell turgor pressure, nutrient absorption, and waste removal. For example, in plant roots, water diffuse into root cells via osmosis because the soil has a higher water potential (lower solute concentration) compared to the inside of the root cells (higher solute concentration).

Diffusion is a fundamental process that is faster in gases than in liquids due to differences in particle movement and density. Temperature, concentration gradients, molecular size, viscosity, and the nature of the diffusing substance all influence the rate of diffusion in fluids. In biological systems, diffusion plays a critical role in processes like transpiration in plants and osmosis in both plants and animals, which are vital for maintaining homeostasis and supporting life functions.

1.4 Effects of forces

Learning Outcomes

a) Know that a force is a push or a pull and that the unit of force is the Newton(k)
b) Know the effects of balanced and unbalanced forces on objects (k,s)
c) Understand the existence of the force of gravity and distinguish between mass and weight(u)
d) Appreciate that the weight of a body depends on the size of the force of gravity acting upon it (k, u,v/a)
e) Understand the concept of friction in everyday life contexts(u)f. Understand the meaning of adhesion and cohesion as forms of molecular forces(u)
f) Explain surface tension and capillarity in terms of adhesion and cohesion and their application (u,v/a)

CHAPTER 4: THE EFFECTS OF FORCES

The Meaning of Force

Force is a physical quantity that can cause an object to change its state of motion (speed up, slow down, remain stationary, or change direction) or alter its shape. It is a vector quantity, which means it has both magnitude (strength) and direction.

The unit of force in the International System of Units (SI) is the Newton (N).

One Newton is defined as the force required to accelerate a 1-kilogram mass by 1 meter per second squared (1 N = 1 kgms^{-2}).

Variety of forces and instances where they occur

Several types of forces that we encounter in everyday life

Gravitational Force: The force of attraction between two masses. It keeps planets in orbit around the sun and causes objects to fall to the ground. The Earth's gravity pulling an apple down from a tree.
Gravity is a natural force that pulls objects toward each other. It is one of the four fundamental forces of nature, and it is responsible for the attraction between masses.
Sir Isaac Newton first mathematically described the concept of gravity in his law of universal gravitation, which states that every mass in the universe attracts every other mass with a force that is proportional to the product of their masses and inversely proportional to the square of the distance between their centers:
Importance of gravity*:*
Gravity is what keeps planets in orbit around stars, moons in orbit around planets, and holds galaxies together. On Earth, gravity gives weight to physical objects and causes objects to fall toward the ground when dropped.

Distinguishing between Mass and Weight
Mass is a measure of the amount of matter in an object. It is a scalar quantity, meaning it has magnitude but no direction. The SI unit of mass is the kilogram (kg). Mass is an intrinsic property of an object and does not change regardless of location (whether on Earth, the Moon, or in space). It represents how much "stuff" is in an object, and it is directly proportional to the amount of inertia the object has (resistance to changes in its state of motion).
Weight is the force exerted on an object due to gravity. It is a vector quantity, meaning it has both magnitude and direction (toward the center of the gravitational source). The SI unit of weight is the Newton (N), the same as any other force. Weight is calculated by multiplying the mass of an object by the acceleration due to gravity at a given location: $W = mg$ where: W is the weight of the object, m is the mass of the object, g is the acceleration due to gravity ($g=10\ m/s^2$ on Earth). *Example: An object with a mass of 10 kg has a weight of* $10\ kg \times 10\ m/s^2 = 100\ N$ *on Earth.*

Key Differences
Mass is constant regardless of where an object is located, while weight varies depending on the gravitational field strength (which changes depending on where you are, such as on Earth, the Moon, or in space). Mass is a measure of the amount of matter while weight is the force exerted by gravity on that mass.

Examples to Illustrate Mass and Weight

On Earth*:* A person with a mass of 70 kg will have a weight of $70\,\text{kg}\times10\,\text{m/s}^2=700\text{N}$. This means that the Earth's gravity is pulling the person downward with a force of 700 newtons.

On the Moon*:* The gravitational acceleration on the Moon is about $1.6\,\text{m/s}^2$, which is approximately $\frac{1}{6}$th of Earth's gravity. The same 70 kg person on the Moon would have a weight of $70\,\text{kg}\times1.6\,\text{m/s}^2=112\,\text{N}$. Although the person's mass remains 70 kg, their weight decreases because the Moon's gravitational force is weaker.

Why weight depends on the force of gravity

Gravitational Force Varies:

The gravitational force exerted by a massive body like Earth depends on the mass of the planet and the distance from its center. The stronger the gravitational force (g), the greater the weight of an object. For example, Earth's gravity is stronger than the Moon's because Earth has more mass. As a result, an object will weigh more on Earth than on the Moon, even though its mass remains the same. Since weight is directly proportional to the gravitational force, any change in g results in a corresponding change in weight.

If gravity is stronger (higher g), the weight increases. If gravity is weaker (lower g), the weight decreases. The object weighs less on the Moon because the Moon's gravitational force is weaker.

Outer Space:

In the microgravity environment of outer space, where g is nearly zero, an object's weight would be nearly zero, making it effectively "weightless." However, its mass remains unchanged. This is why objects weigh differently on Earth, the Moon, or other celestial bodies, even though their mass remains constant. The stronger the gravitational force, the greater the weight; the weaker the gravitational force, the lesser the weight.

Frictional Force:

Friction is the force that opposes the relative motion or tendency of such motion of two surfaces in contact. It acts parallel to the surfaces and opposite to the direction of motion.

Types of Friction:

Static Friction: The frictional force that **prevents** two surfaces from sliding past each other. It must be overcome for motion to start.

Kinetic (Sliding) Friction: The frictional force that **opposes** the movement of two surfaces sliding past each other.

Rolling Friction: The frictional force that opposes the rolling of an object over a surface.

Fluid Friction: The frictional force that opposes the movement of an object through a fluid (liquid or gas).

Friction in Everyday Life

Walking and Running: Friction between your shoes and the ground allows you to push off the ground and move forward. Without friction, your feet would slip, making walking or running impossible. On a slippery surface like ice, the friction is reduced, making it difficult to walk without slipping.

Driving and Braking: The friction between a car's tires and the road allows the car to move forward when the wheels rotate. When you press the brake pedal, the brake pads apply friction to the wheels, slowing the car down. On a wet or icy road, friction is reduced, which can cause the tires to skid, making it harder to control the vehicle.

Holding Objects: When you grasp an object, friction between your fingers and the object helps you hold onto it. The rougher the surface, the more friction, making it easier to grip. It is easier to hold a dry, rough object like a piece of wood than a wet, smooth object like a glass bottle.

Writing and Drawing: Friction between the tip of a pen or pencil and the paper allows you to write or draw. The friction causes the writing material (ink or graphite) to leave a mark on the paper. Writing on a smooth, glossy surface like glass is difficult because of the lack of friction.

Heating by Friction: When two surfaces rub against each other, the friction between them can convert kinetic energy into heat. This is why rubbing your hands together quickly can make them warm. In some traditional methods of starting a fire, sticks are rubbed together to create heat by friction, eventually igniting dry leaves or tinder.

Sports and Athletics: In many sports, friction plays a crucial role. For example, the grip of athletes' shoes on the track or field affects their performance. The design of sports equipment like balls and bats also considers friction. Soccer players wear cleats with spikes to increase friction between their shoes and the grass, improving their grip and preventing slipping.

Furniture and Appliances: Moving heavy furniture across a floor involves friction. Sliding friction occurs when you push the furniture, making it difficult to move. Rollers or casters reduce friction, making it easier to move heavy objects. Placing furniture sliders under heavy items like sofas reduces friction, allowing you to push or pull them with less effort.

Factors affecting Friction

Surface Texture: Rougher surfaces have higher friction because they have more microscopic bumps and irregularities that catch on each other. Sandpaper has more friction than smooth paper because of its rough texture.

Normal Force: The greater the force pressing two surfaces together, the higher the friction. This is why heavier objects experience more friction. Pushing a heavy box across the floor is harder than pushing a lighter one because the heavier box presses down more, increasing friction.

Surface Area: While surface area does not directly affect friction in most cases (since friction is generally independent of the contact area), it can play a role in certain situations, such as when dealing with pressure-sensitive surfaces. Wide tires on a car can increase friction slightly, improving grip on certain terrains.

Materials in Contact: Different materials have different coefficients of friction. For instance, rubber on asphalt has high friction, while ice on metal has low friction. Car tires are made of rubber, which provides good friction on asphalt, while skates are designed to minimize friction on ice.

Reducing and Increasing Friction

Lubrication: Applying a lubricant like oil or grease between two surfaces reduces friction by creating a thin layer that separates the surfaces, allowing them to slide more easily. Oil in a car engine reduces friction between moving parts, preventing wear and tear.

Friction as a Nuisance: Friction causes wear and tear on machine parts, leading to maintenance issues. It reduces efficiency by converting useful kinetic energy into unwanted heat.

Tension Force: The force transmitted through a string, rope, cable, or wire when forces acting from opposite ends pull it tight. The force in a rope holding a hanging object like a chandelier.

Normal Force: The support force exerted upon an object that is in contact with another stable object, example a book resting on a table experiences a normal force from the table that balances its weight.
Applied Force: A force that is applied to an object by a person or another object, like in pushing a door open or pulling a cart.
Air Resistance Force: A type of frictional force that acts against an object as it moves through the air like in a parachute slowing down a skydiver's descent.
Magnetic Force: The force of attraction or repulsion that arises between electrically charged particles because of their motion. It is related to the magnetic fields generated by magnets. Example A magnet sticking to a refrigerator door.
Electrostatic Force: The force between charged particles. Like charges repel, while opposite charges attract. Example a balloon sticking to a wall after being rubbed on hair.

Categorizing Forces:
Contact and Non-Contact Forces
Contact Forces: These forces occur when two objects are physically touching each other. Examples Frictional Force: When you slide a book across a table.
Tension Force: A rope pulling a car.
Normal Force: Chairs pushing up against your body as you sit.
Applied Force: Pushing a shopping cart.

Non-Contact Forces: These forces that occur even when the objects are not physically touching. Examples gravitational Force: The Earth's gravity pulling objects toward its center.
Magnetic Force: A magnet attracting a metal object from a distance.
Electrostatic Force: A charged balloon attracting small pieces of paper without touching them.

Demonstrating the Effects of Forces on Objects
Forces can affect objects in several ways:
Change in Speed: A force can cause an object to accelerate (increase speed), decelerate (decrease speed), or come to a stop. Example applying the brakes to a moving car reduces its speed due to friction.
Change in Direction: A force can change the direction in which an object is moving. Example a soccer player kicking a ball causes it to change direction.
Change in Shape: A force can deform an object, temporarily or permanently. Example squeezing a rubber ball changes its shape, and stretching a rubber band elongates it.

Start or Stop Motion: A force can set an object in motion from rest or bring a moving object to a halt. Example pushing a stationary box causes it to start moving, while friction can stop it from moving.

Examples of the Effects of Forces

Change of Movement:

Acceleration: Pressing the gas pedal in a car increases the speed of the car.

Deceleration: Applying brakes on a bicycle slows it down.

Change of Shape:

Compression: Squeezing a sponge compresses it, reducing its volume.

Tension: Stretching a rubber band increases its length.

Stopping an Object:

Frictional Force: A sliding book eventually stops due to the frictional force between the book and the table surface.

Air Resistance: air resistance slows down a falling object like a feather.

Molecular Behavior of Adhesion and Cohesion

Cohesion: *Cohesion is the attractive force between molecules of the same substance.* It is the force that holds molecules together within a material, like water molecules sticking to each other.

Molecular Behavior: Cohesion occurs because of intermolecular forces, such as hydrogen bonding, Van der Waals forces, or dipole-dipole interactions. In water, for instance, hydrogen bonds between the slightly positive hydrogen atoms of one water molecule and the slightly negative oxygen atoms of another water molecule create strong cohesive forces.

Adhesion: *Adhesion is the attractive force between molecules of different substances*. It is the force that causes one substance to stick to another, such as water molecules sticking to a glass surface.

Molecular Behavior: Adhesion occurs due to similar intermolecular forces as cohesion, but they act between different substances. For example, the polar nature of water allows it to form hydrogen bonds with the molecules of other polar substances, such as glass, which leads to adhesion.

Molecular Mechanisms behind Cohesion and Adhesion

Cohesion in Water: Water molecules are polar, with a partial negative charge on the oxygen atom and partial positive charges on the hydrogen atoms. These polar charges allow water molecules to form hydrogen bonds with each other, leading to strong cohesive forces. This cohesion is responsible for phenomena like surface tension, where the surface of water resists external force because the water molecules are strongly attracted to each other.

Adhesion of Water to other surfaces: When water meets a different material, such as glass, the polar water molecules can form hydrogen bonds with the polar molecules of the glass surface. This interaction creates adhesion, which can be observed when water spreads out on a glass surface rather than forming droplets.

Practical implications of Cohesion and Adhesion

Capillary Action: Capillary action is the ability of a liquid to flow in narrow spaces without the assistance of external forces (like gravity). It occurs due to the combination of cohesive and adhesive forces.

Molecular Behavior: Adhesion causes the liquid to cling to the walls of a narrow tube or pore, while cohesion pulls other liquid molecules along, leading to the upward movement of the liquid.

Examples:

Plants: Capillary action helps transport water from the roots to the leaves in plants through thin tubes called xylem.

Paper Towels: When you dip a paper towel in water, the water moves upward against gravity due to capillary action.

Wetting: Wetting occurs when a liquid spreads out over a solid surface, which is a balance between cohesion (which resists spreading) and adhesion (which promotes spreading).

Molecular Behavior: If the adhesive forces between the liquid and the surface are stronger than the cohesive forces within the liquid, the liquid will spread out (wetting the surface). If cohesive forces are stronger, the liquid will bead up.

Water on Glass: Water wets glass surfaces because the adhesive forces between water and glass are stronger than the cohesive forces within the water.

Waterproof Materials: On surfaces coated with hydrophobic (water-repellent) materials, water beads up instead of spreading out due to weak adhesion and strong cohesion.

Meniscus Formation: The meniscus is the curve seen at the surface of a liquid in response to its container.

Molecular Behavior: The shape of the meniscus depends on the balance between cohesion and adhesion. If adhesion is stronger (as with water in glass), the liquid will curve upwards (concave meniscus). If cohesion is stronger (as with mercury in glass), the liquid will curve downwards (convex meniscus).

Water in a Glass Tube: Water forms a concave meniscus in a glass tube because it adheres strongly to the glass.

Mercury in a Glass Thermometer: Mercury forms a convex meniscus because it has stronger cohesive forces than adhesive forces with the glass.

Applications and Implications

In Biology:
Plant Transport: Adhesion and cohesion are vital for the movement of water and nutrients in plants.
Cell Membranes: Adhesion and cohesion play roles in the behavior of water and other substances at cellular surfaces.
Paints and Coatings: The effectiveness of paints and coatings depends on adhesion to surfaces, which is why surface preparation is crucial.
Adhesives: Glues and tapes rely on strong adhesive forces to stick to surfaces and cohesive forces to stay intact.

In Technology:
Microfluidics: The design of devices that manipulate small amounts of liquids relies heavily on controlling adhesion and cohesion at small scales.
Printing Technologies: Ink adhesion to paper or other materials is crucial for clear and lasting prints.

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.* Surface tension is the result of the cohesive forces between liquid molecules at the surface. It causes the surface of a liquid to behave like a stretched elastic membrane.
Molecular Behavior: At the surface of a liquid, molecules experience a net inward force because they are only attracted to other molecules beside and below them. This creates a tension on the surface.
Water Droplets: Surface tension allows water to form droplets on surfaces.
Floating Objects: Small objects, like a paper clip, can float on the surface of water if they do not break the surface tension.

Other effects of surface tension

Because of surface tension,

Steel needle when carefully placed on top of water floats, despite its greater density.

Some birds and insects can walk on the surface of water.

Some drops of water from the tap are in form of a spherical shape.

Soap film inside the cotton loop when broken makes or forms a circle.

Explanation on surface tension (emphasise meaning):

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.
3. Addition of impurities.
4. Piercing the surface of the liquid with sharp objects.

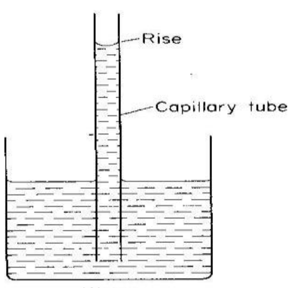
Experiment to demonstrate surface tension

Some water is poured in a clean trough.

It is left to settle and a filter paper (blotting paper) is placed on the water surface.

A pin is carefully placed on top of the filter paper as shown in the figure.

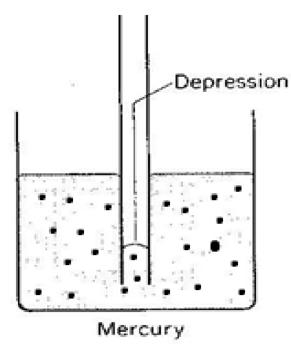
After sometime, the filter paper will absorb water and sink, while the pin will remain floating on the water surface.



CAPILARITY/CAPILARY ACTION:

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

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.

Application of capillarity;

The rising of fuel in a lamp wick/stove
Absorption of water in a towel
The rising of water and mineral salts in plants
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.

1.5 Temperature measurements

Learning Outcomes

a) Understand the difference between heat and temperature(u)
b) Understand how temperature scales are established(u)
c) Calibrate a thermometer and use it to measure temperature (s,u)
d) Compare the qualities of thermometric liquids (u, s,v/a
e) Describe the causes and effects of the daily variations in atmospheric temperature (u,v/a)

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.

There are 3 thermometer scales commonly used.

1) Celsius / centigrade scale(^0C)
2) Fahrenheit (^0F)
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:

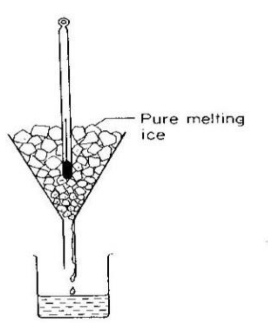
This is the temperature of pure melting ice at standard atmospheric pressure

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;

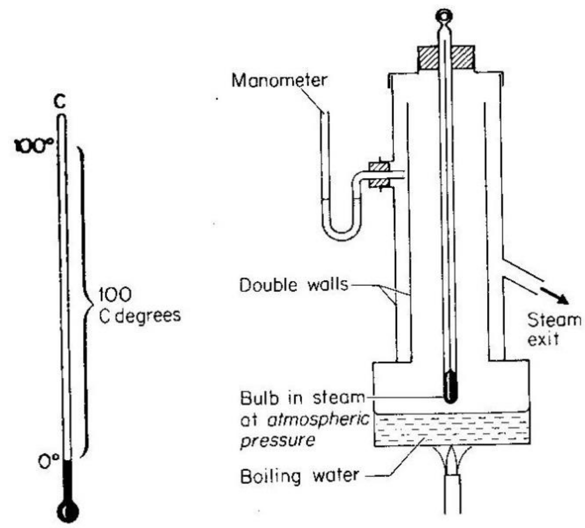
The filter funnel is supported on a retort stand as shown above.

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.

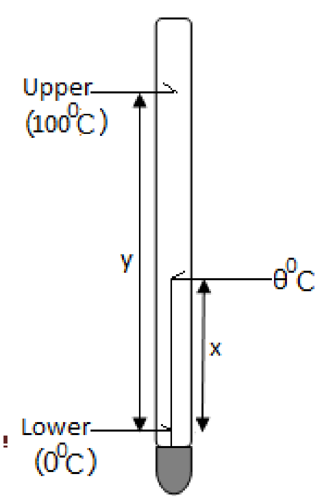
Determination of upper fixed point using a hypsometer

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. Hence, it is said to be calibrated.

Using an uncalibrated 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.



Activity:
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. (Answer: 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 and - 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.

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

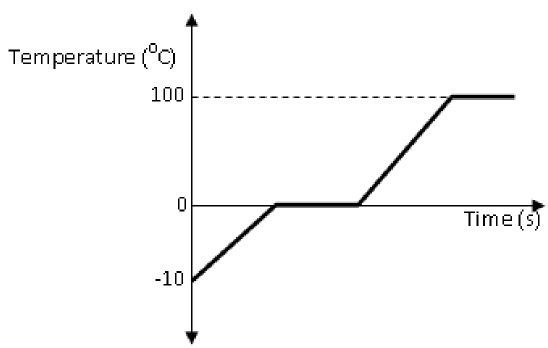
When a solid is heated, the cohesive forces between its molecules are weakened and the molecules begin to vibrate vigorously causing the solid to change into a liquid state

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;

e) Using a thermometer with a big bulb
f) Use of a liquid which has a high linear expansivity
g) Using a narrow bore or reducing the diameter of the bore hole.

1.6 Heat transfer

Learning Outcomes

a) Understand how heat energy is transferred and the rate at which transfer takes place (u,s)
b) Understand what is happening at particle level when conduction, convection, and radiation take place and their application (k, u,v/a)
c) Understand that greenhouse effect and global warming are aspects related to heat transfer on the earth surface (u,v/a)

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

MODES OF HEAT TRANSFER

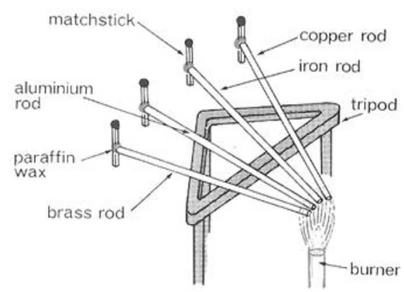
Heat is transferred in three different ways, namely; Conduction, convection and radiation

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. Electrons 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

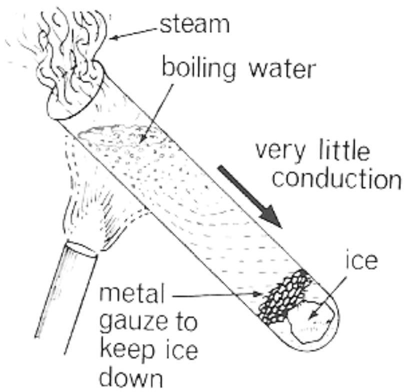
Application of heat conduction

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.

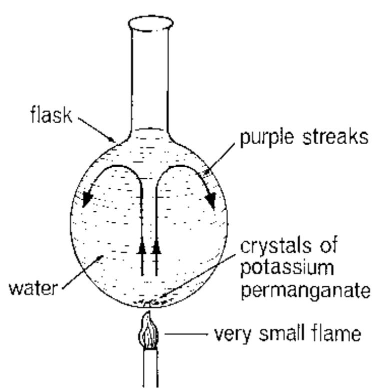
Ice at the bottom remains not melted. This shows that water is poor conductor of heat.

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.

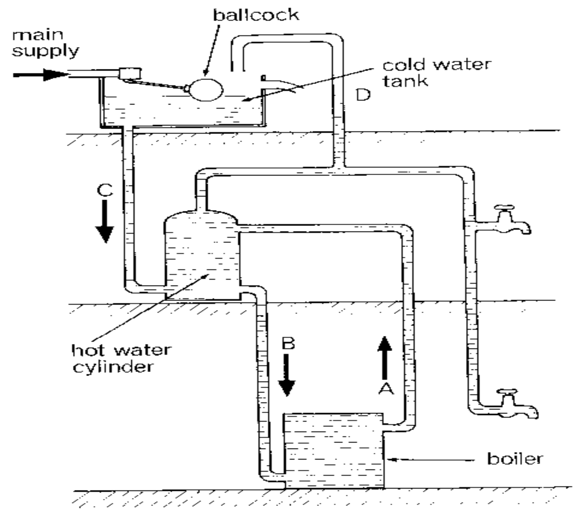
When heat is applied, purple streaks are observed moving upwards in the middle of the flask and down wards at the side of a flask in a circular form. The purple streaks show convection currents.

Explanation of convection currents:

When water at the bottom becomes hot, it expands and becomes less dense.
It is 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*:**

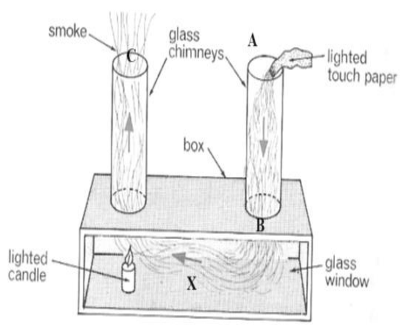
Cold water is supplied to the boiler along the cold water supply pipe. On warming, the cold water in the boiler warms up, *expands* and becomes *less dense*, so it *rises up*.

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, and the cold water downwards.

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.

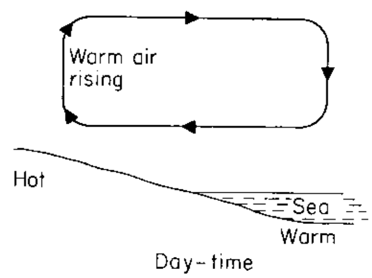
The dense cold air from the paper (smoke) enters X through chimney A to replace the risen air (smoke) causing convection currents.

Application of convection in gases:

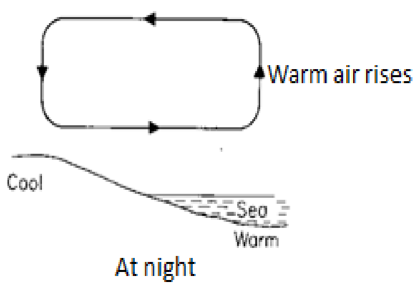
Chimneys in kitchens and factories
Ventilation pipes in VIP latrines
Ventilators in houses
Sea and land breezes

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 *it has 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 seawater (*high specific heat capacity*) 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:

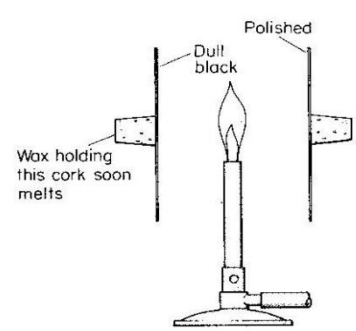
During hot days, rooms get heated up and it is why they are usually provided with ventilators above the floor, through which warm air finds its way out while fresh air enters through the doors and windows. In this way, a circulation of air convection is set up.

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.

The experiment is setup as shown above.

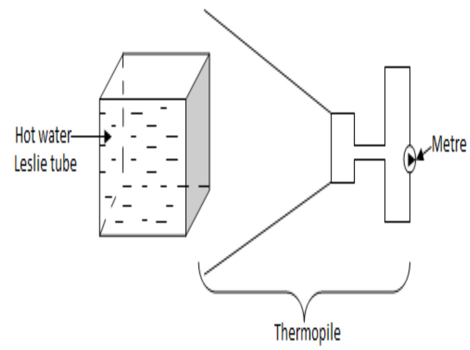
A source of heat is placed midway between a polished and dull surface.

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 is an instrument that converts heat energy into 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 observations are noted:

The greatest deflection at the pointer is obtained when the 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:

Black and dull surfaces

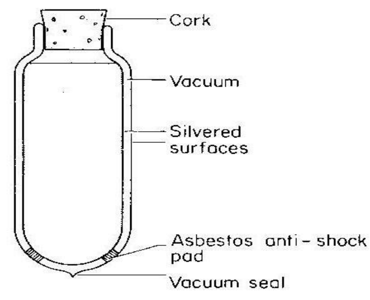
Car radiators are painted black to easily absorb and emit heat

Cooling fins of a refrigerator are black to easily absorb and emit heat

Solar plates or panels are black to easily absorb and emit heat

Polished and white surfaces

White painted buildings keep cool in summer.
Roofs, fuel tanks are made of aluminum and painted to reflect radiant heat.
White coloured clothes are won in summer to keep us cool.
Tea pots, kettles and saucepans are made of aluminium / silvered retain heat for a long time



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
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 clothes

The choice of cloth one puts on depends on conditions of the environment. On hot days, a white cloth is preferable because it reflects most of the heat radiations falling on it
On cold days, a dull black woolen cloth is preferred because it absorbs most of the heat incident on it and can retain for a longer time.

1.7 Expansion of solids, liquids, and gases

Learning Outcomes

f) Understand that substances expand on heating, and recognize some applications of expansion (u,s)

g) Understand the effect and consequences of changes in heat on volume and density of water (u,s)

h) Know about the anomalous expansion of water between 0°C and 4 °C and its implications (u, k,v/a)

Introduction

*When substances are heated, their particles (atoms or molecules) gain kinetic energy and move more rapidly. This increased motion causes the particles to push farther apart from one another, leading to an increase in the substance's volume. This phenomenon is called **thermal expansion**. Thermal expansion occurs because, as temperature raises, the bonds between the particles in solids, liquids, or gases allow for more movement. In solids, this movement is limited, but they still expand slightly. Liquids and gases, having weaker bonds, expand more significantly. The degree of expansion varies based on the material and its state (solid, liquid, or gas).*

For example:

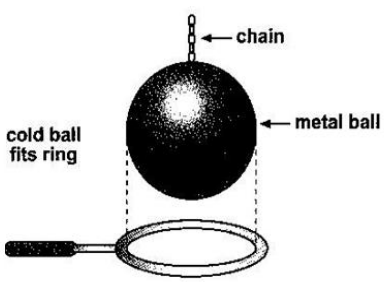
Solids (like metals) expand when heated, but the expansion is usually small.

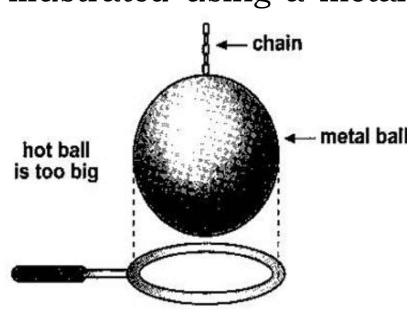
Liquids expand more noticeably than solids. A common example is mercury in a thermometer rising as it heats up.

Gases expand the most because their particles are far apart and free to move.

This is why bridges have expansion joints, and why sealed containers can burst if heated too much, as the gas inside expands.

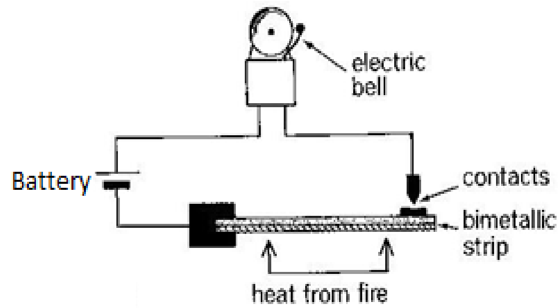
Expansion is an increase in size of a substance. When heated, solids increase in size in all directions. Expansion of solids can be illustrated using a metal ball with a ring.

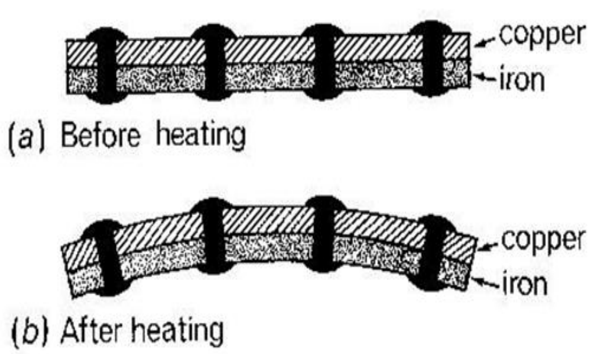




The metal ball passes through the ring when it is cold but when heated, the ball does not pass through the ring any more, showing that it has expanded. It passes through the hole again when it cools, meaning that the metal contracts when it loses heat

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

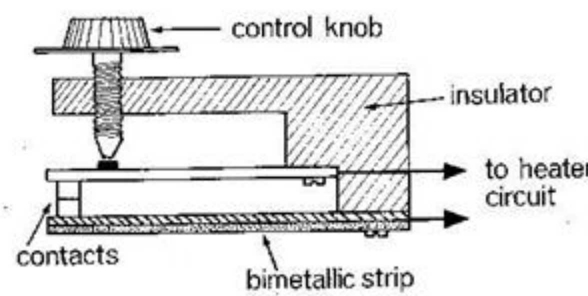




Different metals expand at different rates when equally heated, this can be shown using a metal strip made of two metals such as copper and iron bounded tightly together (bi- metallic strip) when the bi metallic strip is heated, the copper expands more than iron and the strip bends as shown

Uses of a bimetallic strip (application of expansion of solids)

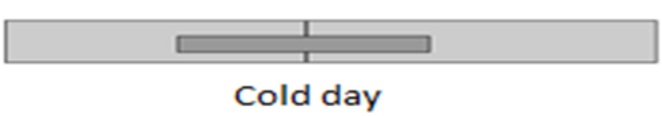
Fire alarm: Heat from the source makes the bi metallic strip bend and completes the electric circuit and the bell rings.



Thermostat: This device makes temperature of appliances or room constant. The thermostat 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.

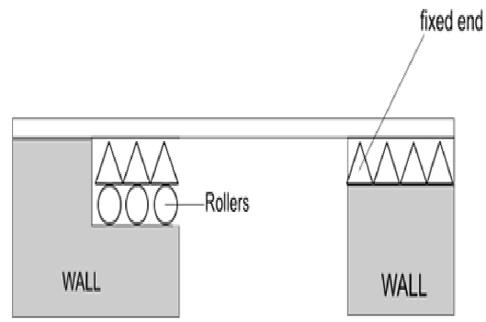
Disadvantages of expansion



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

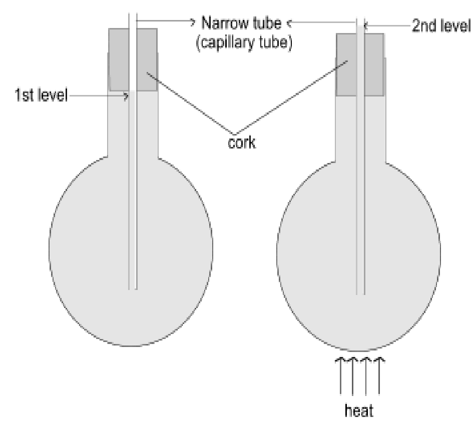
Wires or cables in transmission or telephone cables are normally not pulled tightly during installation in order to allow room for expansion and contraction during extreme weather conditions.

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 expand steadily due to continued heating.

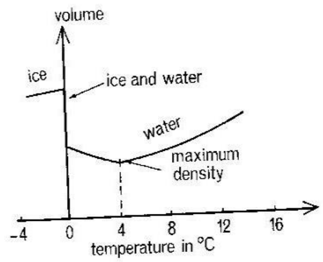
Application of expansion property of liquids

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 $4^0 - 0^0$C, 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

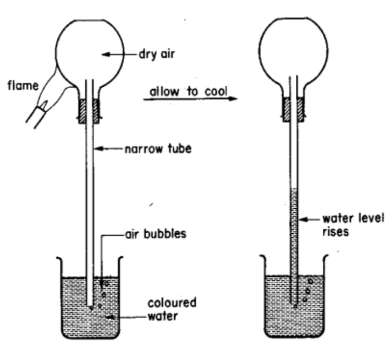
Disadvantages of anomalous behavior of water

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

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.

1.8 Nature of light; reflection of light at plane surfaces

Learning Outcomes

a) Know illuminated and light source objects in everyday life (u,s)
b) Understand how shadows are formed and that eclipses are natural forms of shadows (u)
c) Understand how the reflection of light from plane surfaces occurs and how we can make use of this (k, u, s,gs)

Light is a form of electromagnetic radiation that is visible to the human eye. It plays a crucial role in our daily lives, enabling us to see and perceive the world around us. Light travels in waves and exhibits both particle-like and wave-like properties, a phenomenon known as wave-particle duality. It moves at a constant speed in a vacuum, approximately 299,792 kilometers per second (186,282 miles per second), making it the fastest thing in the universe. Light is essential not only for vision but also for various natural processes, such as photosynthesis in plants, and it is fundamental to many technologies, from medical imaging to telecommunications.
It is a form of energy that travels in waves and can behave both as a wave and as a particle, known as a photon. The visible spectrum of light ranges from about 400 to 700 nanometers in wavelengths, which corresponds to the different colors we see, from violet to red. Beyond the visible spectrum, light also includes ultraviolet, infrared, and other forms of electromagnetic radiation that are not visible to the human eye.
Light is a form of energy that enables us to see
Sources of light:
Light sources can be categorized into natural and artificial types.

NATURAL SOURCES OF LIGHT

The Sun's light is essential for life, driving processes like photosynthesis in plants and regulating the Earth's climate.

Stars: Apart from the Sun, other stars also emit light. Although they are much farther away, they contribute to the light we see in the night sky.

Fire: Fire is a natural source of light produced by combustion, where substances like wood or fossil fuels burn, releasing energy in the form of light and heat.

Bioluminescence: Some organisms, like fireflies, certain types of fungi, and deep-sea creatures, produce their own light through chemical reactions within their bodies. This phenomenon is known as bioluminescence.

Lightning: During a thunderstorm, lightning is a natural electrical discharge that produces a sudden and intense burst of light.

ARTIFICIAL SOURCES OF LIGHT

Incandescent Bulbs: These are traditional light bulbs that produce light by heating a metal filament (usually tungsten) until it glows. However, they are less energy-efficient compared to modern lighting technologies.

Fluorescent Lamps: Fluorescent lamps produce light by passing an electric current through a gas, typically mercury vapor, which emits ultraviolet light. This ultraviolet light then excites a phosphorescent coating on the inside of the bulb, producing visible light.

Light Emitting Diodes (LEDs): LEDs are highly energy-efficient light sources that produce light by passing an electric current through a semiconductor material. They are widely used in various applications, from home lighting to electronic displays.

Compact Fluorescent Lamps (CFLs): CFLs are a more energy-efficient alternative to incandescent bulbs. They operate on a principle similar to that of fluorescent lamps but are designed to fit into standard light fixtures.

Lasers: Lasers produce light that is highly focused and coherent, meaning the light waves are in phase and travel in the same direction. Lasers are used in various applications, including medical devices, communication technology, and cutting tools.

Neon Lights: These are used mainly for signage and decorative purposes. They work by passing an electric current through a gas (such as neon), causing it to emit light.

Both natural and artificial light sources are crucial in various aspects of life, from supporting ecosystems to enabling human activities and technological advancements.

Categories of sources of light

Luminous source of energy

Is that which produces its own light e.g. star, sun, bulb, candle etc.

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.

NATURE OF LIGHT

Wave Nature of Light

Electromagnetic Waves: Light is a type of electromagnetic wave, which means it consists of oscillating electric and magnetic fields that propagate through space. These waves can travel through a vacuum, unlike sound waves, which require a medium.

Wavelength and Frequency: The wave nature of light is characterized by its wavelength (the distance between successive crests of a wave) and frequency (the number of wave crests that pass a given point per second). The color of visible light is determined by its wavelength, with violet light having the shortest wavelength and red light the longest.

Interference and Diffraction: The wave nature of light is evident in phenomena such as interference and diffraction. Interference occurs when two or more light waves overlap and combine, creating patterns of constructive and destructive interference. Diffraction is the bending of light waves around obstacles or through small openings, leading to characteristic patterns.

Polarization: Polarization is another wave-related property, where the orientation of the light wave's oscillations can be restricted to a single plane. Polarized sunglasses, for example, reduce glare by blocking certain orientations of light waves.

Particle Nature of Light

Photons: Light also behaves as though it is made up of particles, called photons. A photon is a discrete packet of energy, with the energy of each photon proportional to the light's frequency. This particle nature of light explains how light can be emitted or absorbed in discrete amounts, a phenomenon that cannot be explained by wave theory alone.

Photoelectric Effect: The particle nature of light was famously demonstrated by Albert Einstein in his explanation of the photoelectric effect. When light shines on a metal surface, it can eject electrons from the surface, but only if the light's frequency is above a certain threshold. This effect showed that light's energy is quantized in photons, with higher-frequency light having higher-energy photons.

Quantum Mechanics: The dual nature of light is a central aspect of quantum mechanics. In this framework, light is understood as having both wave-like and particle-like properties simultaneously, a concept known as wave-particle duality. This duality is not unique to light but applies to all quantum particles.

Speed of Light

Constant Speed: In a vacuum, light travels at a constant speed of approximately 299,792 kilometers per second (186,282 miles per second). This speed is a fundamental constant of nature and is the maximum speed at which information or matter can travel.

Relativity: According to relativity, the speed of light remains constant for all observers, regardless of their motion relative to the light source.

Light as Energy

Electromagnetic Spectrum: Light is just one part of the electromagnetic spectrum, which includes other forms of electromagnetic radiation such as radio waves, microwaves, infrared, ultraviolet, X-rays, and gamma rays. These different types of radiation vary in wavelength and frequency but all share the same basic properties as light.

Energy Transfer: Light transfers energy as it travels, which can be absorbed, reflected, or transmitted by different materials. This energy transfer is responsible for various effects, such as heating objects, driving photosynthesis, and enabling vision.

INTERACTION WITH MATTER

Reflection and Refraction: When light interacts with matter, it can be reflected (bounced back) or refracted (bent). Reflection occurs when light hits a surface and bounces off at the same angle, while refraction occurs when light passes from one medium to another, changing speed and direction.

Absorption and Emission: Light can also be absorbed by matter, transferring its energy to the material. This absorbed energy can later be emitted as light, often at a different wavelength, a process observed in phenomena like fluorescence and phosphorescence.

The nature of light, with its dual wave-particle characteristics, plays a fundamental role in our understanding of the physical universe, influencing everything from the behavior of atoms to the structure of the cosmos.

RAYS AND BEAMS

A ray is an idealized model of light as a straight line that shows the direction of light's propagation. In diagrams, rays are often represented by arrows pointing in the direction the light is traveling.

Properties:

Rays are used to illustrate how light travels, particularly in understanding how light interacts with different media, such as reflecting off surfaces or refracting through lenses.

In reality, light is not a single line but spreads out as a wavefront. However, treating light as rays simplifies the analysis of optical systems, such as lenses, mirrors, and prisms.

The concept of rays is foundational in geometrical optics, where it is used to analyze and predict the paths that light will take through various optical devices. For example, in the study of lenses, rays help determine how an image will be formed by a lens system.

Beams

A beam of light is a collection of rays that are closely aligned and travel together in a single direction.

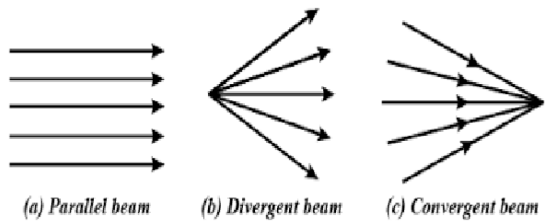
Beams are broader than rays and can spread out over a distance. A laser beam, for example, is a concentrated stream of light rays that stay together over long distances.

Types of Beams:

Parallel Beam: A beam in which all rays are parallel to each other. This is typical of light emitted by lasers or light that has passed through a collimating lens. Parallel beams do not converge or diverge, making them ideal for long-distance propagation.

Diverging Beam:A beam in which the rays spread out from a common point, causing the beam to become wider as it travels. An example of this is light from a flashlight or the beams from a spotlight.

Converging Beam: A beam in which the rays come together or converge at a point. This occurs when light passes through a converging lens, such as in a magnifying glass, where the light focuses to a single point.



Applications:

Illumination:

Beams are commonly used in various lighting applications, such as in flashlights, headlights, and stage lighting. The properties of the beam whether it is narrow or broad, focused or diffused determine how it illuminates an area.

Communication: In optical communication, beams of light, such as laser beams, are used to transmit information over long distances, as they can be directed with high precision and remain coherent over great distances.

Medical and Industrial Use: Beams of light are also used in medical procedures, such as in laser surgery, where a focused beam of light is used to make precise incisions, and in industrial processes, like cutting or welding materials.

Comparison

Directionality: Rays represent the direction of light at a very fine scale, essentially a single path, while beams represent a collection of these paths that travel together.

Focus: A ray is a more theoretical concept used for analyzing light paths in detail, while beams are practical entities that describe real-world light propagation, especially in devices where light needs to be directed, focused, or spread out.

Use in Optics: Both concepts are essential in optics, with rays being crucial for understanding the principles of reflection, refraction, and image formation, and beams being important for practical applications like illumination, communication, and precision cutting.

RECTLINEAR PROPAGATION OF LIGHT

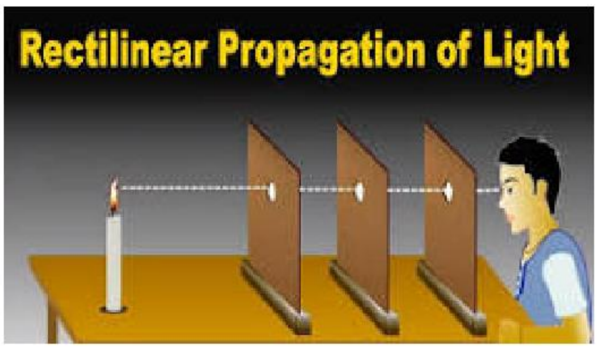
This is the phenomenon where by light travels in a straight line.

The word **rectilinear** literally means "**straight**" in geometry and *the rectilinear propagation of light means that light travels from the source in a straight line.*

Due to this property, *light does not bend due to which we are unable to look around the corner of objects where the light ray falls upon*.

There are two notable phenomenon's related to the rectilinear propagation of light- **reflection and refraction**. Reflection can be demonstrated using a mirror and refraction can be explained when a person puts his hand inside a tube of water, *the hand appears bent and smaller*. Let's perform an experiment to understand the rectilinear propagation of light better.

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

The formation of shadows is a common optical phenomenon that occurs when an opaque object blocks the path of light, preventing it from reaching a surface on the other side. Shadows are an integral part of how we perceive light and objects in our environment.

How Shadows Form

Light Source: Shadows require a light source, such as the Sun, a lamp, or a flashlight. The light source emits rays that travel in straight lines until they encounter an object.

Opaque Object: When these rays meet an opaque object (one that does not allow light to pass through), the object blocks some of the light rays. The area behind the object, where the light cannot reach, becomes darker, creating a shadow.

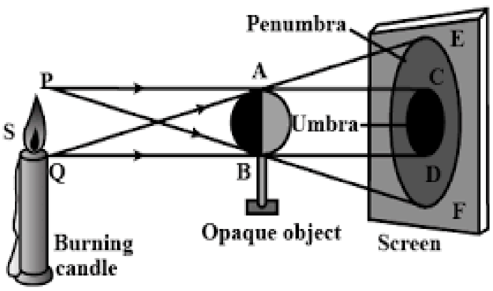
Surface: A shadow is cast onto a surface, such as the ground, a wall, or any other object that can receive light. The surface is where the shadow becomes visible.

Types of Shadows

Shadows can vary in shape, size, and intensity, depending on several factors:

Umbra: The umbra is the darkest part of the shadow, where the light source is completely blocked by the opaque object. In this region, no direct light from the source reaches the surface. The umbra is sharp and well-defined when the light source is small and far away.

Penumbra: Surrounding the umbra is the penumbra, a region where only part of the light source is blocked. In the penumbra, the light is partially obstructed, resulting in a lighter, more diffused shadow. The penumbra occurs because light sources often have a finite size, and some light rays can partially reach the surface around the edges of the object.



Shadow (umbra and penumbra both) due to an extended source of light

Antumbra: In some cases, particularly with large and distant light sources, an antumbra can form. This is a region beyond the umbra and penumbra where the shadow appears lighter because the light from the edges of the light source converges again.

Factors Influencing Shadow Formation

Size of the Light Source:

Point Source: A small or point light source, like a distant star, creates sharp, well-defined shadows because the light rays are almost parallel.

Extended Source: A larger light source, such as the Sun or a lamp, produces softer, more diffused shadows with a noticeable penumbra, as the light rays spread out more and cover different angles.

Distance between the object and the surface:

Close Distance: When the object is close to the surface where the shadow falls, the shadow appears sharp and well-defined.

Far Distance: If the object is farther from the surface, the shadow becomes larger and more diffused, as the light has more space to spread out and partially fill in the shadowed area.

Angle of the Light Source:

Low Angle: When the light source is at a low angle (close to the horizon, such as during sunrise or sunset), shadows are elongated and stretched out.

High Angle: When the light source is directly overhead, shadows are shorter and fall directly beneath the object.

Shape of the Object: The shape of the shadow is influenced by the shape of the object blocking the light. Simple shapes like circles or squares cast shadows that closely resemble their form, while complex objects create intricate shadow patterns.

Examples of Shadow Formation

During a solar eclipse, the Moon passes between the Earth and the Sun, casting a shadow on the Earth. The umbra causes a total eclipse in specific areas, while the penumbra causes a partial eclipse in others. Similarly, a lunar eclipse occurs when the Earth casts its shadow on the Moon. Common objects like trees, buildings, and people cast shadows in everyday life. The changing position of these shadows throughout the day provides information about the time of day and the position of the Sun.

Importance of Shadows

Shadows play a crucial role in how we perceive the depth and shape of objects. They provide visual cues that help us understand the three-dimensional structure of our environment.

Artists and photographers often use shadows to create contrast, mood, and emphasis in their work. The interplay of light and shadow adds depth and texture to images.

Shadows are also important in scientific observations, such as in the study of celestial bodies. For example, the measurement of shadows can help determine the size and distance of planets and moons.

In summary, shadows are formed when an opaque object blocks light from reaching a surface, creating regions of darkness. The characteristics of a shadow, such as its sharpness, size, and intensity, depend on factors like the light source, the distance between the object and the surface, and the shape of the object. Shadows are not only a natural consequence of light but also a powerful tool in visual perception and artistic expression.

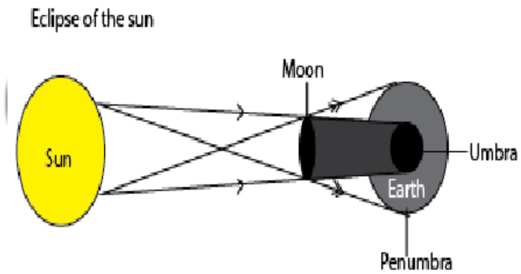
Shadows are formed when light rays are obstructed by an opaque object

ECLIPSES

Eclipses are fascinating astronomical events that occur when one celestial body moves into the shadow of another, blocking or obscuring light. There are two primary types of eclipses visible from Earth: solar eclipses and lunar eclipses. Each type of eclipse is the result of specific alignments between the Sun, Earth, and Moon.

Solar Eclipse

A solar eclipse occurs when the Moon passes between the Earth and the Sun, casting a shadow on the Earth. This alignment blocks the Sun's light from reaching certain areas of the Earth, leading to different types of solar eclipses.



Types of Solar Eclipses

Total Solar Eclipse: Occurs when the Moon completely covers the Sun, as seen from Earth. During a total solar eclipse, the Moon’s umbra (the darkest part of its shadow) touches the Earth's surface.

The sky darkens as if it were twilight, and the Sun’s corona, or outer atmosphere, becomes visible as a halo around the Moon.

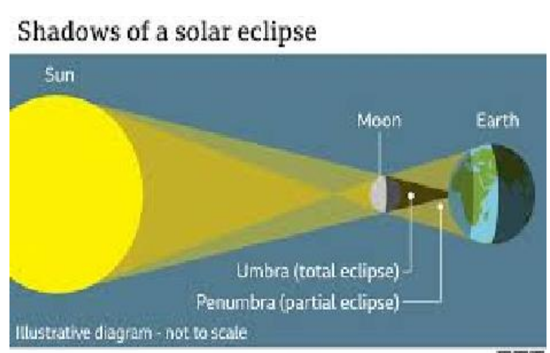
This type of eclipse can only be observed from a narrow path on the Earth’s surface, known as the path of totality.

Partial Solar Eclipse: Occurs when only a part of the Sun is obscured by the Moon. In this case, the Moon’s penumbra (the lighter part of its shadow) falls on the Earth, leading to only a portion of the Sun being covered. A partial solar eclipse is visible over a much larger area than a total eclipse but is less dramatic.

Annular Solar Eclipse: Occurs when the Moon is directly in front of the Sun but is too far from Earth to completely cover it. This results in a ring of sunlight, known as an “annulus” or “ring of fire,” being visible around the dark disk of the Moon. The Moon’s apparent size is smaller than the Sun’s, leading to this distinctive appearance.

Hybrid Solar Eclipse:

A rare type of eclipse that transitions between a total and an annular eclipse along different sections of the path. In some areas, viewers may experience a total eclipse, while in others; they will see an annular eclipse.



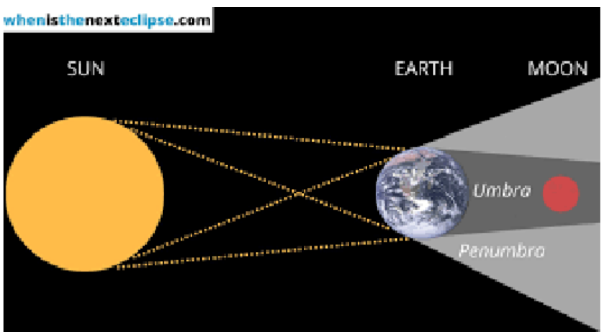
Formation of a Solar Eclipse

A solar eclipse can only occur during a new moon when the Sun, Moon, and Earth are aligned in a straight line, with the Moon between the Sun and Earth.

The Moon's orbit is slightly tilted relative to the Earth's orbit around the Sun. Because of this tilt, solar eclipses don't occur every month. They only happen when the new moon occurs near one of the points where the Moon's orbit crosses the Earth's orbital plane, called **nodes**. The shadow cast by the Moon consists of two parts: the umbra and the penumbra. The umbra causes the total eclipse, while the penumbra causes a partial eclipse.

Lunar Eclipse

A lunar eclipse occurs when the Earth passes between the Sun and the Moon, casting a shadow on the Moon. This alignment prevents sunlight from directly reaching the Moon, causing it to darken and sometimes take on a reddish color.



Types of Lunar Eclipses

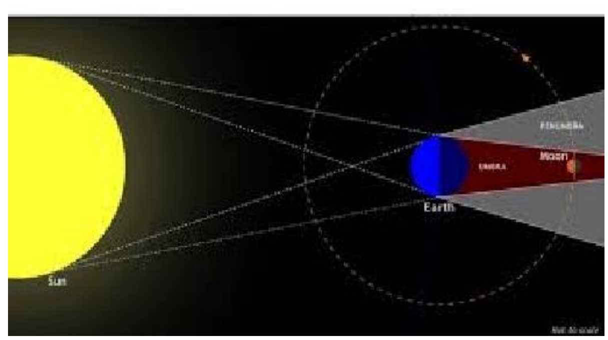
Total Lunar Eclipse: Occurs when the entire Moon passes through the Earth's umbra.During a total lunar eclipse, the Moon can appear red or coppery, a phenomenon known as the "Blood Moon." This reddish color is due to the Earth's atmosphere bending and filtering sunlight, allowing only the red wavelengths to reach the Moon.
Total lunar eclipses are visible from anywhere on the night side of the Earth.

Partial Lunar Eclipse: Occurs when only a portion of the Moon enters the Earth's umbra. This results in a part of the Moon being darkened, while the rest remains illuminated by direct sunlight.

Penumbral Lunar Eclipse: Occurs when the Moon passes through the Earth's penumbra, the outer part of its shadow. A penumbral lunar eclipse is subtle, with the Moon slightly darkening, and is often difficult to observe without careful attention.

Formation of a Lunar Eclipse

A lunar eclipse can only occur during a full moon when the Sun, Earth, and Moon are aligned, with the Earth between the Sun and the Moon.



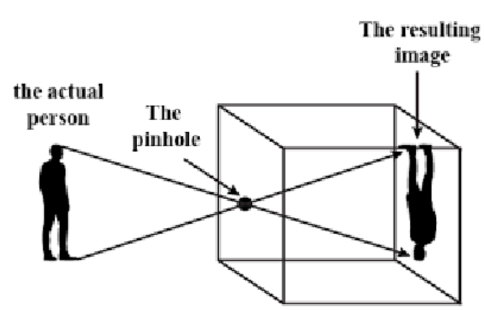
Similar to solar eclipses, lunar eclipses do not occur every month because of the tilt of the Moon's orbit. They happen when the full moon occurs near the nodes of the Moon's orbit.
The Earth's shadow is divided into the umbra and penumbra. When the Moon passes through the umbra, a total or partial lunar eclipse occurs, while passage through the penumbra results in a penumbral eclipse.

Frequency and Observation
Solar Eclipses: Solar eclipses are rarer for any given location on Earth because the path of totality is narrow. On average, a total solar eclipse occurs somewhere on Earth about every 18 months, but it may take several decades for one to be visible from the same location.
Lunar Eclipses: Lunar eclipses are more common than solar eclipses and are visible from anywhere on the night side of Earth. A total lunar eclipse occurs roughly once every 2.5 years from any given location.

Significance of Eclipses
Eclipses have been observed and recorded by various cultures throughout history, often associated with myths, legends, and omens.
Eclipses provide valuable opportunities for scientific study, such as observing the Sun's corona during a total solar eclipse or studying the Earth's atmosphere by analyzing the light filtered during a lunar eclipse.

In summary, eclipses are extraordinary celestial events that occur due to the specific alignment of the Sun, Earth, and Moon. Solar eclipses happen when the Moon blocks the Sun's light from reaching Earth, while lunar eclipses occur when the Earth blocks sunlight from reaching the Moon. The type and appearance of an eclipse depend on the positions and distances of these celestial bodies relative to each other.

THE PINHOLE CAMERA
A pinhole camera is a simple and fascinating optical device that demonstrates the basic principles of image formation. It is an early form of camera that does not use lenses but relies on a tiny aperture, or "pinhole," to project an image onto a surface.



Components of a Pinhole Camera

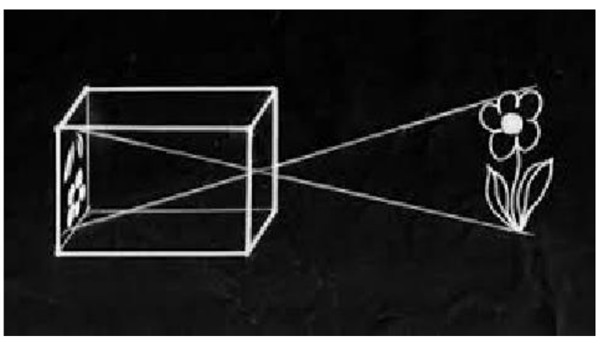
Box or Container: The pinhole camera typically consists of a light-tight box or container. The container can be made from various materials, such as cardboard, metal, or plastic, and must be sealed to prevent light from entering except through the pinhole.

Pinhole Aperture: The pinhole is a small, precisely made hole in one side of the box. It is the only entry point for light. The size of the pinhole affects the clarity and brightness of the image produced. It can be made by puncturing a thin sheet of metal or foil, or using a fine needle to create a tiny hole.

Image Surface: Inside the box, opposite the pinhole, there is a surface where the image is projected. This surface can be a photographic film, a piece of photographic paper, or a screen. The image forms on this surface as light passes through the pinhole and projects onto it.

Lens Cap (Optional): Some pinhole cameras include a lens cap or cover to protect the pinhole from light when not in use, allowing the user to open it only when taking a photograph.

How a Pinhole Camera Works



Light Passage: Light from the scene outside the camera enters through the pinhole. Because the pinhole is small, it allows only a narrow beam of light to pass through, which projects an inverted image of the scene onto the image surface inside the camera.

Image Formation: The light rays from different parts of the scene pass through the pinhole and travel in straight lines to the opposite side of the box. The point where light rays from each part of the scene converge on the image surface forms a reversed and inverted image.

Exposure Time: The exposure time required for a pinhole camera to capture an image depends on the size of the pinhole and the intensity of the light. Since pinhole cameras generally have a small aperture, the exposure time can be relatively long, ranging from several seconds to minutes or even hours.

Characteristics of images produced by Pinhole Cameras

The image formed in a pinhole camera exhibits several distinctive characteristics due to the fundamental principles of optics and light behavior.

Inverted and Reversed Image: The image formed in a pinhole camera is inverted, meaning it appears upside down compared to the actual scene. This occurs because light rays traveling from the top of the scene through the pinhole cross over and hit the bottom part of the image surface, and vice versa. Similarly, the left side of the scene ends up on the right side of the image surface. The image is also reversed left to right. This is a consequence of the straight-line paths of light rays crossing through the pinhole and projecting onto the image surface.

Softness and Blurriness: The image produced by a pinhole camera is generally less sharp compared to images from modern cameras with lenses. This softness results from the diffraction of light waves around the edges of the pinhole. The smaller the pinhole, the greater the diffraction effect, leading to a blurrier image. Due to the diffraction, the edges of objects in the image may appear fuzzy. This effect is more pronounced if the pinhole is not perfectly round or if the image surface is not flat.

Large Depth of Field: One of the notable characteristics of a pinhole camera image is its large depth of field. Objects at varying distances from the camera are all in focus, unlike cameras with lenses that have a limited depth of field and require precise focusing.

Uniform Focus: This is because the pinhole allows light from all parts of the scene to converge onto the image surface, without the need for adjusting focal length.

Image Size and Sharpness: The size of the image is related to the size of the pinhole and the distance between the pinhole and the image surface. A larger pinhole or a longer distance between the pinhole and the image surface will result in a larger image.

There is a trade-off between image sharpness and size. A smaller pinhole produces a sharper image but requires longer exposure times and may reduce the image's brightness. Conversely, a larger pinhole creates a brighter and larger image but with reduced sharpness.

Exposure Time: Due to the small size of the pinhole, pinhole cameras generally require longer exposure times compared to cameras with lenses. The longer exposure is needed to gather enough light to form a visible image on the photographic paper or film.

Distortion: The image may exhibit some distortion, particularly if the image surface is not perfectly flat or if the pinhole is irregular. This distortion can include curvature or stretching, depending on the shape and positioning of the image surface relative to the pinhole.

Light Intensity: The brightness of the image is influenced by the size of the pinhole. A smaller pinhole allows less light to enter, resulting in a dimmer image. To compensate, the exposure time must be increased.

Applications of Pinhole Cameras

Educational Tool: Pinhole cameras are commonly used in educational settings to teach the principles of optics, light, and image formation. They provide a hands-on way to understand how cameras work without the complexity of lenses and electronic components.

Artistic Photography: Many artists and photographers use pinhole cameras to create unique and artistic images. The distinctive softness and characteristic look of pinhole photographs are valued for their aesthetic qualities.

Scientific Experiments: Pinhole cameras can be used in scientific experiments to study light behavior, image formation, and optical properties. They are also used in experiments related to the study of astronomical phenomena.

Historical and Cultural Interest: Pinhole cameras are historically significant as one of the earliest forms of photographic devices. They offer insight into the evolution of photography and the development of optical technology.

Building a Pinhole Camera

Materials: A simple pinhole camera can be constructed from a cardboard box or a tin can, a thin sheet of metal or foil for the pinhole, and photographic paper or film.

Construction: Cut a small hole in one side of the box or can for the pinhole. Attach the pinhole to the hole and seal the box to prevent any light leakage. Place the photographic paper or film on the opposite side of the box.

Exposure: Point the pinhole camera at the desired scene and expose the photographic paper or film for the required amount of time. Develop the image according to the photographic process used.

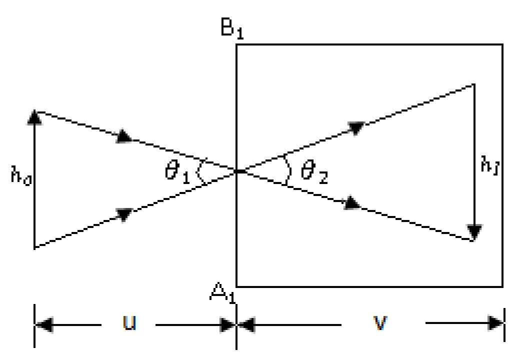
In summary, a pinhole camera is a simple yet powerful tool that demonstrates the fundamental principles of photography and optics. Its basic design, reliance on light, and ability to produce unique images make it a valuable educational and artistic device.

MAGINIFICATION

This is the ratio of image size to object size:

$$m = \frac{v}{u} = \frac{h_1}{h_o}$$

By Proportionality; where V = image distance from pinhole to screen, and U= is the object distance from pinhole to object



Note

Example (Try it out in groups)

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 the magnification of the image and the size of the image. **Solutions** M = 4 and (h=8 cm)

Reflection of light by plane surfaces

Reflection of light is a fundamental optical phenomenon that occurs when light waves encounter a surface and bounce back into the original medium. This process allows us to see objects around us by reflecting light into our eyes. When light reflects off plane surfaces such as mirrors or flat sheets of metal the behavior of the reflected light follows specific principles governed by the laws of reflection.

The Nature of Plane Surfaces

A plane surface is a flat, smooth surface that reflects light in a predictable manner. Unlike curved surfaces, which can distort light, plane surfaces reflect light at a consistent angle, making them ideal for creating clear and accurate images. Common examples of plane surfaces include mirrors, calm water surfaces, and flat glass windows. These surfaces reflect light in a manner that adheres to the fundamental principles of geometric optics.

Laws of Reflection

First Law of Reflection:

The angle of incidence is equal to the angle of reflection.

Explanation: When a light ray strikes a plane surface, the angle at which it approaches the surface (the angle of incidence) is equal to the angle at which it bounces away from the surface (the angle of reflection). These angles are measured with respect to the normal, which is an imaginary line perpendicular to the surface at the point of incidence.

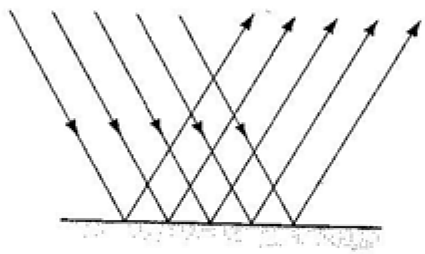
Second Law of Reflection:

The incident ray, the reflected ray, and the normal the point of incidence all lie in the same plane.

Explanation: The path of the incoming and outgoing light rays, along with the normal to the surface, are all contained within the same plane. This ensures that the reflection is predictable and consistent.

Types of Reflection

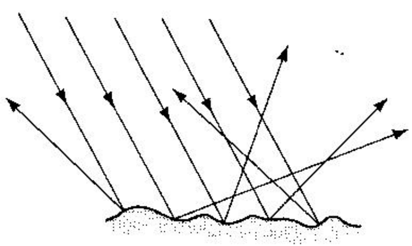
Specular Reflection/Regular reflection:



Regular reflection

Description: This occurs on smooth, shiny surfaces such as mirrors and polished metals. In specular reflection, parallel light rays are reflected parallel to each other, preserving the image's clarity and details. This creates a clear and defined image with minimal distortion.

Diffuse Reflection/Irregular reflection



Diffuse reflection

Description: This occurs on rough or matte surfaces where light rays are scattered in many directions. This type of reflection happens because the surface irregularities cause the incident rays to reflect at various angles. This produces a less clear image, with light being spread out, which helps in illuminating spaces and reduces glare.

Applications of Reflection by Plane Surfaces

Mirrors utilize plane surfaces to reflect light and form clear images. They are used in various applications, including personal grooming, optical instruments, and in telescopes.

Plane mirrors are crucial components in devices like periscopes and microscopes, where precise light reflection is necessary to view objects or phenomena.

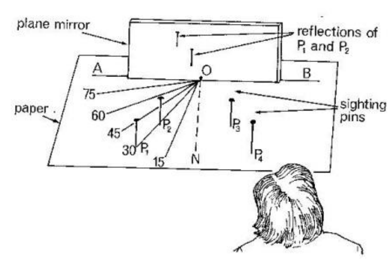
Plane surfaces are used in lighting design to reflect and direct light efficiently, enhancing visibility and reducing shadows.

Reflective surfaces in buildings can be used for aesthetic purposes, creating visually appealing effects and improving natural light distribution.

Application of diffuse reflection

Ability to see many objects at the same time

Ability to read a book

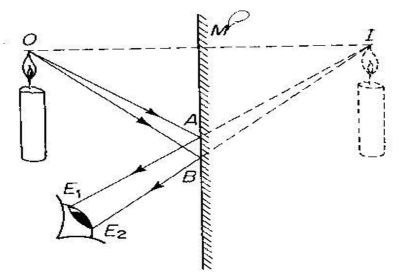


Experiment to verify laws of reflection

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.
Verifying the laws of reflection

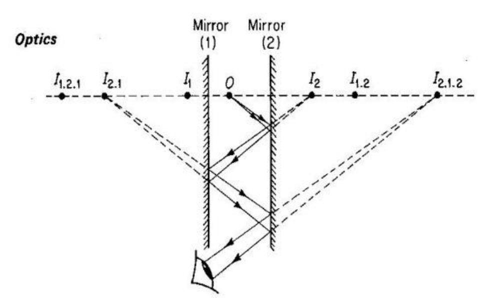
NATURE OF IMAGE FORMED BY A PLANE MIRROR
The image formed is of the same size as the object
The image distance from the mirror is equal to the object distance from the mirror.
The image is laterally inverted.
It is virtual i.e. can't be formed on the screen

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 images are 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



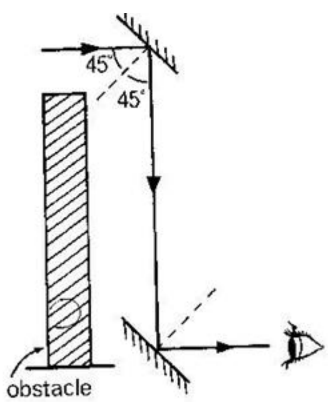
give an image $I_{(1,2)}$ in mirror m_2 just as I_2 gives an image $I_{(2,1)}$ in mirror m_2. $I_{(1,2)}$ in mirror m_2 gives $I_{(1,2,1)}$ after reflection in m_1 while I $_{(2,1,2)}$ after reflecting in Mirror m_2.

Image formed by an inclined mirror at an angle θ

The number of image formed by 2 mirrors inclined at an angleθ, is given by $n = (\frac{360}{\theta} - 1)$,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 = ∞ (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.

Activity:

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.



Periscope

This is the instrument used for looking over or on top obstacles. It is made of 2 plane mirrors inclined at each other at an angle of 45^0. It is mainly used in submarines.

Other uses of plane mirrors include:

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.

Senior Two

2.1 Work, energy, and power

Learning Outcomes

a) Know that the sun is our major source of energy, and the different forms of energy(k)
b) Know that energy can be changed from one form into another and understand the law of conservation of energy (k,u)
c) Understand the positive and negative effects of solar energy(u)

d) Understand the difference between renewable and nonrenewable energy resources with respect to Uganda. (u, v/a)
e) Know and use the relationship between work done, force, and distance moved, and time taken (k,s)
f) Understand that an object may have energy due to its motion or its position and change between kinetic and positional potential energy (u,s)
g) Know the mathematical relationship between positional potential energy and kinetic energy, and use it in calculations (k, u, s,gs)
h) Understand the meaning of machines and explain how simple machines simplify work (u,s)
i) Understand the principles behind the operation of simple machines (u, s, gs)

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.
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=Fdcosθ**, 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. *Energy is the capacity/ability 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 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
A watt is the power developed when one joule of work is done in one second.i.e $1W = 1Js^{-1}$.

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.
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 by reason of its motion e.g. running water, moving bullet etc. S.I unit; *joules*

Kinetic energy is given by, $K.E = \frac{1}{2}mv^2$, where m is the mass of the body, v is the speed or velocity.

Activity

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

KE = 16 J

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

$K.E = \frac{1}{2}mv^2$ = 3000J

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

$K.E = \frac{1}{2}mv^2$ v= 11.2m/s

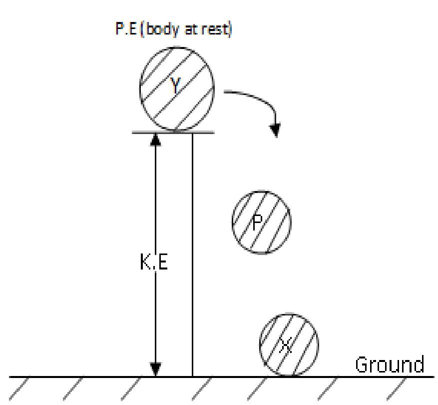
PONTENTIAL ENERGY

This is the energy possessed by a body due to its position in a gravitation field or relative to 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

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 $=\frac{1}{2}mv^2$, 2mgh $=mv^2$, 2gh $= v^2$, $v = \sqrt{2gh}$, where V is the speed with which the stone lands on the ground.

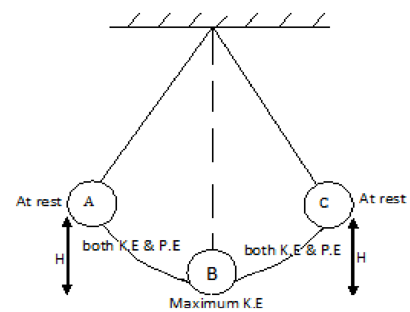
Activity

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 = 1200J**)

(b).If the stone falls with a velocity of 2m/s, find its Kinetic energy. (**KE = 2J**)

(c).Find the velocity with which it hits the ground.(**V= 48.9m/s**)



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

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

(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. (V=20m/s)

2. 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.

3. 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

4. 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

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

2.2 Turning effect of forces, centre of gravity, and stability

Learning Outcomes

a) Understand the turning effect of forces and its applications (u, s,v/a)
b) Understand and apply the concept of centre of gravity (u, s,v/a)

MOMENTS AND EQUILIBRIUM

The concept of turning of a force refers to the moment of a force or torque, which is the rotational effect produced when a force is applied to an object at a certain distance from a pivot or axis of rotation.

Essentially, it explains how a force causes an object to rotate around a point or axis.

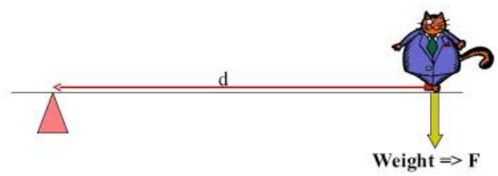
Elements of Turning of a Force:

Force (F): The push or pull applied to the object.

Pivot (Fulcrum): The fixed point around which the object rotates.

Distance (d): The perpendicular distance between the point where the force is applied and the pivot or axis of rotation.

This distance is called the moment arm or lever arm.



Moment of a Force (Torque):

The moment (or torque) is calculated using the formula:

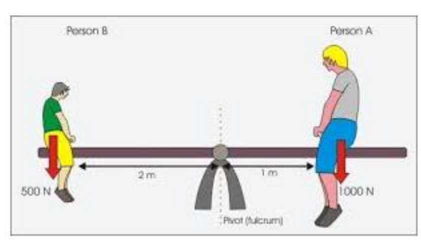
Moment (Torque)=Force×Perpendicular distance from the pivot

$\tau = F \times d$. Where: T is the moment or torque (measured in Newton-meters, Nm), F is the force (measured in Newtons, N), d is the perpendicular distance from the pivot (measured in meters, m)

Practical Examples:

Opening a Door: When you push a door, the door rotates around its hinge (the pivot). The further from the hinge you apply the force, the easier it is to open the door, because the turning effect (moment) increases.

Using a Wrench: Applying force on the handle of a wrench at a greater distance from the bolt gi ves more torque, making it easier to turn the bolt.



Factors Affecting Turning of a Force:

Magnitude of the Force: A larger force will produce a greater turning effect.

Distance from the Pivot: The farther the force is applied from the pivot, the greater the moment.
Direction of the Force: For maximum turning effect, the force must be applied perpendicular to the object. If it's not, only the perpendicular component of the force contributes to the turning effect.
This concept is crucial in mechanical systems, where controlling torque is essential for the operation of levers, gears, and other rotational systems.

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
The Principle of Moments, also known as the Law of Moments, is a fundamental concept in mechanics that states:
For an object to be in equilibrium, the sum of the clockwise moments about a pivot must equal the sum of the counterclockwise moments about the same pivot.
In simple terms, this means that if an object is balanced (i.e., not rotating), the turning effects of the forces acting in one direction (clockwise) must be exactly balanced by the turning effects of the forces acting in the opposite direction (counterclockwise).

Key Concepts:
Moment of a Force: the moment is the turning effect of a force. It is given by the formula: Moment=Force x Perpendicular Distance from the Pivot The unit of moment is Newton-meters (Nm).
Clockwise Moment: When a force causes an object to rotate in the direction of a clock's hands, it is a clockwise moment.
Counterclockwise Moment: When a force causes an object to rotate in the opposite direction to a clock's hands, it is a counterclockwise moment.
Principle of Moments Formula:
For an object to be in equilibrium (not rotating), the sum of the moments in the clockwise direction must equal the sum of the moments in the counterclockwise direction.
Mathematically, ∑Clockwise Moments=∑Counterclockwise Moments
$F_1 \times d_1 + F_2 \times d_2 + \cdots = F_3 \times d_3 + F_4 \times d_4 + \ldots$
Where: $F_1, F_2, \ldots$ are forces causing clockwise rotation, $d_1, d_2, \ldots$ are the corresponding perpendicular distances to the pivot, $F_3, F_4, \ldots$ are forces causing counterclockwise rotation, and $d_3, d_4, \ldots$ are their corresponding perpendicular distances to the pivot.

Application of the Principle of Moments:

Seesaw: On a seesaw, two children sit on either side of the pivot (the fulcrum). If one child is heavier, they will sit closer to the pivot, while the lighter child will sit further away to balance the seesaw. The clockwise moment from the heavier child is balanced by the counterclockwise moment from the lighter child. This keeps the seesaw level. If the moments are not equal, the seesaw will tip toward the side with the greater moment.

Lever: When using a lever to lift a heavy object, the effort force applied on one side must create a moment equal to the moment created by the weight of the object on the other side for the system to balance. This explains how levers can be used to lift heavy loads with smaller forces, by increasing the distance from the pivot where the force is applied.

Balancing Beams: In mechanical structures, such as bridges or cranes, the principle of moments is used to ensure that all forces acting on the structure are balanced to prevent rotation or collapse.

Example

Consider a seesaw where a 60 N child sits 2 m from the pivot on one side, and a 40 N child sits on the other side. To balance the seesaw, we can find the distance the second child should sit from the pivot.

Using the principle of moments:

Clockwise Moment=Counterclockwise Moment

For the 60 N child:

$60\,\text{N} \times 2\,\text{m} = 120\,\text{Nm}$

Let d be the distance for the 40 N child:

$40\,\text{N} \times d = 120\,\text{Nm}$

Solving for d:

$d = 120\,\text{N/m}40\,\text{N} = 3\,\text{m}$

So, the 40 N child should sit 3 meters from the pivot to balance the seesaw.

Conditions for Equilibrium:

There are two conditions for an object to be in static equilibrium:

Translational Equilibrium: The net force acting on the object must be zero, meaning there is no linear motion.

Rotational Equilibrium: The sum of the clockwise moments must equal the sum of the counterclockwise moments, ensuring there is no rotation.

Importance of the Principle of Moments:

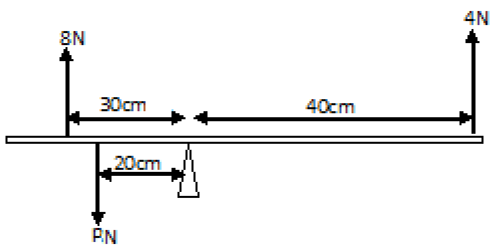
Engineering and Construction: Ensures structures like bridges, cranes, and buildings are stable and balanced.

Mechanical Systems: Helps in designing levers, gears, and other rotating systems for effective functioning.

Daily Life: From using wrenches to balance scales, the principle is applied in various practical situations.

In summary, the Principle of Moments governs rotational equilibrium, ensuring that when forces act on a system at different distances from a pivot, the system remains balanced if the clockwise and counterclockwise turning effects (moments) are equal.

Examples: Forces of 8N, pN and 4N act on a body as shown;



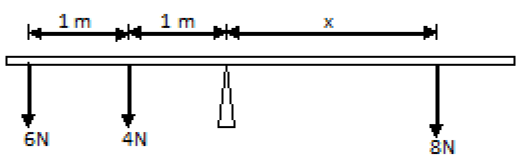
Find the value of P if the system is in equilibrium.

Sum of Anti-clockwise moments = Sum of clockwise moments

4 x 40 + p x 20 = 8 x 30

P = 4N

Forces below act on the plank as shown



If the body is in equilibrium find the distance x

Anti-clockwise = clockwise moments

6 x 2 + 4 x1 = 8 x

X = 2m

Center of Gravity

The center of gravity* (CG) *is the point in a body or system where the entire weight of the object can be considered to be concentrated for purposes of analysis. When a force such as gravity acts on an object, it is as if all the mass of the object is located at this single point. Understanding the center of gravity is crucial for maintaining balance and stability in structures and moving objects.

Key Concepts of Center of Gravity:

Definition: The center of gravity is the point at which the weight of an object is evenly distributed in all directions, and around which the object balances in any orientation. It is the theoretical point where the gravitational force acts on an object.

For Symmetrical Objects: In objects with uniform density and symmetrical shape (such as a sphere or cube), the center of gravity is located at the geometric center of the object.

For Asymmetrical Objects: In objects with irregular shapes or non-uniform density, the center of gravity may be closer to the heavier part of the object. The center of gravity is not necessarily located inside the object — for example, in hollow or irregularly shaped objects; the CG may lie outside the physical material.

How to Find the Center of Gravity:

For simple shapes with uniform mass, the center of gravity can be found geometrically. For example:

Rectangle or Cube: The center of gravity is located at the intersection of the diagonals.

Circle or Sphere: The center of gravity is at the geometric center.

For more complex or irregular objects, the center of gravity can be determined experimentally by balancing the object at different points or through calculation, often using integration for continuous mass distributions.

Balance and Stability:

If the center of gravity is low and close to the base of an object, the object tends to be more stable.

If the center of gravity is high or located away from the base, the object is less stable and more prone to tipping over.

Practical Examples of Center of Gravity:

Balancing Objects: For a seesaw to balance, the center of gravity of the entire system must be located directly over the pivot point.

Vehicles: In cars and trucks, a lower center of gravity improves stability and reduces the risk of rollover. That's why race cars are designed with low profiles to keep the center of gravity close to the ground.

Athletics and Sports: In gymnastics, athletes must keep their center of gravity within their base of support to maintain balance during movements. In sports like high jump, athletes manipulate their body position to raise their center of gravity for better jumps.

Construction: Cranes and tall buildings need careful design to ensure that their center of gravity remains within their base of support, preventing them from toppling over.

Center of Gravity and Center of Mass:

In many situations, center of gravity and center of mass are used interchangeably because the force of gravity acts uniformly across the object.

However, they can differ in cases where gravitational fields vary across the object, such as very large objects or in astrophysical scenarios.

Center of Mass: This is the point where the mass of an object is evenly distributed, regardless of external forces (like gravity).
Center of Gravity: This is the point where the gravitational force effectively acts on an object.
In everyday situations (under uniform gravity, like on Earth), the two points coincide.
Mathematical Calculation of the Center of Gravity:

For a system of particles or a complex object, the center of gravity can be calculated using the formula: $CG=\sum mi \cdot ri$
Where: m_i is the mass of each particle or segment of the object, r_i is the position vector of each particle relative to a chosen reference point, $\sum m_i$ is the total mass of the object.

Application of the Center of Gravity in Physics and Engineering:
Aviation: The center of gravity is critical in aircraft design. The position of the CG affects an airplane's stability and control. If it's too far forward or backward, the plane could become unstable or difficult to control.
Robotics: Robots are designed with low centers of gravity to avoid tipping over when moving or carrying objects.
Construction Equipment: Cranes and heavy lifting machines are designed with counterweights to adjust the center of gravity for stability during operation.
The center of gravity is the point where the total weight of an object appears to act.
For uniform objects, it is typically located at the geometric center, while for irregular objects; it is closer to the heavier side.
Stability and balance are directly related to the position of the center of gravity relative to the base of support.
A lower center of gravity typically increases stability, while a higher one decreases it.

Experimental Method to determine the Center of Gravity of an Irregular Object:
Materials Needed:
- The irregular object (e.g., a cardboard cut-out)
- A piece of string

- A plumb line (a string with a weight at the end)
- A pin or nail
- A marker

Procedure:

Suspend the irregular object from any point along its edge using a pin or nail. This point of suspension should be arbitrary, and it will act as a temporary pivot point.

Hang a plumb line from the same pin or nail that is used to suspend the object. The plumb line will point straight down due to gravity.

Once the object is hanging freely and the plumb line is steady, use the marker to draw a line along the path of the plumb line on the surface of the object. This line represents one potential path through the center of gravity.

Choose another point along the edge of the object and repeat the process. Suspend the object from this new point, hang the plumb line, and draw another line along the plumb line.

The point where the two lines intersect is the center of gravity of the irregular object. This intersection point is where the entire weight of the object is effectively concentrated.

To improve accuracy, you can suspend the object from a third point and draw a third line. All lines should intersect at the same point, confirming the location of the center of gravity.

The stability of a body refers to its ability to maintain equilibrium and resist disturbances that might cause it to tip, fall, or rotate.

Key Concepts of Stability:

Equilibrium: *A body is in equilibrium when the sum of the forces and the sum of the moments acting on it are zero. There are three types of equilibrium:*

Stable Equilibrium: If the body is slightly disturbed, it returns to its original position. This usually occurs when the center of gravity is low and the base of support is wide.

Unstable Equilibrium: If the body is disturbed, it moves further away from its original position. This occurs when the center of gravity is high or the base of support is narrow.

Neutral Equilibrium: If the body is disturbed, it remains in its new position. This is typical for objects that have a flat surface, like a sphere on a flat plane.

Center of Gravity: The location of the center of gravity plays a crucial role in stability. A lower center of gravity typically increases stability, while a higher

center of gravity decreases it. This is because a lower center of gravity means that the object has a greater resistance to tipping.
Base of Support: The area beneath an object that includes all points of contact with the ground. A wider base of support generally leads to greater stability. If the center of gravity falls within this base, the object will be stable; if it falls outside, the object will topple.

Factors affecting Stability:
Height of the Center of Gravity:
A high center of gravity increases the likelihood of tipping. For example, tall vehicles (like trucks) are more prone to rollovers than lower vehicles (like sedans).
Width of the Base of Support:
A wider base increases stability. For example, a tripod has three points of contact, making it more stable than a two-legged structure.
Position of the Center of Gravity Relative to the Base:
When the center of gravity is directly above the center of the base of support, the object is more stable. If it shifts outside this area, the object becomes unstable.

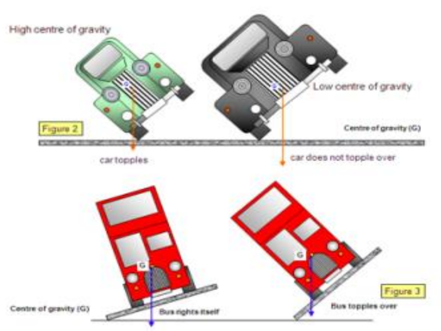
Distribution of Mass:
How mass is distributed affects stability. For example, a low and wide shape is generally more stable than a tall and narrow shape because the mass distribution lowers the center of gravity.
Stability Analysis:
Stability Triangle:
To visualize stability, consider a triangle formed by the points of contact with the ground. If the center of gravity lies within this triangle, the object is stable.
Tipping Point:
The tipping point is reached when the line of action of the weight (a vertical line passing through the center of gravity) falls outside the base of support.
Dynamic Stability:
In moving objects (like vehicles), stability is affected by factors such as speed, momentum, and the forces acting during acceleration or deceleration.
Applications of Stability:
Engineering and Architecture: Structures like bridges, buildings, and towers must be designed to ensure that their center of gravity remains within their base of support to prevent collapse.
Vehicles: Car designs focus on lowering the center of gravity to improve handling and reduce the risk of rollover.

Sports and Physical Activities: Athletes and performers often use techniques to lower their center of gravity to maintain balance during dynamic movements, such as in gymnastics or martial arts.
Robotics: Robots are designed with stability in mind to prevent tipping during movement or when carrying loads.

Summary:

Stability is crucial for maintaining balance and preventing tipping or falling.
Center of Gravity and Base of Support are key factors influencing stability.
A low center of gravity and a wide base of support generally result in greater stability.
Understanding stability is essential in design and engineering to ensure the safety and effectiveness of structures and objects.

Illustration



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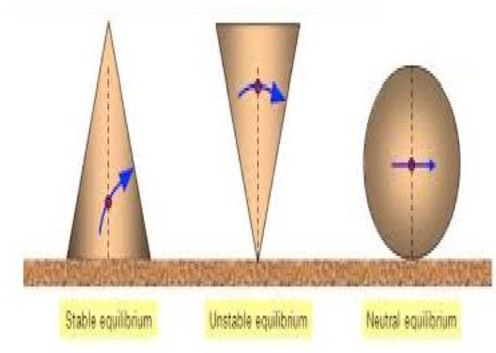


Determination of mass of a beam or rod or any straight material

Determining the mass of a beam, rod, or any straight material can be accomplished using several methods, depending on the available tools and the precision required.

Using a Balance Scale:

Method:1

Measure the length of the beam or rod using a ruler or measuring tape.
Use a balance scale to weigh the object directly. Ensure the balance is calibrated and zeroed before use.
Record the mass displayed on the scale.
This method is the most straightforward for solid and homogenous materials, giving a direct measurement of mass.

Calculating Mass from Volume and Density:

If the beam or rod is of uniform cross-section and material, you can calculate its mass using the formula:

Mass=Volume x Density

Method:2
Measure the dimensions of the beam or rod.
For a cylindrical rod: Volume=$\pi r^2 h$, where r is the radius and h is the height(length).
For a rectangular beam: Volume=width×height×length
Find the density of the material (usually available in material property tables).
Multiply the volume by the density to get the mass.

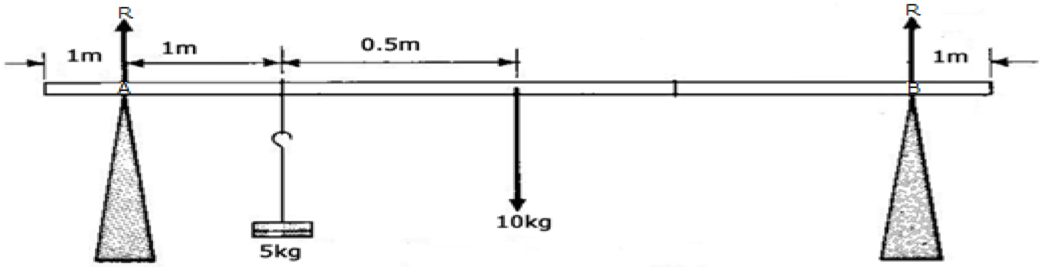
Using a Lever Balance:
This method is useful for longer beams or rods where it might be difficult to use a standard scale.

Method:3
Set up a lever balance with the beam positioned on the fulcrum (pivot point).
Place known weights on one side of the lever.
Adjust the position of the known weights until the lever is balanced.
Calculate the mass of the beam using the principle of moments. The relationship can be expressed as: Mass of beam= Mass of weights x distance from pivot

Using Water Displacement Method (for Irregular Shapes):
If the beam or rod has an irregular shape, you can measure its mass based on its volume via the water displacement method.

Method:4
Fill a graduated cylinder with water and record the initial volume.
Submerge the beam or rod in the water and measure the new water level.
The volume of water displaced equals the volume of the beam or rod.
Use the density of the material to calculate the mass using:
Mass=Volume displaced x density

Activity
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.
Draw a diagram showing all forces acting on the bar and calculate the reactions due to the men acting on the bar



Verify that the Reaction at A= 83.33N and Reaction at B = 66.67N.

2.3 Pressure in solids and fluids

Learning Outcomes

a) Understand that pressure is the result of a force applied over an area (u,s)
b) Understand the effect of depth on the pressure in a fluid and the implications of this (u,s)
c) Understand the nature of the atmosphere and how atmospheric pressure is measured (u,s)
d) Know the structure of the atmosphere and the significance of the different layers (k, u,v/a)
e) Understand the use of the Bernoulli effect in devices like aerofoils and Bunsen burner jets(u)f. Understand the concept of sinking and flotation in terms of forces acting on a body submerged in a fluid(u)g. Understand and apply the Archimedes' principle in different situations (u, s,v/a)

Pressure is defined as force acting normally per unit area.
SI unit is Nm^{-2} or Newton per square metre or Pascal. 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, sharp panga against blunt panga, high-heeled shoe against gumboots, bicycle tire against tractor tire, etc. 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, and the rest applies. 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.

Activity (Work in groups)

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.

Minimum and maximum pressure

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

Activity

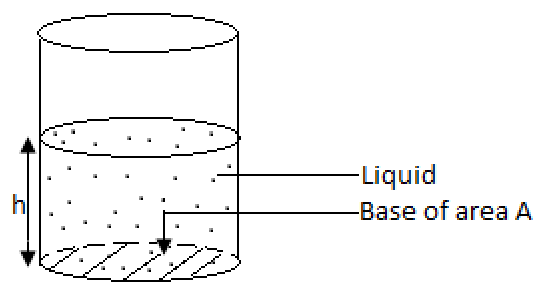
a). A box measures 5m by 1m by 2m and has weight of 60N while resting on the surface. What is the minimum pressure?

b). A box of dimensions of 6m x 2m x 4m exerts its weight of 400N on the floor. Determine its maximum pressure, minimum pressure, and density

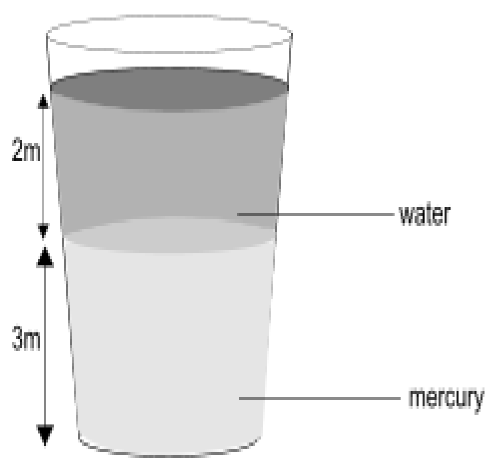
PRESSURE IN LIQUIDS

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; depth (h) of the liquid and density (ρ) of the liquid



Activity



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 the pressure that mercury exerts on the vessel and 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

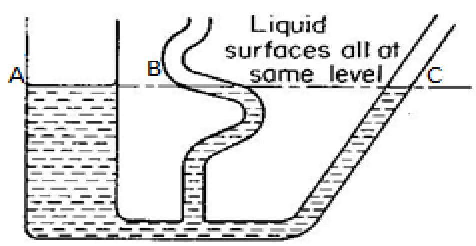
The holes are unblocked and the sizes of water jets noted

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.

Experiment to show that pressure is independent of cross section area and shape of container



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

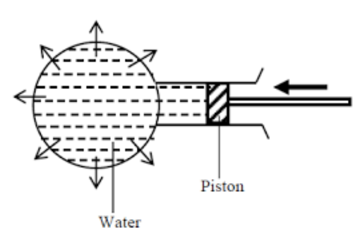
The liquid reaches the same height h in all the tubes.

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

PRINCIPAL OF TRANSMISSION OF PRESSURE IN LIQUIDS

*(***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

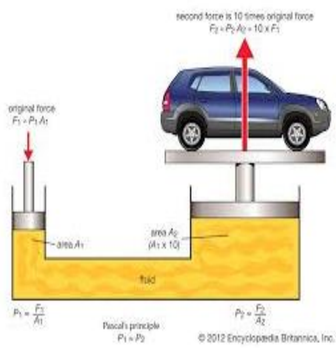


Experiment to verify the principle of transmission of pressure in liquids

A spherical container is pinched at different points around it.
The piston is moved in such way that it pushes "the plunger" 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.*

Application of the Pascal's principle:
Some machines where the Pascal's principle are used include; hydraulic car jacks, shock absorbers (cylinders),Hydraulic car brakes, Hydraulic press, Hydraulic lifts, and Hydraulic bulldozers, and many others.

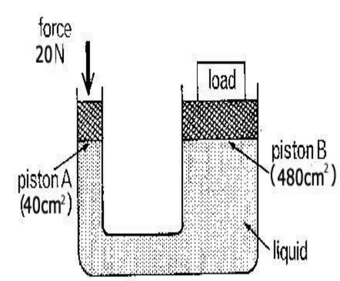
HYDRAULIC Press/Machine



A hydraulic press consists of two connected cylinders of different bores, filled with a liquid or any other incompressible fluid and fitted with piston shown in the figure. 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. $P_1 = P_2$; $\frac{F_1}{F_2} = \frac{A_1}{A_2}$

Activity

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

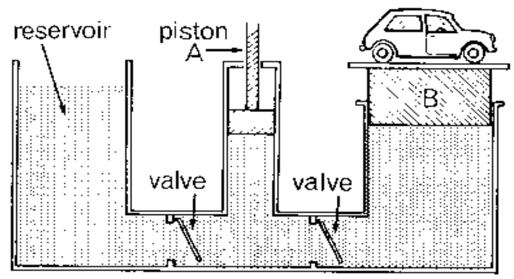


Pressure at B = pressure at A= 5000 Nm^{-2}
Weight W =pressure at B x piston area B
=5000 x0.048= 240N

3.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

4.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

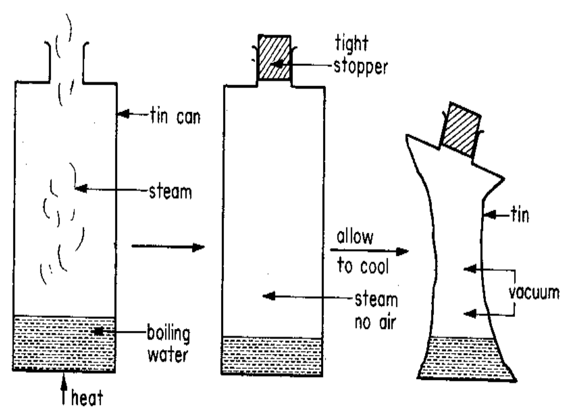


This is commonly used in garages; it lifts cars so that repairs and service on them can be done easily underneath the car
A force applied to the small piston, raises the large piston, which lifts the car. One valve allows the liquid to pass from the small cylinder to the wider one. A second valve allows 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;



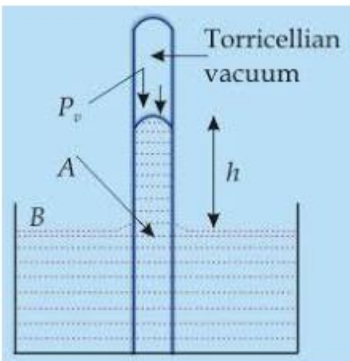
Crushing can experiment or collapsing can experiment
A metal can with its tight stopper removed, is heated until the small quantity of water in boils.
When the steam has driven out all the air, the cork is tightly replaced and the heat removed at the same time.
Cold water is poured over the can. This 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.

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.***

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

Atmospheric pressure = Barometer height x Density of liquid x gravity

Example

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= 0 .76x 13600 x 10 = 103360 Nm^{-2}

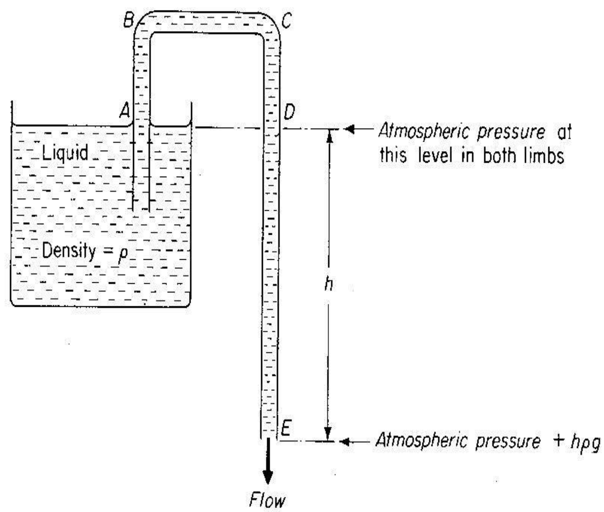
In the same place atmosphere pressure is the same as using water;

P = hpg. 103360 = h x 1000 x 10. h = 103360/ 1000 X 10. ***h= 1034m***

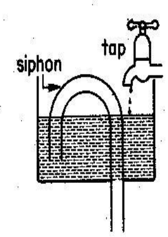
The answer to the question above, explains why water is not used in a barometer because the column will be too long.

Applications of Atmospheric pressure
Atmospheric pressure may be made useful in rubber suckers, bicycle pump, lift pump, force pump, siphon, water supply system and drinking straw among others.
Uses of rubber sucker;
-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.

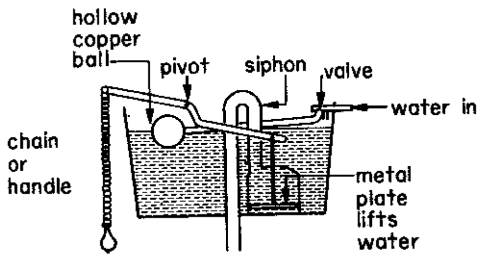
The siphon;
This is used to take the liquid out of vessels (eg. Aquarium, petrol tank)



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
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.



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.



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.

Water supply system

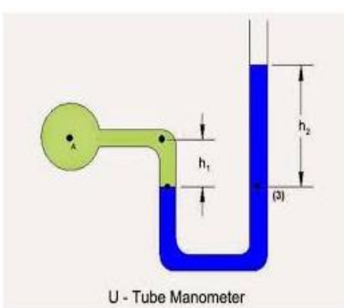
Water supply in towns often comes from a reservoir on a high groundwater flows from it through a pipe to any tap or storage tank that is below the water reservoir.

In very tall building it may be necessary to first pump water to a large tank on a roof. Reservoirs of water supply in hydroelectric 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.***

Manometer



U - Tube 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.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}

2.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

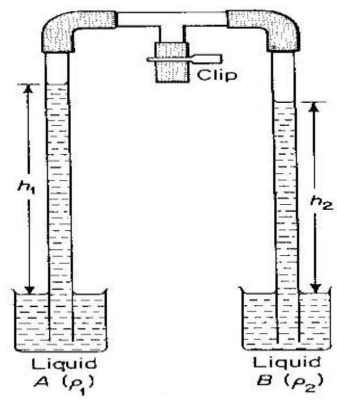
$h_1\ p_1\ g_1 = h_2\ p_2\ g_2$. h x 13600 x 10 = 54.4 x 1000 x 10

h = 4 cm. Therefore at B, P = H + 4 .P = 4 +76 = 80cmHg

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

Difference of P = hpg → 5.0 x 10^4 = h x 1.3 x 10.h = 3846.15m or 3.85km

Comparison of densities of liquids using Hare's apparatus

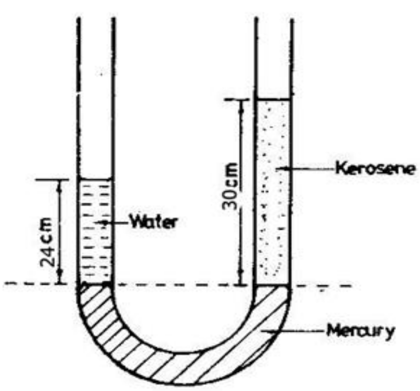


Liquids of different densities are placed in glass pots as shown above. When the gas tap is opened each liquid rises to different height h_1 and h_2.Since they are subjected to the same gas supply,

Pressure on liquid 1 = pressure on liquid 2

$h_1\rho_1 g = h_2\rho_2 g$. $\frac{h_1}{h_2} = \frac{\rho_2}{\rho_1}$

Activity: (In groups)



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

Determine the density of kerosene

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

(i) Density kerosene

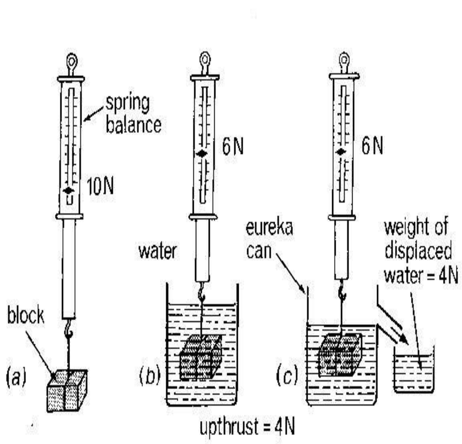
(ii) Relative density of kerosene

Fluids motion: Floating and Sinking:

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.

Archimedes' principle: *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' principle



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 obtained 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.

Activity (In groups)

1. A glass block weighs 25N. When wholly immersed in water, the block appears to weigh 15N, calculate the up thrust.

2.A body weighs 1N in air and 0.3N when wholly immersed in water. Calculate the weight of water displaced.

3.A metal weights 20N in air and 15N when fully immersed in water. Calculate the weight of displaced water, volume of displaced water, volume of metal, and density of metal. (Density = $1000kg/m^2$)

Application of Archimedes' principle

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

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 Ww
Find the up thrust in liquid $= Wa - W_1$
Find the up thrust in water $= Wa - Ww$
Obtain RD of a liquid from $R.D = \frac{Wa - W_1}{Wa - Ww}$

Activity

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.

FLOATING OBJECTS

There are two vertical forces which act on an object when immersed in water, weight (W) and upthrust (U). If W is less than U the object rises, If W is equal to upthrust U object floats, and If W is greater than upthrust 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.

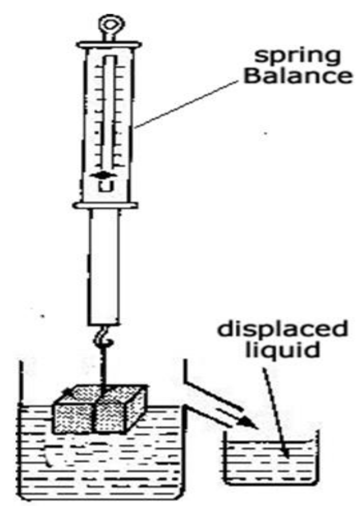
Law of floatation

It states that a floating object displaces its own weight of the fluid in which it floats.

Experiment to verify law of floatation

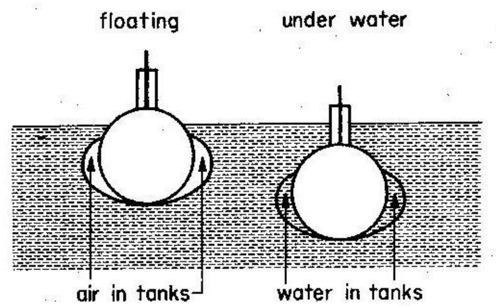
Method

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 collects the displaced water.
Weigh the displaced water. It is obtained out that weight of water displaced = weight of object W_a



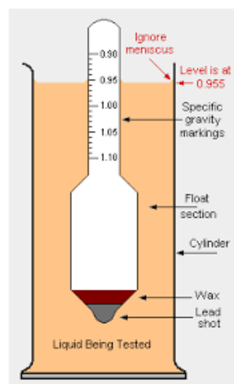
Application of law of floatation

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.



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. Upthrust = 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.

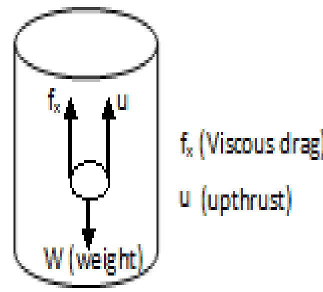
Hydrometers

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).

Motion of a body through fluids



When a body falls through a fluid, it is acted on by forces namely -weight of the body, viscous force and 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.*

The uniform velocity attained by a body falling through a fluid when the net force on the body is zero.
In case of a balloon or a rain drop falling, the resisting force or retarding force on the body is called air resistance

Bernoulli's effect and its applications

2.4 Mechanical properties of Materials and Hooke's law

Learning Outcomes

a) Understand how the mechanical properties of common materials can be utilised in physical structures (u, s, v/a)
b) Understand that the tensile strength of materials is determined by the properties of the substances they are composed of (u)
c) Understand that heating changes the structure and properties of some materials(u)

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:

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

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

Plasticity
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.
Strength
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.

Hardness

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

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

Toughness

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.

Brittleness

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.

Ductility

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.

Malleability

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.

Creep

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.

Fatigue

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 property 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.

Mechanical properties

It is strong, stiff and somehow hard.

Bricks and blocks as building materials

These are stony materials.

Used 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-enforced.*

Reinforced concrete

Pour wet concrete on steel rods when it dries; it is stuck on the rods, which is strong under tension. This forms a re-enforced concrete.

It can also be re-enforced by putting fiber in concrete when it is wet and leave it to harden.

Other re-inforcing materials include;

Bamboo stripes

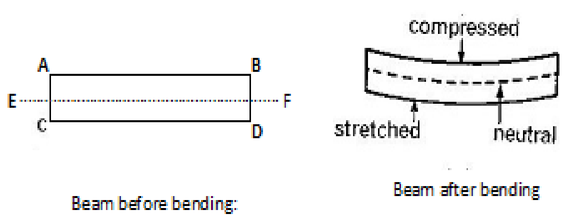
Wood stands

Metal rods and wire mesh.

Advantages of re-inforcing 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).



AB – Under compression
DC – Under tension
EF – unstretched i.e. it neither under tension nor under 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-Shape girders. This I-shaped girder is used in construction of large structures like bridges. Hollow tube/girder (hollow cylinder), Square beam/girder, Triangular beam/girder and L – Shaped girder.
Advantages of hollow beams

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

Disadvantages of solid beams

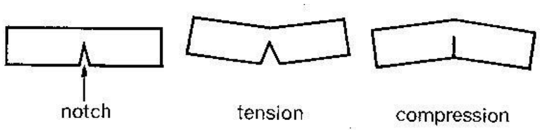
They are heavier
They are economically expensive
They are weak

Disadvantages of a material used in the neutral axis:

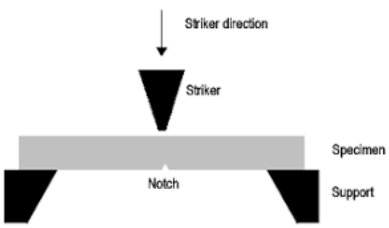
It is a wastage and un necessary

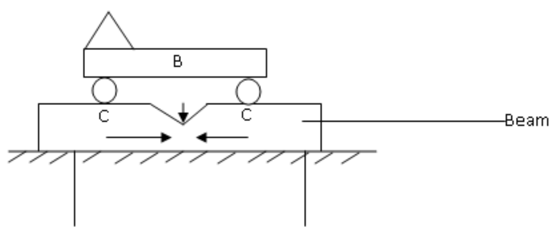
NOTCH AND NOTCH EFFECTS

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;

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

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

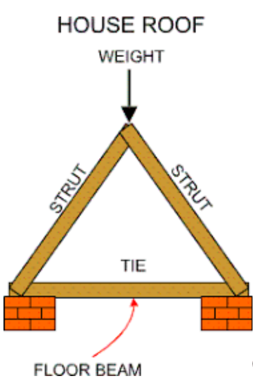
Two straws are fixed on the side of a piece of soft board.

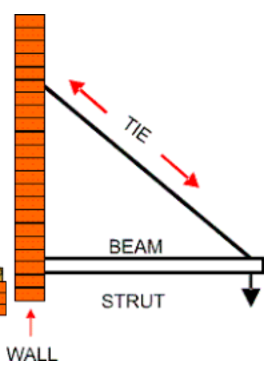
A small load is added at the end B. The structure supports the load.

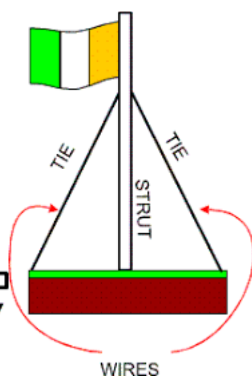
The string of the same length now replaces the straw AB.

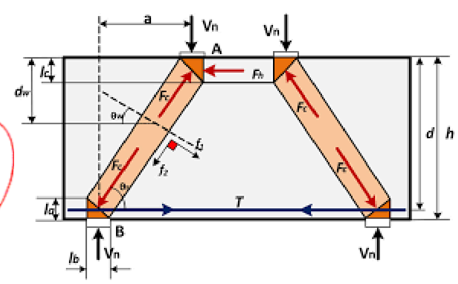
If the structure still supports the load, then AB is under tension hence it is a tie.

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.





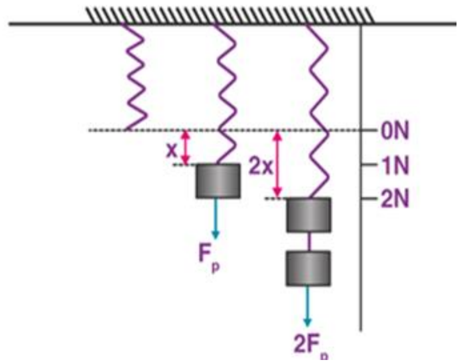




HOOKE'S LAW OF ELASTICITY

Hooke's law states that ***the strain of the material is proportional to the applied stress within the elastic limit of that material****. When the elastic materials are stretched, the atoms and molecules deform until stress is applied, and when the stress is removed, they return to their initial state.*

Mathematically, Hooke's law is expressed as: $F = -kx$. In the equation, F is the force, x is the extension in length, k is the constant of proportionality known as the spring constant.



*The figure shows the stable condition of the spring when no load is applied, the condition of the spring when elongated to an amount x under the load of 1 N, the condition of the spring elongated to 2x under the influence of load 2 N.*Depending on the material, different springs will have different spring constants, which can be calculated. The figure shows us three instances, the stable condition of the spring, the spring elongated to an amount x under a load of 1 N, and the spring elongated to 2x under a load of 2 N. If we substitute these values in the Hooke's law equation, we get the spring constant for the material in consideration.

Solution:

We know that the spring is displaced by 5 cm, but the unit of the spring constant is Newtons per meter. This means that we have to convert the distance to meters.

Converting the distance to meters, we get 5 cm = 0.05 m; Now substituting the values in the equation, we get

$F = -k.x$, 500 N = – k x 0.05 m

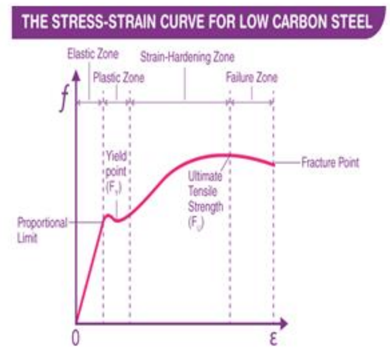
Now, we need to rework the equation so that we can calculate the missing metric, which is the spring constant, or k. Looking only at the magnitudes and therefore omitting the negative sign, we get

500 N/0.05 m = k :k = 10000 N/m

Therefore, the spring constant of the spring is 10000 N/m.

The figure below shows the stress-strain curve for low carbon steel.

The material exhibits elastic behaviour up to the yield strength point, after which the material loses elasticity and exhibits plasticity. From the origin till the proportional limit nearing *yield strength*, *the straight line implies that the material follows Hooke's law. Beyond the elastic limit between proportional limit and yield strength, the material loses its elasticity and exhibits plasticity. The area under the curve from origin to the proportional limit falls under the*



elastic range. The area under the curve from a proportional limit to the rupture/fracture point falls under the plastic range.
The material's ultimate strength is defined based on the maximum ordinate value given by the stress-strain curve (from origin to rupture). The value provides the rupture with strength at a point of rupture.

HOOKE'S LAW APPLICATIONS

Following are some of the applications of Hooke's Law:
It is used as a fundamental principle behind the manometer, spring scale, and the balance wheel of the clock.
Hooke's law sets the foundation for seismology, acoustics and molecular mechanics

HOOKE'S LAW DISADVANTAGES

Following are some of the disadvantages of Hooke's Law:
Hooke's law ceases to apply past the elastic limit of a material.
Hooke's law is accurate only for solid bodies if the forces and deformations are small.
Hooke's law isn't a universal principle and only applies to the materials as long as they aren't stretched way past their capacity.

Example

1. An elastic wire of length 10cm has force applied on it of 3N. Find its extension and elastic constant k.
Extension $e = l - l_0 = 12 - 10 = 2cm = 0.02m$, Using $F = K e$, $3 = k \times 0.02$ $K = 150Nm^{-1}$
2. A spring extends by 0.5 cm when a load of 0.4N hangs on it. Find the load required to cause an extension of 1.5cm, and what additional load causes the extension of 1.5cm?

Method 1

Using F =K e, 0.4 = k x0.5, K = 0.8N/cm, F_2=ke_2 F= 0.8 x 1.5 = 1.2N.

Method 2

F_2 = 1.2N

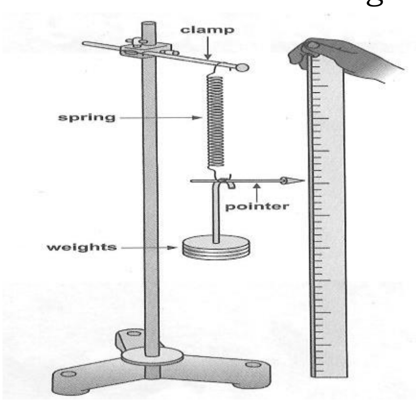
Additional load required = (1.2 – 0.4) = 0.8N

Activity

A spring has an un-stretched length of 12 cm. When a force of 8N is attached to its length becomes 6cm.Find its extension produced, the constant of the spring and 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

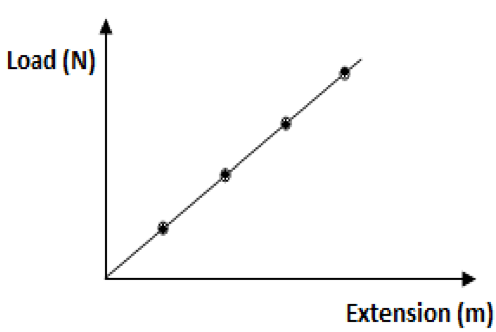
The new position X of the pointer whenever the spring is loaded is recorded

The extension for each load added is recorded from e = x – x_0.

A graph of load against extension is plotted as shown

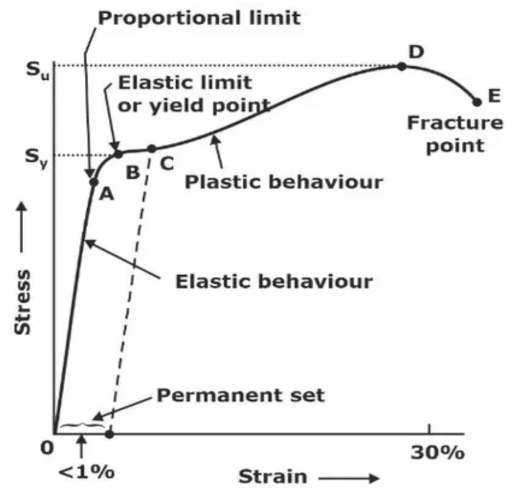
A straight line passing through the origin verified hook's law.

A graph of load against extension for a ductile wire



Plastic deformation

Deformation often referred to strain, is the change in the size and shape of an object due to the change in temperature or an applied force. Depending on the size, material and the force applied, various forms of deformation may occur. Based on these factors, deformation is classified into the following:



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.

Elastic deformation refers to a temporary deformation of a material's shape that is self-reversing after removing the force or load. Elastic deformation alters the shape of a material upon the application of a force within its elastic limit. This physical property ensures that elastic materials will regain their original dimensions following the release of the applied load. Here deformation is *reversible and non-permanent.* Elastic deformation of metals and ceramics is commonly seen at low strains; their elastic behavior is generally linear.

The mechanisms that cause plastic deformation differ widely. Plasticity in metals is a consequence of dislocations while in brittle materials such as concrete, rock and bone, plasticity occurs due to the slippage of microcracks. There are two prominent mechanisms of plastic deformation in metals and they are slipping and Twinning

Slip and Twinning

Slip is the prominent mechanism of deformation in metals. A slip involves the sliding of blocks of crystal over one another along different crystallographic planes known as slip planes.

In twinning, the portion of crystals takes up an orientation related to the orientation of the rest of the untwined lattice in a symmetrical and definite way. In the image given below, the depiction of slip and twinning deformation in a face-centred cubic crystal.

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. $stress = \frac{Force}{area}$

SI unit: N/m^2

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

i.e. $strain = \frac{extension}{original\ length}$

Strain has no units.

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

$$E = \frac{stress}{strain}$$

SI unit = N/m^2

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

Activity (Work out in groups)

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?

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) Tensile strain
(iii) Young's modulus

3.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 the **t**ensile stress and tensile stress.

4.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 the tensile stress, tensile strain and the young's modulus

2.5 Reflection of light at curved surfaces

Learning Outcomes

a) Understand reflection of light and the formation of images by curved mirrors(u)
b) Use ray diagrams to show how images are formed by curved mirrors and the nature of the images(s)
c) Determine the focal length of concave mirrors using a variety of methods. (s,gs)

Reflection of Light by Curved Surfaces

Reflection of light refers to the bouncing back of light rays when they hit a surface. In the context of curved surfaces, such as concave and convex mirrors, the reflection of light follows specific patterns depending on the shape of the surface. Understanding how light interacts with these curved mirrors is key to predicting the type of image that will be formed.

A mirror is a surface that reflects almost all incidents light. Mirrors come in two types: those with a flat surface, known as plane mirrors, and those with a curved surface, called spherical mirrors. In this article, we will explore two specific types of spherical mirrors: convex mirrors and concave mirrors. We will also delve into the concept of ray diagrams, which help us understand how light behaves when it interacts with these mirrors. By examining the ray diagram of a spherical mirror, we can gain insights into the fascinating phenomena of reflection and image formation.

Mirrors

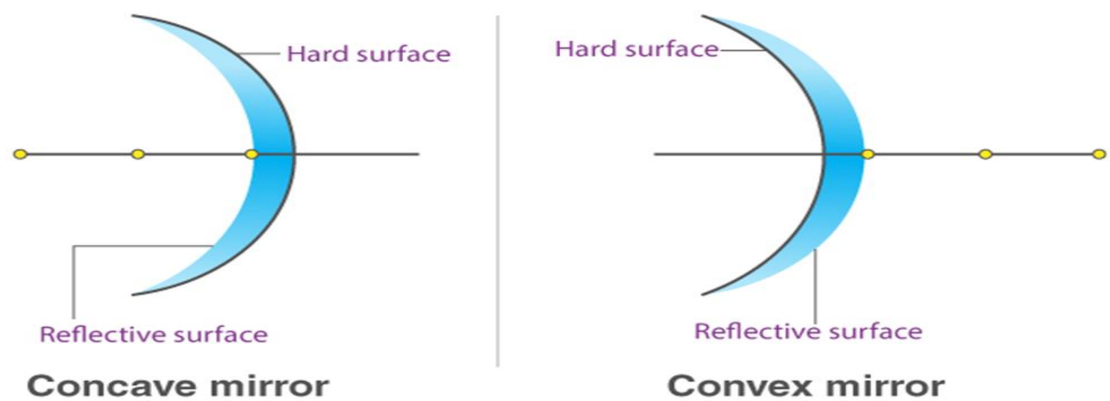
A mirror plays a fascinating role in reflecting light, resulting in the formation of images. When an object is placed in front of a mirror, we observe its reflection. Incident rays originate from the object, and the reflected rays converge or appear to diverge to create the image. Images formed by mirrors can be classified as real image or virtual image. Real images are produced when light rays converge and intersect, while virtual images are formed when light rays appear to diverge from a point.

Ray diagrams are employed to comprehend the behaviour of light and better understand image formation. These diagrams use lines with arrows to represent incident and reflected rays, allowing us to trace their paths and interactions with the mirror. By interpreting ray diagrams, we gain valuable insights into how images are formed and a deeper understanding of how our eyes perceive objects through reflection.

Plane Mirror vs Spherical Mirror

A plane mirror is a flat, smooth reflective surface with a clear, undistorted reflection. When an object is reflected in a plane mirror, it always forms a virtual image that is upright, of the same shape and size as the object.

On the other hand, a spherical mirror exhibits a consistent curvature. It possesses a constant radius of curvature (In the context of spherical mirrors, the radius of curvature refers to the distance between the centre of the spherical mirror and its curved surface.). Spherical mirrors can create both real and virtual images, depending on the position of the object and the mirror. Spherical mirrors are further categorized into **concave** and **convex mirrors**, each with distinct properties and image formation characteristics.



In the upcoming sections, we will detail the characteristics of convex and concave mirrors, along with a comprehensive understanding of the images formed by these mirrors when the object is placed at various positions with the help of ray diagrams.

Characteristics of Concave and Convex Mirrors

Concave Mirror Definition

A concave mirror is a curved mirror where the reflecting surface is on the inner side of the curved shape. It has a surface that curves inward, resembling the shape of the inner surface of a hollow sphere. Concave mirrors are also converging mirrors because they cause light rays to converge or come together after reflection. Depending on the position of the object and the mirror, concave mirrors can form both real and virtual images.

Characteristics of Concave Mirrors

Converging Mirror: A concave mirror is often referred to as a converging mirror because when light rays strike and reflect from its reflecting surface, they converge or come together at a specific point known as the focal point. This property of concave mirrors allows them to focus light to a point.

Magnification and Image Formation: When a concave mirror is placedvery close to the object, it forms a magnified, erect, and virtual image. The image appears larger than the actual object and is upright. The virtual image is formed as the reflected rays appear to diverge from a point behind the mirror.

Changing Distance and Image Properties: As the distance between the object and the concave mirror increases, the size of the image decreases. Eventually, at a certain distance, the image transitions from virtual to real. In this case, a real and inverted image is formed on the opposite side of the mirror.

Versatile Image Formation: Concave mirrors have the ability to create images that can vary in size, from small to large, and in nature, from real to virtual. These characteristics make concave mirrors useful in various applications such as telescopes, shaving mirrors, and reflecting headlights.

Convex Mirror Definition

A convex mirror is a curved mirror with the reflecting surface on the curved shape's outer side. It has a surface that curves outward, resembling the shape of the outer surface of a sphere. Convex mirrors are also known as diverging mirrors because they cause light rays to diverge or spread out after reflection. Convex mirrors always form virtual, erect, and diminished images, regardless of the object's position. They are commonly used in applications requiring a wide field of view, such as rear-view mirrors and security mirrors.

Characteristics of Convex Mirrors

Diverging Mirror: A convex mirror is commonly referred to as a diverging mirror because when light rays strike its reflecting surface, they diverge or spread out. Unlike concave mirrors, convex mirrors cause light rays to diverge from a specific focal point.

Virtual, Erect, and Diminished Images: Regardless of the distance between the object and the convex mirror, the images formed are always virtual, erect, and diminished. The image appears upright, smaller than the actual object, and behind the mirror. When traced backwards, the virtual image is formed by the apparent intersection of diverging rays.

Wide Field of View: One of the significant characteristics of convex mirrors is their ability to provide a wide field of view. Due to the outwardly curved shape, convex mirrors can reflect a broader area compared to flat or concave mirrors. This property makes them useful when a larger perspective is required, such as in parking lots, intersections, or surveillance systems.

Image Distance and Size: Convex mirrors always produce virtual images closer to the mirror than the object. The image formed by a convex mirror appears diminished or smaller than the object. This reduction in image size allows a greater expanse of the reflected scene to be captured within the mirror's field of view.

Image Formation by Spherical Mirrors

By understanding some crucial guidelines for ray incidence on concave and convex mirrors, we can predict and analyze the behaviour of light rays, aiding in constructing accurate ray diagrams and comprehending image formation processes.

Guidelines for rays falling on the concave and convex mirrors

Oblique Incidence: When a ray strikes a concave or convex mirror at its pole, it is reflected obliquely, making the same angle as the principal axis. This principle of reflection ensures that the angle of incidence is equal to the angle of reflection, maintaining the symmetry of the reflected rays.

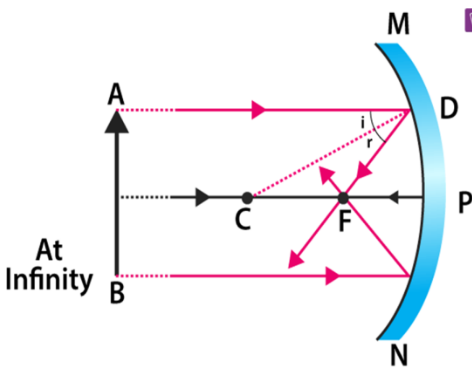
Parallel Incidence: When a ray parallel to the principal axis strikes a concave or convex mirror, the reflected ray follows a specific path. In the case of a concave mirror, the reflected ray passes through the focus on the principal axis. Similarly, for a convex mirror, the reflected ray originates from the focus on the same side as the incident ray.

Focus Incidence: When a ray passes through the focus and strikes a concave or convex mirror, the reflected ray will be parallel to the principal axis. This characteristic holds for concave and convex mirrors and is crucial in determining the path of reflected rays.

Centre of Curvature Incidence: A ray passing through the centre of curvature of a spherical mirror will retrace its path after reflection. This principle illustrates that when a ray hits the mirror's centre of curvature, it undergoes reflection and follows the exact same path in the opposite direction.

IMAGE FORMATION BY CONCAVE MIRROR

The object's position in relation to a concave mirror affects the type and characteristics of the image formed. Different scenarios result in different types of images:

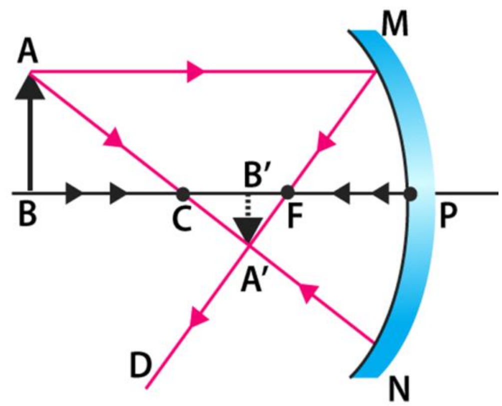


Object at Infinity

A real and inverted image is formed at the focus when the object is placed at infinity. the size of the image is significantly smaller than that of the object.

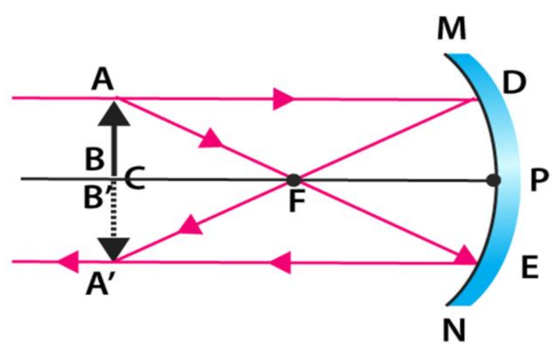
OBJECT BEYOND THE CENTRE OF CURVATURE

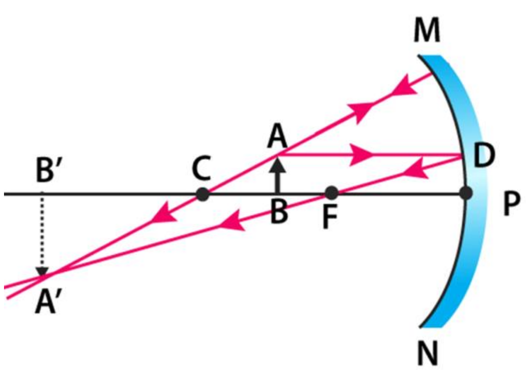
When the object is positioned beyond the centre of curvature, a real image is formed between the centre of curvature and the focus. The size of the image is smaller compared to that of the object.



Object at the Centre of Curvature or Focus

When the object is placed at the centre of curvature, or the focus, a real image is formed at the centre of curvature. The size of the image remains the same as that of the object.

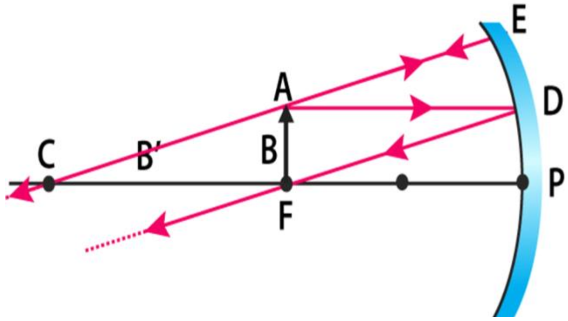




OBJECT BETWEEN THE CENTRE OF CURVATURE AND FOCUS

If the object is located between the centre of curvature and the focus, a real image is formed behind the centre of curvature. The size of the image is larger compared to that of the object.

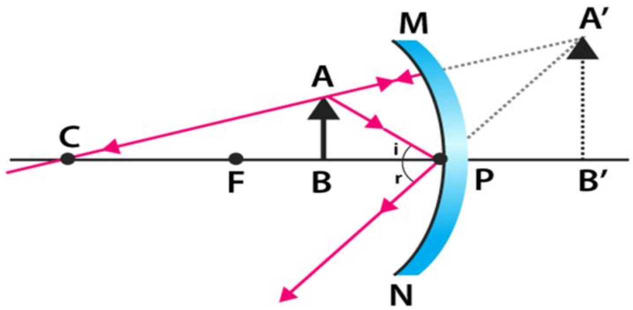
the



OBJECT AT THE FOCUS

When the object is positioned exactly at the focus, a real image is formed at infinity. The size of the image is much larger than that of object.

Object between the Focus and the Pole



Placing the object between the focus and the pole results in the formation of a virtual and erect image. The size of the image is larger compared to that of the object.

CONCAVE MIRROR IMAGE FORMATION SUMMARY

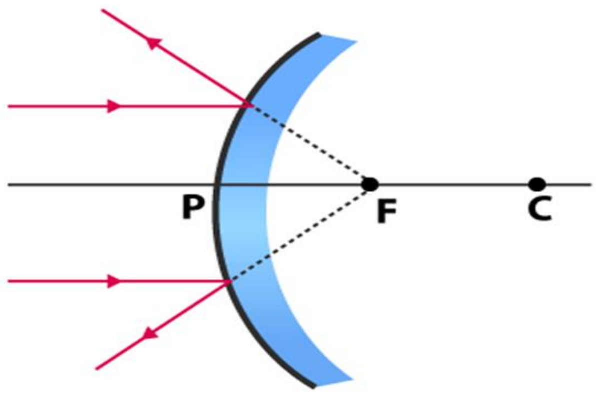
S. No	**Position of Object**	**Position of Image**	**Size of Image**	**Nature of Image**
1	Object at Infinity	At the Focus	Highly Diminished	Real and Inverted
2	Object Beyond the Centre of Curvature	Between the Centre of Curvature and Focus	Diminished	Real and Inverted
3	Object at the Centre of Curvature or Focus	At the Centre of Curvature	Same Size	Real and Inverted
4	Object Between the Centre of Curvature and Focus	Behind the Centre of Curvature	Enlarged	Real and Inverted
5	Object at the Focus	At Infinity	Highly Enlarged	Real and Inverted
6	Object Between the Focus and the Pole	Behind the Mirror	Enlarged	Virtual and Erect

IMAGE FORMATION BY CONVEX MIRROR

A convex mirror produces specific characteristics in the images formed. Let's explore the types of images formed by a convex mirror.

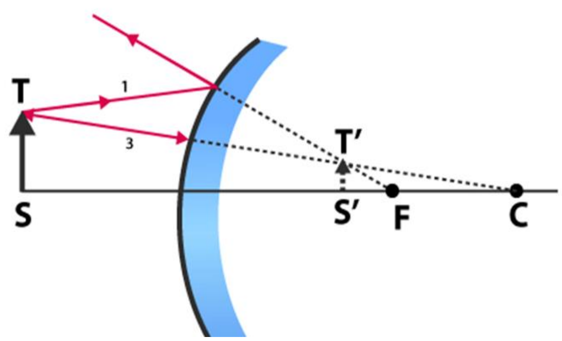
OBJECT AT INFINITY

When the object is positioned at infinity, a virtual image is formed at the focus of the convex mirror. The size of the image is significantly smaller than that of the object.



OBJECT AT A FINITE DISTANCE

When an object is placed at a finite distance from the mirror, a virtual image is formed between the pole and the focus of the convex mirror.



The size of the image is smaller than compared to that of the object.

It's important to note that in both cases, the images formed by a convex mirror are always virtual and erect. The nature of a convex mirror causes light rays to diverge upon reflection, creating virtual images with reduced sizes. Understanding these principles helps us accurately predict the characteristics of images formed by convex mirrors.

Concave Mirror Image Formation Summary

S. No	**Position Of Object**	**Position of Image**	**Size of Image**	**Nature of Image**
1	At Infinity	At the focus F, behind the mirror	Highly diminished	Virtual and Erect
2	Between Infinity and the Pole	Between P and F, behind the mirror	Diminished	Virtual and Erect

REFLECTION LAWS FOR CURVED SURFACES:

Reflection from curved surfaces still obeys the laws of reflection:

Law 1: The angle of incidence (angle between the incident ray and the normal) equals the angle of reflection (angle between the reflected ray and the normal).

Law 2: The incident ray, the normal to the surface at the point of incidence, and the reflected ray all lie in the same plane.

Concepts of Curved Mirrors:

Focal Point (F): The point where parallel light rays meet (for concave mirrors) or appear to diverge from (for convex mirrors) after reflection.

Center of Curvature (C): The center of the sphere of which the curved mirror is a part. For concave mirrors, it is in front of the mirror; for convex mirrors, it is behind.

Radius of Curvature (R): The distance between the mirror's surface and its center of curvature.

Principal Axis: A straight line passing through the center of curvature and the focal point, perpendicular to the surface of the mirror.

Real Image vs. Virtual Image:

Real Image: Formed when reflected rays converge and meet at a point; can be projected on a screen (seen with concave mirrors).

Virtual Image: Formed when reflected rays diverge and appear to originate from a point behind the mirror; cannot be projected on a screen (seen with both concave and convex mirrors).

Applications of Curved Mirrors:

Concave Mirrors:

Used in telescopes to gather and focus light from distant celestial bodies.

Used in headlights and flashlights to direct light into a focused beam.

Used in shaving or makeup mirrors to produce magnified, virtual images.

They are also used to provide a magnified image of the face for applying make-up or shaving.

In illumination applications, concave mirrors are used to gather light from a small source and direct it outward in a beam as in torches, headlamps and spotlights, or to collect light from a large area and focus it into a small spot, as in concentrated solar power.

Concave mirrors are used to form optical cavities, which are important in laser construction. Some dental mirrors use a concave surface to provide a magnified image.

The mirror landing aid system of modern aircraft carriers also uses a concave mirror.

Convex Mirrors:

Used in vehicle side mirrors because they offer a wider field of view, helping drivers see more of the road. Convex mirror lets motorists see around a corner.

Commonly used in security mirrors in stores or parking lots for better surveillance due to the wide-angle reflection.

The passenger-side mirror on a car is typically a convex mirror. In some countries, these are labeled with the safety warning "Objects in mirror are closer than they appear", to warn the driver of the convex mirror's distorting effects on distance perception. Convex mirrors are preferred in vehicles because they give an upright (not inverted), though diminished (smaller), image and because they provide a wider field of view as they are curved outwards.

These mirrors are often found in the hallways of various buildings (commonly known as "hallway safety mirrors"), including hospitals, hotels, schools, stores, and apartment buildings. They are usually mounted on a wall or ceiling where hallways intersect each other or where they make sharp turns. They are useful for people to look at any obstruction they will face on the next hallway or after the next turn. They are also used on roads, driveways, and alleys to provide safety for road users where there is a lack of visibility, especially at curves and turns.

Convex mirrors are used in some automated teller machines as a simple and handy security feature, allowing the users to see what is happening behind them. Similar devices are sold to be attached to ordinary computer monitors. Convex mirrors make everything seem smaller but cover a larger area of surveillance.

Determine the focal length of concave mirrors using a variety of methods

Determining the Focal Length of Concave Mirrors

The focal length (f) of a concave mirror is the distance from the mirror's surface to its focal point, where parallel light rays converge after reflection. Several methods can be used to determine the focal length of concave mirrors, including direct experimentation with light sources, practical observation of image formation, and mathematical calculations.

Using a Distant Object (Sunlight or Distant Light Source)

Method Overview:

This is one of the simplest methods and relies on the fact that light rays from distant objects (such as the sun) are nearly parallel when they reach the mirror. These parallel rays converge at the focal point after reflection.

Steps:
Take the concave mirror outside on a sunny day or use a distant artificial light source.
Position a screen or white paper in front of the mirror.
Adjust the position of the screen until a sharp, bright spot of light (the focused rays) appears on the screen. This point is where the parallel rays converge.
Measure the distance from the mirror's surface to the screen. This distance is the focal length (f).

Notes:
This method works well for objects far away because the incoming rays are nearly parallel.
The sharpness of the focused spot helps in accurately determining the focal length.Typically used to determine the focal length of mirrors used in telescopes or headlights.

Using the Image of a Nearby Object (Object-Image Distance Method)

Method Overview:

This method uses an object at a finite distance from the mirror and applies the mirror formula to calculate the focal length based on the object distance and image distance.

Mirror Formula: $\frac{1}{f} = \frac{1}{u} + \frac{1}{v}$

Where: f is the focal length, u is the object distance (distance from the object to the mirror), and v is the image distance (distance from the image to the mirror).

Steps:
Place an object (such as a candle or a small object) at a measured distance (u) in front of the concave mirror.
Adjust a screen until a sharp image of the object forms on the screen. This is a real image formed by the mirror.
Measure the distance from the mirror to the image (v).

Use the mirror formula to calculate the focal length f.

Notes: This method requires careful measurement of the object and image distances.

The object should not be placed too close to the focal point to avoid complications in obtaining a sharp image.

Using the Focal Length Formula and Parallax Method

Method Overview:

This method involves creating a virtual image inside the mirror using a bright object and relies on visual observation of parallax to find the exact focal point.

Steps:

Place a bright object (such as a light bulb or candle) at a measured distance in front of the concave mirror.

Stand behind the object and look into the mirror. Move your head slightly from side to side.

If there is no parallax between the object and its reflection (they appear to overlap and move together), the object is at the focal point.

Measure the distance from the mirror to the object; this distance is the focal length.

Notes: This method works well for concave mirrors with shorter focal lengths.

Parallax refers to the apparent shift in the position of an object when viewed from different angles. When parallax is zero, the object is located at the focal point.

Using Ray Diagrams and Graphical Methods

Method Overview:

This method is based on drawing ray diagrams to scale and using the properties of concave mirrors to graphically find the focal point.

Steps:

Draw a principal axis on a sheet of paper.

Mark the center of curvature and the mirror on the axis.

Draw two rays from the top of the object:

One ray parallel to the principal axis, which reflects through the focal point.

Another ray passing through the focal point, which reflects parallel to the principal axis. Where the reflected rays intersect is where the image is formed.

Measure the distance from the mirror to the focal point to determine the focal length.

Notes: This is a theoretical method that helps visualize how light behaves with concave mirrors.

It's useful for learners to understand ray diagrams and the relationship between object distance and image formation.

Using an Optical Bench Setup (Laboratory Method)

Method Overview:

This method uses precise instruments in a laboratory setting to measure focal length more accurately.

Equipment:

Optical bench (a straight, graduated track for positioning mirrors and objects),

Concave mirror,

Light source,

Measuring instruments (ruler or caliper).

Steps:

Place the concave mirror on the optical bench at a fixed position.

Position an object (light source or object with clear edges) at a specific distance from the mirror.

Move a screen along the optical bench to capture the sharp image.

Record the object distance and image distance.

Use the mirror formula to calculate the focal length.

Notes: This method is precise and commonly used in physics labs.

The optical bench allows for fine adjustments and accurate measurements.

Conclusion:

The focal length of a concave mirror can be determined using a variety of methods, each suited to different contexts:

The distant object method is simple and effective for sunlight or distant sources.

The object-image distance method and parallax method provide more accurate results for nearby objects.

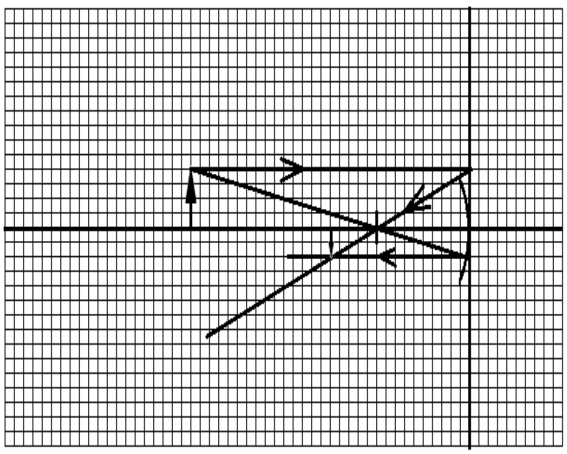
Ray diagrams help with conceptual understanding, while the optical bench method is precise and ideal for controlled experiments in a lab setting.

By using one or more of these methods, learners can gain a deep understanding of how concave mirrors focus light and how focal length plays a critical role in optical applications.

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

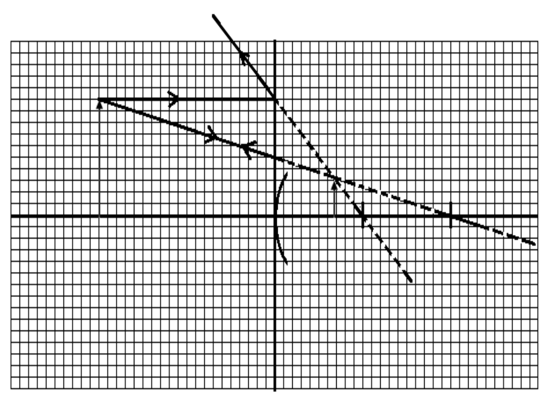
OR

This is the ratio of image distance from distance from the mirror to the object distance from the mirror

$M = \frac{v}{u}$,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. Draw a ray diagram, locate the position of the image. Calculate the magnification (1cm: 5cm)



USES OF CURVED MIRRORS

Convex mirrors: They are used as driving mirrors because;

They give a wide field of view, and they give upright images of the object

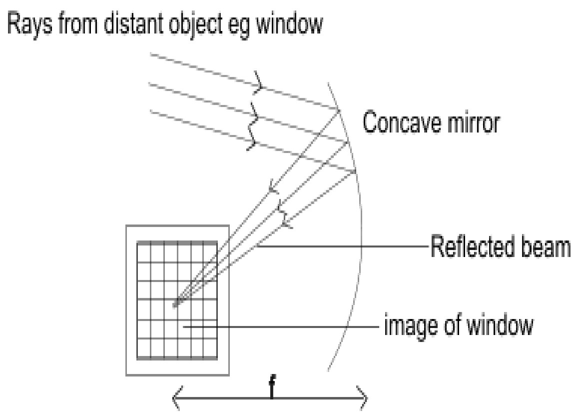
Disadvantages

It gives a false impression of the distance of an object

The object is diminished.

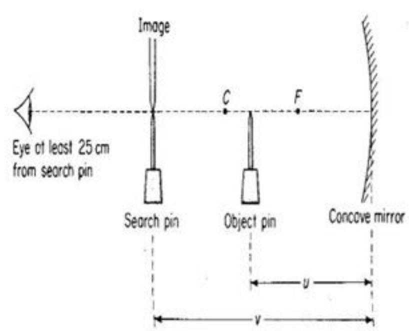
Concave mirror
Used in head lamps , torches , parabolic mirrors
It can be used as shaving mirror
Used by dentists for magnification
Can be used in astronomical telescope (reflecting type)
Can be used as solar concentrators

MEASURING FOCAL LENGTH OF A CONCAVE MIRROR
METHOD 1:
Distant object method (rough method)
Hold a concave mirror at one end focusing the 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, $\frac{1}{f} = \frac{1}{u} + \frac{1}{v}$
A mean value for focal length f is obtained from the mirror formula

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

By scale drawing (using graph paper)

1. Find 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

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.

2.6 Magnets and magnetic fields

Learning outcomes

a) *Know that a small number of materials are magnetic, but most are not (k)*
b) *Know how magnets can be made and destroyed (k, s)*
c) *Understand the behaviour of magnets and magnetic fields(u)*
d) *Know that the earth is a magnet and how a compass is used to determine direction (k, s)*

The force which causes attraction or repulsion by a magnet is called magnetic force. A magnet has two types of poles, a north pole and a south pole. Like poles repel while unlike poles attract. Some materials are attracted by a magnet while others are not. Those which are attracted are called magnetic materials while those not attracted are called non-magnetic materials.

Magnetic and non-magnetic materials are classified based on their interaction with a magnetic field. Magnetic materials are those that can be attracted to a magnet, while non-magnetic materials do not exhibit this property. The distinction between these two types is due to the atomic structure and the alignment of electrons within the material, which determines whether or not it responds to a magnetic field.

Magnetic Materials

Magnetic materials are primarily composed of metals that have magnetic properties. These materials contain regions called magnetic domains, which are groups of atoms with aligned magnetic moments. In the presence of a magnetic field, these domains align themselves in the direction of the field, allowing the material to be attracted to the magnet. Common magnetic materials are iron, nickel, and cobalt. Magnetic materials are often used in applications that require the manipulation of magnetic fields, such as in electromagnets, motors, and electronic devices.

Characteristics of Magnetic Materials:
They are attracted to a magnet.
Their magnetic domains can be aligned in a magnetic field.
When placed near a magnet, they experience a force that draws them toward the magnetic field.
Examples include iron, nickel, cobalt, and some alloys like steel (which contains iron).

Examples of Magnetic Materials:

Iron: One of the most common magnetic materials. It is highly susceptible to magnetization and retains magnetic properties even after being removed from a magnetic field.
Nickel: Another magnetic metal, nickel is often used in the production of alloys with strong magnetic properties.
Cobalt: A magnetic metal that can also be used to produce permanent magnets.
Steel: An alloy of iron, steel is magnetic due to its iron content. It can become magnetized but may lose its magnetism over time unless treated to become a permanent magnet.

Non-Magnetic Materials

Non-magnetic materials are materials that do not exhibit any magnetic properties. In these materials, the magnetic domains do not align in the presence of a magnetic field, or they do not have magnetic domains at all. Non-magnetic materials may include non-metals as well as certain metals. Non-metals such as wood, plastic, and rubber are inherently non-magnetic because they do not contain any elements with magnetic properties. Some metals, like copper, aluminium, and zinc, are also non-magnetic due to their atomic structure, which prevents the alignment of magnetic domains.

Characteristics of Non-Magnetic Materials:
They are not attracted to a magnet.
They do not have magnetic domains or their domains do not align with a magnetic field.
They experience no force when placed in a magnetic field.
Examples include wood, plastic, rubber, copper, aluminium, and zinc.
Examples of Non-Magnetic Materials:
Copper: A non-magnetic metal commonly used in electrical wiring due to its excellent conductivity and lack of magnetic interference.
Aluminium: Another non-magnetic metal that is lightweight and often used in manufacturing and packaging.
Zinc: A non-magnetic metal used for galvanization to prevent rusting in steel and iron.
Wood: An organic, non-metallic material that is non-magnetic and often used in construction and manufacturing.
Rubber: A flexible, non-magnetic material often used for insulation and protective coverings.

How to Identify Magnetic and Non-Magnetic Materials

The classification of materials into magnetic and non-magnetic can be done using a simple experiment with a magnet. By bringing a magnet close to various materials, learners can observe whether the material is attracted to the magnet (indicating it is magnetic) or not (indicating it is non-magnetic).

Testing Magnetic Properties:

Magnetic Materials: When a magnet is brought near a magnetic material like iron or nickel, it will be attracted to the magnet. If the material is a permanent magnet, it will either be attracted to or repel the other magnet depending on the poles.

Non-Magnetic Materials: When a magnet is brought near non-magnetic materials like wood, rubber, or copper, there will be no attraction or movement. These materials do not interact with magnetic fields.

Magnetic and Non-Magnetic Metals

It’s important to note that not all metals are magnetic. While metals like iron, nickel, and cobalt are strongly magnetic, other metals, like copper, aluminium, and zinc, are not. The magnetic properties of a metal depend on the arrangement of its electrons and the ability of its atomic structure to allow magnetic domains to align in a magnetic field.

Magnetic Metals: Iron (Fe), Nickel (Ni), Cobalt (Co) , and Steel (an alloy of iron)

Non-Magnetic Metals: Copper (Cu), Aluminium (Al), Zinc (Zn), Gold (Au),and Silver (Ag)

Applications of Magnetic and Non-Magnetic Materials

Magnetic Materials:

Electromagnets: Magnetic materials like iron are used in electromagnets, which are essential components in motors, generators, and transformers.

Permanent Magnets: Magnets made from cobalt or certain alloys of iron are used in speakers, sensors, and electronic devices.

Data Storage: Magnetic materials are used in hard drives to store data magnetically.

Non-Magnetic Materials:

Electrical Wiring: Non-magnetic metals like copper and aluminium are used in electrical wiring and electronics because they do not interfere with the magnetic fields generated by electrical currents.

Construction: Non-magnetic materials like wood and rubber are used in construction for insulation and protection.

Food Packaging: Aluminium, a non-magnetic material, is widely used in packaging food and beverages because of its non-reactive nature.

The classification of materials as magnetic or non-magnetic is based on their response to a magnetic field. Magnetic materials, such as iron, nickel, and cobalt, are attracted to magnets, while non-magnetic materials, such as wood, copper, and aluminium, are not. This distinction is critical in various applications, from manufacturing to electronics, where the presence or absence of magnetic properties can influence the material's use.

Task 2: Investigation of Magnetic Poles and the Law of Magnetism

Investigation of Magnetic Poles and the Law of Magnetism

Overview:

Magnetism is a force of attraction or repulsion that acts at a distance due to a magnetic field. Magnets have two poles, called the north pole (N) and the south pole (S). The behavior of magnets, particularly how their poles interact with each other, is governed by fundamental principles known as the law of magnetism. This investigation focuses on understanding the properties of magnetic poles, the interactions between them, and the law of magnetism.

Magnetic Poles:

Magnetic poles are the regions at the ends of a magnet where the magnetic field is strongest. Every magnet, regardless of its size or shape, has two poles:

North Pole (N): The pole that points toward the Earth's geographical north when the magnet is allowed to move freely.

South Pole (S): The pole that points toward the Earth's geographical south.

Magnetic Poles Always Come in Pairs: A crucial aspect of magnetism is that magnetic poles always come in pairs. You cannot isolate a single north or south pole. If you break a magnet in half, each half will have its own north and south poles.

Interaction of Magnetic Poles:

The behavior of magnets in relation to one another depends on how their poles interact. The fundamental rule governing the interaction between magnetic poles is:
Like poles repel: When two north poles (N-N) or two south poles (S-S) of magnets are brought close together, they repel each other.
Opposite poles attract: When a north pole (N) is brought near a south pole (S), they attract each other.

Investigation of Magnetic Pole Interaction:

To investigate the behavior of magnetic poles, learners can perform the following steps:

Materials Needed:
Two bar magnets, A smooth surface on which the magnets can freely move (e.g., a table or board).
Procedure:
Bring the north pole of one bar magnet near the north pole of another magnet and observe the interaction. The magnets will repel each other.
Repeat the experiment with the south poles of both magnets. Again, the magnets will repel each other.
Now, bring the north pole of one magnet near the south pole of the other magnet. The magnets will attract each other and move toward each other.
Record observations and confirm that like poles repel and opposite poles attract.
Observation:
Like poles (N-N or S-S) push away from each other, while opposite poles (N-S) pull toward each other.
This behavior follows the fundamental law of magnetism.

The law of magnetism states:
Like poles repel each other.
Opposite poles attract each other.

This principle is analogous to the behavior of electric charges, where like charges (positive-positive or negative-negative) repel each other, and unlike charges (positive-negative) attract each other.

Explaining Magnetic Attraction and Repulsion:

The force between two magnetic poles depends on the strength of the magnets and the distance between them. The closer two poles are, the stronger the force of attraction or repulsion.

This force is a result of the alignment of the magnetic domains within the materials. When opposite poles come near each other, their magnetic fields align in a complementary way, causing attraction. When like poles come near each other, their fields oppose one another, causing repulsion.

Identifying North and South Poles of a Magnet:

There are several methods to identify which pole of a magnet is north and which is south.

Using a Compass:
A compass needle is itself a small magnet. The north-seeking end of the compass needle will point toward the south pole of a magnet.
To identify the poles of a bar magnet, hold the compass near one end of the magnet. If the north ends of the compass needle points toward the magnet, then the pole near it is the magnet's South Pole. If the north end of the compass needle points away, the magnet's pole near the compass is the North Pole.
Using a Freely Suspended Magnet:
When a bar magnet is suspended freely (e.g., by a string), it will naturally align itself with the Earth's magnetic field.
The end of the magnet that points toward the Earth's geographic north is the magnet's North Pole. The opposite end, pointing toward the Earth's geographic south, is the magnet's South Pole.

Interaction with another Known Magnet:

By bringing a magnet with known poles close to an unknown magnet, you can determine the polarity of the unknown magnet. Like poles will repel, and opposite poles will attract.

Why Magnetic Poles Cannot Be Isolated:

One of the fundamental properties of magnets is that you cannot isolate a single pole (i.e., a monopole). If you cut a bar magnet in half, each resulting piece will still have both a north and a south pole. This happens because the magnetic domains inside the material continue to align in a manner that creates both poles, no matter how small the magnet becomes.

Investigating Magnetic Fields around Poles:
Visualizing Magnetic Fields:
Magnetic fields can be visualized using iron filings and a bar magnet.
Materials Needed: A bar magnet, a piece of paper, and iron filings.
Procedure:
Place the magnet under the paper and sprinkle iron filings on top.
Gently tap the paper to allow the iron filings to arrange themselves along the magnetic field lines.
Observation:
The iron filings will form a pattern that shows the magnetic field lines emerging from the North Pole and curving around to enter the South Pole.
The field lines are densest near the poles, where the magnetic force is strongest.
Conclusion: The magnetic field lines indicate the direction and strength of the magnetic field, with lines moving from the North Pole to the South Pole.

Practical Applications of Magnetic Poles:
Understanding magnetic poles and the law of magnetism is critical in many technological applications:

Electric Motors and Generators: Motors and generators use the interaction between magnetic fields and electric currents to produce motion or electricity.
Magnets in Electronics: Magnetic poles are used in data storage devices, speakers, and sensors.
Magnetic Compasses: The principle that a magnet aligns with the Earth's magnetic field is the basis of how a compass works for navigation.
Magnetic Levitation: Magnetic repulsion (like poles repelling) is used in technologies like maglev (magnetic levitation) trains, which hover above tracks due to strong repulsive forces between magnets.

The investigation of magnetic poles reveals that magnets always have a north and a south pole, and their interactions follow the law of magnetism, where like poles repel and opposite poles attract. Magnetic fields can be visualized using iron filings, and the principles of magnetic pole interaction are applied in numerous practical devices and technologies.

Task 3: Plotting Magnetic Fields with Iron Filings

Plotting Magnetic Fields with Iron Filings

Overview:

Magnetic fields are invisible regions around a magnet where magnetic forces can be felt. To visualize these fields, one effective method is using iron filings. Iron filings are small particles of iron that align themselves along the magnetic field lines when placed near a magnet. By observing the arrangement of these filings, learners can gain insights into the structure and behavior of magnetic fields around different magnets.

Understanding Magnetic Fields:

A magnetic field is the area around a magnet where magnetic forces act. The field lines represent the direction and strength of the magnetic field, and they always move from the North Pole to the south pole of the magnet.

Magnetic Field Lines:
These are imaginary lines that help visualize the magnetic force.
The direction of the lines shows the direction of the magnetic force: from the north pole to the South Pole.
The density or closeness of the lines indicates the strength of the field. The field is strongest near the poles, where the lines are closest together.
Materials Needed for the Experiment:
Bar Magnet (or any other magnet, such as a horseshoe magnet), Iron Filings, A Sheet of Paper (or plastic or glass sheet), Tap or a soft tapping surface (to gently vibrate the filings)

Procedure for Plotting Magnetic Fields:

Setup:
Place the magnet on a flat surface, such as a table.
Place the sheet of paper over the magnet. This sheet acts as a surface for the iron filings and prevents direct contact between the filings and the magnet, allowing the filings to move freely.
Carefully sprinkle iron filings evenly over the paper, ensuring that the filings cover the area around the magnet.
Avoid clumping the filings in one place, as this may obscure the pattern of the magnetic field lines.
Gently tap the paper to help the iron filings settle and align themselves along the magnetic field lines. The tapping helps the filings overcome friction and better respond to the magnetic forces.

Observation:

The iron filings will gradually arrange themselves into distinct patterns. These patterns represent the magnetic field lines.

The filings will form curved lines that emanate from the north pole of the magnet and curve around to enter the South Pole.

Observing and Interpreting the Magnetic Field Patterns:

Magnetic Field around a Bar Magnet:

Around a bar magnet, the iron filings will form patterns showing the magnetic field lines emerging from the north pole and curving around to enter the south pole. The field lines are densest near the poles, indicating that the magnetic force is strongest at the poles. The lines spread out as they move away from the poles, showing that the field weakens with distance.

Characteristics of the Field Lines:
Closed Loops: The magnetic field lines form continuous closed loops. They exit from the North Pole, travel through space, and enter the South Pole before passing through the magnet to complete the loop.
Direction: The direction of the magnetic field is from the North Pole to the South Pole outside the magnet, and from the South Pole to the North Pole inside the magnet.
Density of Lines: The closer the lines are to each other, the stronger the magnetic field. Near the poles, the lines are densely packed, indicating a strong field. As you move away from the magnet, the lines spread out, representing a weaker field.
Field Lines Never Cross: Magnetic field lines never intersect or cross each other. This is because at any given point, the magnetic field can only have one direction.

Drawing the Magnetic Field:
After observing the pattern of the iron filings, learners can draw diagrams to represent the magnetic field lines.
Drawing Field Lines:
Start from the north pole of the magnet and draw lines that curve outward and around the magnet, eventually leading to the South Pole.
The lines should be more concentrated near the poles and spread out as they move away.
Inside the magnet, draw lines that connect from the South Pole back to the North Pole to complete the loop.

Indicating Direction:
Use arrows to indicate the direction of the field lines. The arrows should point outward from the North Pole and inward toward the South Pole.
Exploring Magnetic Fields of Different Shapes of Magnets:
The shape of the magnet affects the configuration of the magnetic field. Using iron filings, learners can explore how the field changes with different types of magnets.

Horseshoe Magnet:

A horseshoe magnet has its poles much closer together compared to a bar magnet. When plotting the field of a horseshoe magnet, the iron filings will show a concentrated pattern of field lines between the north and south poles, indicating a strong magnetic field in this region.

Circular Magnets or Ring Magnets:

For a circular or ring magnet, the magnetic field lines will form concentric loops around the magnet, with a more complex pattern emerging compared to the bar or horseshoe magnets.

Magnetic Dipoles:
If two bar magnets are placed end-to-end, the filings will show how the field lines flow between the two magnets.
If the magnets are placed with like poles facing each other (N-N or S-S), the iron filings will show a repulsive pattern where the field lines bend away from each other, indicating a weak or zero field in the center.
Magnetic Field of Two Magnets in Different Configurations:

Two Bar Magnets with Opposite Poles Facing Each Other (N-S):

When two bar magnets are placed with opposite poles (north pole of one magnet and south pole of the other) facing each other, the iron filings will show field lines connecting the poles. This indicates a strong attraction between the poles.

Two Bar Magnets with Like Poles Facing Each Other (N-N or S-S):

If the like poles of two bar magnets are placed near each other, the field lines will bend away from each other, creating a repulsive pattern. The iron filings will show this by forming an empty space or curved lines between the magnets.

Practical Applications of Magnetic Field Visualization:

Magnetic Field Mapping: Plotting magnetic fields with iron filings is used to map the field distribution of permanent magnets and electromagnets in research and industrial applications.

Magnetic Sensors and Devices: Understanding magnetic field distribution helps in designing sensors like Hall effect sensors, which detect magnetic fields for use in devices like smartphones and electric vehicles.

Data Storage: Hard drives use magnetic fields to store data. Understanding the magnetic field patterns of the tiny magnetic domains on a hard disk allows engineers to improve storage technologies.

Medical Imaging: Magnetic fields play a key role in medical imaging techniques such as MRI (Magnetic Resonance Imaging). Visualizing and understanding magnetic fields helps improve these technologies.

Plotting magnetic fields using iron filings is a simple and effective way to visualize the otherwise invisible magnetic field lines around a magnet. By observing how iron filings align with the magnetic field, learners can gain a deeper understanding of the properties of magnetic fields, such as their direction, strength, and behavior in the presence of different types of magnets. The process provides valuable insights into both theoretical and practical aspects of magnetism, with applications ranging from basic science to advanced technology.

Task 4: Magnet Strength and Magnetic Needle Investigation

Magnet Strength and Magnetic Needle Investigation

Magnetism is a force that can vary in strength depending on the size, shape, and material of the magnet. The strength of a magnet determines how well it can attract or repel other magnetic materials and the distance at which its magnetic force is effective. This investigation covers methods of measuring magnet strength, including using a chain of nails or pins, and also explores how a magnetized needle behaves when suspended freely, an important concept in navigation and compass use.

1. Measuring Magnet Strength Using a Chain of Small Nails or Pins

Objective:

To investigate the strength of a magnet by observing how many small nails or pins it can hold in a chain.

Materials Needed:

A bar magnet or any other magnet, A collection of small nails or pins, A ruler to measure the length of the chain.

Procedure:
Arrange the Nails or Pins:
Hold the magnet horizontally, either in your hand or on a stable surface.
Touch the magnet's north or South Pole to a small nail or pin. This nail will become magnetized and, in turn, be able to attract another nail.

Creating a Chain:
Attach additional nails or pins one by one to the end of the previous one, forming a chain.
Continue adding nails until the magnet can no longer hold the next one in the chain due to the decreasing strength of the magnetic force at a greater distance.
Measure the Length of the Chain:
Count how many nails or pins the magnet can hold before the chain breaks due to the magnetic force becoming too weak to support further nails.
You can also measure the length of the chain from the magnet to the last pin held.

Observations:
Stronger magnets will be able to hold a longer chain of nails or pins.
Weaker magnets will form a shorter chain, as they lose their ability to magnetize the additional pins sooner.
The strength of the magnetic field decreases as the distance from the magnet increases. The magnet can hold fewer nails the farther the chain extends from its pole.

Conclusion:

The length of the chain and the number of nails or pins a magnet can hold are direct indicators of the magnet's strength. A stronger magnet can attract and hold more pins, forming a longer chain, while a weaker magnet cannot hold as many.

Factors Affecting Magnet Strength:

Size of the Magnet: Larger magnets generally produce stronger magnetic fields.

Type of Material: Magnets made from materials like neodymium (a rare-earth metal) are much stronger than those made from iron or ferrite.

Magnetization Process: How a magnet was manufactured and magnetized affects its strength.

Investigation of a Magnetized Needle Suspended Freely

A magnetized needle can be used to investigate the directional properties of a magnet, particularly how it aligns with the Earth's magnetic field. This concept is the foundation of the compass and is used in navigation.

Objective: To investigate how a magnetized needle behaves when suspended freely, and understand how it aligns with the Earth's magnetic poles.

Materials Needed: A sewing needle or any small metallic needle, A magnet (preferably a strong bar magnet), Thread or a thin piece of string, A bowl of water (optional, for floating the needle), Paper to record observations.

Procedure:

Magnetizing the Needle:

Rub the needle along the magnet in one direction several times. This action aligns the magnetic domains inside the needle, magnetizing it.

Ensure that you stroke the needle in the same direction for consistent magnetization.

Suspending the Needle:

Tie a thread around the center of the needle and suspend it from a stable object (like a stand or a pencil) so that it can rotate freely in the air.

Alternatively, you can place the needle on the surface of a bowl of water, where it will float and rotate freely.

Observation:

After a few moments, the needle will stop moving and point in a specific direction.

The north-seeking end of the needle will align itself with the Earth's magnetic north, while the other end points to the south.

Confirming Direction:

Use a compass to confirm that the needle's north-seeking end is pointing toward geographic north (which is close to the Earth's magnetic north pole).

If suspended freely, the needle will always settle in a north-south direction, due to the Earth's magnetic field.

Explanation of the Behavior:

Earth as a Magnet:

The Earth itself behaves like a giant magnet, with a magnetic field that extends into space. It has a magnetic north pole (located near the geographic south) and a magnetic south pole (located near the geographic north). A magnetized needle aligns with this field, with its north pole seeking the Earth's magnetic south (geographic north) and its south pole seeking the Earth’s magnetic north (geographic south).

Magnetized Needles in Compasses:

This principle is used in compasses, where a magnetized needle is mounted so it can rotate freely. The needle aligns with the Earth's magnetic field and points north, allowing people to navigate.

Conclusion:
A magnetized needle, when suspended freely, will always align itself with the Earth’s magnetic field, with the north-seeking pole pointing toward the Earth’s magnetic north. This investigation demonstrates the directional properties of magnets and how they are used in navigation through tools like the compass.

Researching Earth as a Magnet and Navigation with a Magnet

Earth’s Magnetic Field:
The Earth behaves like a giant bar magnet, with a magnetic field that extends from the core of the planet into space. This field is what compasses and magnetized needles respond to when aligning in a north-south direction.
The Earth’s magnetic poles are not perfectly aligned with the geographic poles. The magnetic north pole is actually located near the geographic south, and the magnetic South Pole near the geographic north.

How Earth’s Magnetic Field is generated:

The Earth’s magnetic field is believed to be generated by the movement of molten iron and other metals in the Earth's outer core. This motion creates electric currents, which in turn generate the magnetic field through a process called the ***geodynamo effect.***

Magnetic Declination: Magnetic declination refers to the angle between the directions a compass needle points (magnetic north) and the geographic North Pole. This angle varies depending on your location on Earth.

Magnet and Navigation: Magnets are critical tools in navigation because of their ability to align with the Earth's magnetic field. A compass is the most common navigational tool that uses a freely rotating magnetized needle to determine direction. Navigating with a Compass: By using a compass, individuals can orient themselves and find directions based on the needle’s alignment with magnetic north. This is particularly useful when navigating unfamiliar terrain or at sea where landmarks are unavailable.

The investigation of magnet strength using small nails or pins provides a simple way to measure how strong a magnet is by observing how many objects it can attract and hold. On the other hand, the behavior of a magnetized needle suspended freely demonstrates the directional properties of magnets, which are fundamental in navigation. The Earth's magnetic field acts as a guiding force for magnetized objects, helping us understand how compasses work and why they have been indispensable tools for explorers and navigators throughout history.

Task 5: Earth as a Magnet and Navigation with Magnets

Earth as a Magnet and Navigation with Magnets

Overview: The Earth exhibits magnetic properties similar to a giant bar magnet, with a magnetic field that influences compass navigation and various technological applications. Understanding Earth's magnetism and how it aids navigation provides insight into the fundamental principles of magnetism and its practical applications.

Earth as a Magnet

Earth’s Magnetic Field:

Magnetic Field Generation:

The Earth's magnetic field is generated by the movement of molten iron and other metals in the outer core, a process known as the **geodynamo effect.**

As these molten metals move, they generate electric currents, which in turn produce a magnetic field. This field extends from the Earth's core into space.

Magnetic Poles:

Magnetic North Pole: The magnetic north pole is the point where the Earth's magnetic field lines point vertically downwards. It is located near the Earth's geographic South Pole.

Magnetic South Pole: The magnetic South Pole is where the magnetic field lines point vertically upwards. It is located near the Earth's geographic North Pole.

Geographic Poles: The geographic north and south poles are based on the Earth's rotational axis and do not align perfectly with the magnetic poles.

Magnetic Field Lines:

Magnetic field lines emerge from the magnetic north pole, curve around the Earth, and re-enter at the magnetic South Pole. They form closed loops through the Earth's interior. The field lines are denser near the poles, indicating stronger magnetic forces, and spread out as they move away from the poles.

Magnetic Declination:

Magnetic declination is the angle between the direction a compass needle points (magnetic north) and true geographic north. This angle varies depending on your location on Earth.

Variation across the Globe: Declination values can be positive or negative, depending on whether magnetic north is east or west of true north. Navigational charts and compasses often include declination adjustments.

Magnetic Field Strength:

The strength of Earth's magnetic field varies by location and depth. The field is generally stronger near the poles and weaker at the equator.

Magnetic Anomalies: Local variations in Earth's magnetic field, known as magnetic anomalies, occur due to the presence of certain minerals and geological structures.

Navigation with Magnets

Principle of the Compass:

Magnetized Needle: A compass uses a magnetized needle that aligns itself with the Earth's magnetic field. The needle's north-seeking pole points toward the Earth's magnetic South Pole.

Compass Construction:

Needle: A thin, elongated magnetized piece of metal.
Pivot: The needle is mounted on a pivot or gimbal to allow free rotation.
Graduated Dial: The compass face is marked with directions (N, S, E, W) and degrees for precise navigation.
Using a Compass:

Holding the Compass:

Hold the compass level and steady to ensure the needle can rotate freely.
Reading Directions:
Allow the needle to settle and point toward magnetic north.
Align the compass housing or dial with the direction of travel.
Use the compass to determine headings and bearings relative to magnetic north.

Adjusting for Declination:

Account for magnetic declination by adjusting the compass reading based on local declination values. This ensures accuracy when navigating.

Magnetic Navigation Techniques:

Bearing and Heading:
Bearing: The direction or angle between the current position and the destination, measured clockwise from north.
Heading: The direction in which a vehicle or person is moving, which may need adjustment for drift and wind.
Map and Compass Navigation:
Use a topographic map alongside a compass to plot courses and navigate terrain. Align the map with magnetic north using the compass, and measure bearings to follow a specific route.

Great Circle Routes:

For long-distance navigation, such as in aviation, navigators use great circle routes. These are the shortest paths between two points on the Earth's surface, taking into account the curvature of the Earth.

Applications of Magnetic Navigation:

Aviation: Pilots use compasses and magnetic headings to navigate aircraft, along with other instruments like GPS.
Marine Navigation: Mariners use magnetic compasses and charts to navigate ships across oceans and seas.
Hiking and Backpacking: Compass navigation is crucial for outdoor enthusiasts to find their way in remote areas where GPS signals may be weak or unavailable.

3. Magnetic Phenomena and Their Impact on Navigation

Magnetic Variation and Anomalies:
Magnetic Variation: Refers to the changes in Earth's magnetic field over time due to solar activity and geomagnetic storms. These variations can affect navigation accuracy.
Magnetic Anomalies: Local deviations in the Earth's magnetic field caused by geological formations or mineral deposits can affect compass readings.

Impact of Solar Activity:

Solar Storms: Solar flares and coronal mass ejections can disturb the Earth's magnetic field, causing temporary deviations in compass readings and affecting navigation systems.
Auroras: Solar activity can also cause auroras, which are visible manifestations of the interaction between solar wind and Earth's magnetic field.

4. Modern Navigation Technologies:

While traditional magnetic compasses are still widely used, modern navigation relies on various advanced technologies:

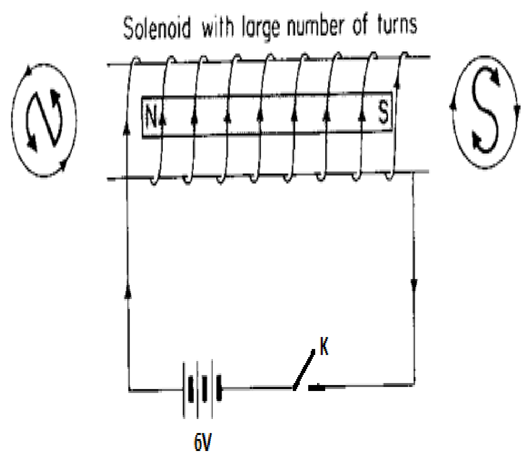
Global Positioning System (GPS): Uses satellites to provide precise location data and directions based on latitude and longitude.
Inertial Navigation Systems (INS): Utilizes accelerometers and gyroscopes to track movement and orientation without external references.
Magnetometers: Instruments that measure the strength and direction of magnetic fields. Used in various applications, including mineral exploration and scientific research.

The Earth acts as a giant magnet, generating a magnetic field that extends into space and influences various navigational tools and technologies. Understanding the Earth's magnetic field, including its poles, declination, and strength, is crucial for accurate navigation. Traditional magnetic compasses,

along with modern technologies like GPS and magnetometers, play essential roles in ensuring effective navigation and exploration. By leveraging both historical and contemporary methods, navigators can traverse the globe with greater precision and confidence.
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;
Electrical method
Stroke method
Induction method

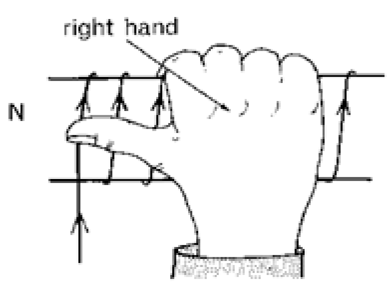


Electrical method

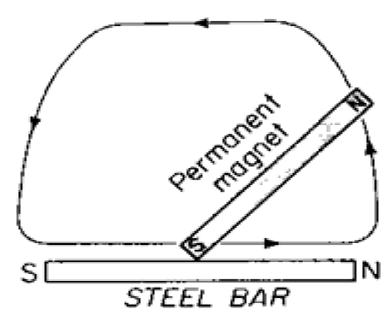
A cylindrical coil (solenoid) wound with 500 and above turns is connected in series with a 6V or 12V battery and a switch
A steel bar is placed inside the solenoid as shown below
The switch K is switched on and then off
On removing and testing the steel bar, it is obtained to be magnetized

Determining the polarity of an electrically magnetized steel bar

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



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



Stroke method

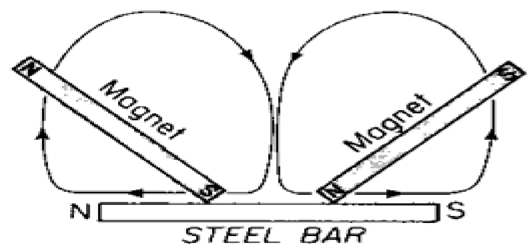
This can be done in two ways, i.e. Single stroke or Double stroke.

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 obtained 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 obtained to be magnetized.



Induction method
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 obtained out that after some time, the magnetic material becomes a magnet and can attract other pieces.

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.

Demagnetization
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.

Storing a magnet

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. 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.

Earth's magnetic field
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).

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
Soft magnetic materials: These are materials that can easily lose their magnetism.
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 obtained in electric bells

Used in magnetic shielding

Uses of Hard magnetic materials

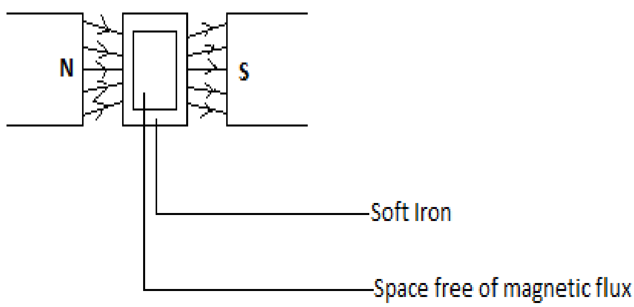
Used for making permanent magnets e.g. those used in radio speakers and motors

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

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.

2.7 Electrostatics

Learning Outcomes

a) *Understand everyday effects of static electricity and explain them in terms of the build-up and transfer of electrical charge (u,s)*
b) *Apply knowledge of electrostatic charge to explain the operation of devices like lightening conductors (u, s,v/a)*

Static electricity is a form of electric charge that accumulates on the surface of objects. It is created by the transfer of electrons between materials, resulting in an imbalance of electrical charges. This phenomenon is most noticeable in everyday life through various simple and relatable examples.

Fundamentals of Static Electricity
Basic Concepts:

Positive Charge: Caused by a deficiency of electrons.
Negative Charge: Caused by an excess of electrons

Static Electricity: The buildup of electric charge on an object, which remains stationary until discharged.

Insulators and Conductors:
Insulators: Materials that do not allow free movement of electrons (e.g., rubber, glass).
Conductors: Materials that allow free movement of electrons (e.g., metals like copper, aluminum).

Friction:
When two different materials are rubbed together, electrons are transferred from one material to the other. The material losing electrons becomes positively charged, while the material gaining electrons becomes negatively charged.

Everyday Examples of Static Electricity
A. Charging a Balloon
Procedure:
Rub a balloon against your hair or a woolen sweater for a few seconds.
Effect: The balloon becomes negatively charged as it gains extra electrons from your hair or the sweater.

Observation: The balloon can pick up small pieces of paper or make your hair stand on end.
Explanation: The balloon's negative charge repels electrons from the small pieces of paper, leaving them with a slight positive charge, causing an attractive force between the balloon and the paper.
B. Charging a Comb
Procedure:
Rub a plastic comb with a woolen cloth.
Effect: The comb becomes negatively charged due to the gain of electrons from the wool.
Observation: The comb can attract small pieces of paper or hair.
Explanation: The comb's negative charge attracts the positive charges in the small pieces of paper or hair, resulting in an attractive force.
C. Static on Clothing
Procedure: After drying clothes in a tumble dryer, observe how they stick together or cling to your body.
Effect: Clothes become statically charged due to friction during the drying process.
Explanation: The friction between clothes causes a transfer of electrons, making some clothes positively charged and others negatively charged. Opposite charges attract, causing the clothes to cling together.
3. Key Concepts Explained
A. How Friction Generates Electric Charge
Process: When two materials are rubbed together, electrons are transferred from one material to the other. This transfer results in one material becoming positively charged (loss of electrons) and the other becoming negatively charged (gain of electrons).
Example: Rubbing a balloon on your hair transfers electrons from your hair to the balloon. The balloon becomes negatively charged, and your hair becomes positively charged.
B. Charging by Induction
Process: Charging by induction occurs without direct contact between objects. A charged object is brought close to a neutral object, causing a redistribution of charges within the neutral object.
Example: Bringing a negatively charged rod close to a neutral metal sphere will repel electrons in the sphere away from the rod. This causes the side of the sphere closest to the rod to become positively charged.
C. Charge Transfer
Process: Charge transfer can occur through direct contact or induction. Electrons move from one object to another when they touch, balancing the

charge between them. **Example:** Touching a negatively charged object to a neutral object will transfer some of the excess electrons to the neutral object, making both objects negatively charged.

D. Particles Responsible for Charge

Electrons: Electrons are the particles responsible for electric charge. They carry a negative charge. The movement of electrons between objects creates static electricity.

Protons: Protons, found in the nucleus of an atom, carry a positive charge. In static electricity, protons remain fixed in place, while electrons move to create an imbalance of charge.

Everyday Examples of Static Electricity

Static Electricity: Static electricity refers to the buildup of electric charge on the surface of objects. This occurs when there is an imbalance between positive and negative charges.

Examples: Charging a Balloon:

Procedure: Rub a balloon against your hair or a woolen sweater.

Effect: The balloon becomes negatively charged and can attract small bits of paper or other lightweight materials. This happens because the balloon acquires extra electrons from the hair or sweater.

Charging a Comb:

Procedure: Rub a plastic comb with a woolen cloth.

Effect: The comb becomes negatively charged and can attract small pieces of paper or hair. This is similar to the balloon example, where the comb picks up extra electrons.

Static on Clothing:

Procedure: After removing clothes from a dryer, they often cling together.

Effect: Clothes can become statically charged through friction with each other in the dryer. This static charge causes the clothes to stick together or to other materials.

Friction Generates Electric Charge:

How It Works: When two materials rub against each other, electrons are transferred from one material to another. The material that gains electrons becomes negatively charged, while the material that loses electrons becomes positively charged.

Insulators vs. Conductors: On insulators, electric charge can build up because these materials do not allow electrons to move freely. For example, when rubbing a balloon, the balloon (an insulator) can retain the charge.

Charging by Induction:
How It Works: Charging by induction involves bringing a charged object close to a neutral object without direct contact. The presence of the charged object causes a redistribution of charges within the neutral object. This results in the neutral object acquiring a charge opposite to that of the charged object.
Example: If a negatively charged rod is brought near a neutral metal sphere, electrons in the sphere will be repelled, causing a positive charge to appear on the side closest to the rod.

Charge Transfer:
How It Works: Charges can be transferred between objects through direct contact or by induction. When two objects come into contact, electrons can move from one to the other, transferring the charge.
Particles Responsible for Charge:
Electrons: The primary particles responsible for electric charge are electrons. Electrons carry a negative charge. The movement of electrons from one object to another creates static electricity.

Gold Leaf Electroscope
Function of a Gold Leaf Electroscope:
A gold leaf electroscope is a device used to detect electric charge. It consists of a metal rod with a gold leaf at the end. The rod is housed in a container with a glass lid.
How It Works:
When a charged object comes into contact with the metal rod, it transfers charge to the electroscope. The gold leaf and the metal rod both become charged. If the electroscope is positively charged, the gold leaf will repel and move away from the rod. If it is negatively charged, the gold leaf will move away from the rod similarly. The gold leaf moves because like charges repel each other. When both the rod and the leaf have the same type of charge, they push away from each other.

Occurrences of Lightning in Uganda:
Frequency: Uganda experiences frequent thunderstorms, especially during the rainy seasons (March to May and September to November). Lightning is common in areas with high humidity and warm temperatures.
Impact: Lightning strikes can cause fires, damage to buildings, and even fatalities. Understanding the patterns and frequency of lightning can help in disaster preparedness and safety.
Causes of Lightning:

Static Discharge: Lightning is a form of static discharge that occurs when electric charges build up in clouds and the atmosphere. This buildup is caused by friction between different layers of air masses.
Charge Accumulation: As air currents cause collisions between ice crystals and water droplets in thunderstorms, static electricity accumulates. When the charge becomes strong enough, it is released as lightning.

Lightning Conductors:
How They Work: Lightning conductors are metal rods placed on buildings and structures to safely conduct lightning strikes into the ground. They provide a path of low resistance for the electrical charge, preventing damage to the structure.
Installation: Lightning conductors are installed at the highest points of a building and connected to a grounding system that disperses the charge safely into the earth.
Staying Safe in a Thunderstorm:
Stay indoors and avoid using electrical appliances. Lightning can strike through electrical wiring.
If caught outside, find a shelter away from tall objects like trees or metal structures.
If no shelter is available, crouch low to the ground to reduce the risk of being struck.
Do not swim or bathe during a lightning storm, as water can conduct electricity.

Geographical Distribution:
Western and Central Regions: Areas in Western and Central Uganda, including cities like Kampala, experience more frequent thunderstorms due to the convergence of moist air masses and elevated terrain.
Northern and Eastern Regions: These areas also experience lightning, but the frequency can be influenced by the seasonal movements of the Intertropical Convergence Zone (ITCZ), which affects weather patterns.

Factors Influencing Lightning Occurrence:
Topography: Elevated regions and mountainous areas are more prone to thunderstorms and lightning.
Humidity: High humidity levels, common in tropical climates, contribute to the formation of thunderstorms and lightning.
Temperature: Warm temperatures increase the likelihood of convection currents, which can lead to thunderstorm development.

Causes of Lightning in Uganda
A. Static Discharge:
Formation: Lightning is caused by the buildup of electrical charges within thunderstorms. This occurs when friction between ice crystals and water droplets within clouds generates static electricity.
Charge Accumulation: When the charge in a thundercloud becomes strong enough, it is discharged as lightning.
Weather Patterns:
Intertropical Convergence Zone (ITCZ): The ITCZ, a region where trade winds converge, can lead to intense thunderstorms and lightning in Uganda.
Convection Currents: Rising warm air causes moisture to condense, forming clouds and leading to the development of thunderstorms.

Impact of Lightning in Uganda
Property Damage:
Buildings: Lightning strikes can cause fires, damage electrical systems, and affect infrastructure.
Agriculture: Lightning can damage crops and cause fires in agricultural areas.
Human Safety:
Injuries and Fatalities: Lightning strikes pose significant risks to human safety. There are reports of injuries and fatalities due to lightning strikes in Uganda.
Environmental Impact:
Forest Fires: Lightning can ignite forest fires, affecting biodiversity and ecosystems.

Lightning Safety and Preparedness
Safety Measures:
Seek Shelter: During a thunderstorm, stay indoors and avoid using electrical appliances.
Avoid Tall Objects: Stay away from tall objects such as trees and metal structures that can attract lightning.
Lightning Rods and Conductors:
Installation: Buildings and structures in lightning-prone areas should be equipped with lightning rods and conductors to safely channel lightning strikes into the ground.
Community Awareness:
Education: Increasing public awareness about lightning safety and preparedness can help reduce injuries and fatalities.

Research and Monitoring

Meteorological Data:

Monitoring: Government and meteorological agencies track lightning occurrences and provide weather forecasts to warn of potential thunderstorms.

Research: Ongoing research helps in understanding lightning patterns and improving safety measures.

Technological Advances:

Lightning Detection Systems: Implementation of advanced detection systems can help predicts and monitors lightning activity.

Conclusion

Lightning is a significant weather phenomenon in Uganda, influenced by the country's climatic and geographical features. Lightning is a dramatic manifestation of static electricity resulting from the buildup and discharge of electrical charges in the atmosphere. The process involves friction, charge buildup, and the eventual release of electrical energy in the form of a lightning strike.

Friction and Charge Buildup

Friction in Thunderstorms

Formation of Thunderstorms:

Thunderstorms develop due to the rising of warm, moist air from the Earth's surface into the atmosphere. This rising air is called convection.

As the warm air rises, it cools and condenses, forming clouds. Within these clouds, turbulent air currents and the collision of particles create the conditions for friction.

Role of Friction:

Within the cloud, friction occurs between different particles, including water droplets, ice crystals, and snowflakes.

Mechanism: As particles collide and interact, electrons are transferred between them. This frictional process causes an imbalance in electric charges.

Charge Separation

Charge Distribution:

Positive and Negative Charges: The friction between particles causes a separation of charges within the cloud. Lighter, positively charged particles (e.g., ice crystals) tend to move to the upper regions of the cloud, while heavier, negatively charged particles (e.g., water droplets) settle toward the lower regions.

Charge Accumulation: The upper part of the cloud becomes positively charged, and the lower part becomes negatively charged. The ground below also becomes positively charged due to induction.

Electric Field Creation:
As the separation of charges continues, an electric field develops between the negatively charged lower part of the cloud and the positively charged ground or upper regions of the cloud.
Electric Field Strength: The strength of the electric field increases as more charge accumulates and the distance between charges grows.
Formation and Discharge of Lightning

Charge Buildup and Breakdown
Critical Electric Field:
Threshold: When the electric field strength between the cloud and the ground reaches a critical threshold (typically around 1,000,000 volts per meter), the air can no longer insulate the electric charges effectively.
Breakdown: The insulating properties of air break down, and a conductive path is created for the electric charges to travel.

Formation of a Lightning Channel:
Step Leaders: The discharge begins with a series of step leaders, which are ionized pathways that form between the cloud and the ground. These paths allow the electrical charge to move more easily.
Return Stroke: Once a conductive path is established, a return stroke of electrical current travels rapidly upward from the ground to the cloud. This return stroke is what we see as a visible lightning flash.

Lightning Strike and Thunder
Visible Lightning: The return stroke is extremely bright due to the high temperatures (up to 30,000 Kelvin) in the lightning channel. The intense heat causes the surrounding air to expand rapidly, producing a shockwave.
Thunder: The rapid expansion of heated air creates a pressure wave that we hear as thunder. Thunder follows the lightning flash because sound travels slower than light.

Types of Lightning
Cloud-to-Ground (CG) Lightning:
Description: Lightning that occurs between the negatively charged lower part of the cloud and the positively charged ground.

This is the most dangerous type of lightning, often resulting in ground strikes that can cause damage or fires.

Cloud-to-Cloud (CC) Lightning: Lightning that occurs between different regions within the same cloud or between separate clouds. These are often seen as bright, forked lightning that illuminates the sky.

Intra-Cloud (IC) Lightning:
Lightning that occurs within a single cloud, between different charges regions. Characteristics up the entire cloud without a visible bolt.

Atmospheric Conditions Influencing Lightning

A. Humidity and Temperature:

High Humidity: Increases the likelihood of thunderstorm development and lightning, as moist air contributes to charge buildup.

Warm Temperatures: Enhance convection currents and cloud formation, leading to more frequent thunderstorms.

B. Geographic Features:

Topography: Elevated regions and mountainous areas can enhance lightning frequency due to increased convection and turbulent air.

C. Seasonal Patterns:

Rainy Seasons: Lightning occurrences are higher during rainy seasons when thunderstorms are more frequent.

Lightning results from the intricate interplay between friction, charge buildup, and atmospheric conditions. Friction within thunderstorms separates electric charges, leading to the development of a strong electric field. When this field reaches a critical threshold, a lightning discharge occurs, creating a visible flash and a corresponding thunder sound. Understanding these processes helps in predicting lightning occurrences and improving safety measures during thunderstorms.

How Lightning Conductors Protect Buildings and Structures

Lightning conductors, also known as lightning rods, are essential for protecting buildings and structures from the damaging effects of lightning strikes. They provide a safe path for lightning to follow, directing the electrical energy harmlessly into the ground. Understanding how lightning conductors work is crucial for ensuring the safety and longevity of structures in lightning-prone areas.

Components of a Lightning Conductor System

A. Lightning Rod: The lightning rod is a metal rod, usually made of copper or aluminum, mounted at the highest point of a building or structure.

Function: It serves as the point where lightning is most likely to strike. The rod is designed to attract and intercept lightning strikes.

B. Conductors:

Metal conductors (usually copper or aluminum) connect the lightning rod to the ground. These conductors create a low-resistance path for the electrical charge to travel from the lightning rod to the ground.

C. Grounding System:

The grounding system consists of metal rods or plates buried in the ground.

It disperses the electrical charge safely into the earth. The grounding system must be in good contact with the soil to effectively conduct the charge.

D. Bonding:

Bonding refers to the connection of the lightning conductor system to other conductive parts of the building, such as metal plumbing or electrical systems.

Function: This ensures that all conductive parts of the building are at the same electrical potential, reducing the risk of side flashes or damage.

How Lightning Conductors Work

A. Attraction and Interception:

The lightning rod is designed to attract lightning because it is the highest point of the structure. While lightning rods do not prevent lightning from striking, they provide a controlled point of entry. When lightning strikes, the rod intercept the electrical discharge and prevents it from hitting other parts of the building.

B. Conducting the Charge:

The metal conductors create a direct path for the electrical energy to travel from the lightning rod to the ground. This pathway is designed to be low in electrical resistance. The electrical energy travels along the conductors, bypassing sensitive parts of the building and avoiding potential damage.

C. Grounding:

Once the electrical energy reaches the ground, the grounding system disperses it safely into the earth. The metal rods or plates in the ground conduct the charge into the soil, where it is absorbed and neutralized. Proper grounding ensures that the electrical energy does not cause harm to the building’s structure, electrical systems, or occupants.

Protection Mechanisms

A. Prevention of Fire:

Direct Protection: By directing lightning safely into the ground, lightning conductors prevent lightning from causing fires by striking flammable materials or electrical systems.

Indirect Protection: The system also reduces the risk of secondary fires caused by electrical surges or damage to wiring.

B. Protection of Electrical Systems:

Surge Protection: Lightning conductors help prevent power surges and electrical damage by directing lightning away from electrical components and wiring.

Equipment Safety: They protect sensitive equipment and electronics from potential damage due to lightning-induced electrical surges.

C. Protection of Occupants:

Safety: By preventing lightning strikes from entering the building, lightning conductors reduce the risk of injuries or fatalities caused by electrical discharge.

Shielding: The system helps maintain a safe environment for occupants during thunderstorms.

Installation and Maintenance

A. Installation:

Location: Lightning rods should be installed at the highest points of a building or structure, such as rooftops or spires.

Design: The system must be designed to cover the entire structure, ensuring that all potential strike points are protected.

Professional Installation: Installation should be carried out by qualified professionals to ensure compliance with safety standards and regulations.

B. Maintenance:

Regular Inspections: Lightning conductors and grounding systems should be regularly inspected for damage or corrosion.

Repair and Replacement: Any damaged components should be repaired or replaced promptly to ensure continued effectiveness.

Upgrades: In some cases, upgrading the system may be necessary to meet current safety standards or address changes in building structure.

Limitations and Considerations

No Complete Prevention:

Lightning Attraction: While lightning conductors provide protection, they do not prevent lightning from striking. They merely provide a safe path for the electrical discharge.

Importance of Comprehensive Protection:
Overall Safety: Lightning conductors should be part of a comprehensive safety plan, including other measures such as surge protectors and grounding of electrical systems.

Lightning conductors are crucial for protecting buildings and structures from the destructive effects of lightning strikes. By intercepting and safely conducting lightning to the ground, these systems prevent fires, protect electrical systems, and ensure the safety of occupants. Proper installation and maintenance of lightning conductors are essential for effective protection and long-term safety.

Safety Tips: Guidelines to follow during thunderstorms.
Thunderstorms can be both thrilling and dangerous. Following proper safety guidelines during a thunderstorm is crucial to protect yourself, your family, and your property from lightning, strong winds, hail, and heavy rain. Here are essential safety tips to keep in mind during thunderstorms:
Seek Shelter Indoors
Stay Inside:
Find Safe Shelter: Move indoors to avoid exposure to lightning and severe weather conditions. Buildings offer the best protection from lightning strikes and flying debris.
Avoid Windows: Stay away from windows to prevent injury from shattered glass due to strong winds or hail.
Avoid Electrical Appliances:
Unplug Devices: Disconnect electronic devices and appliances to avoid damage from power surges caused by lightning strikes.
Avoid Using Corded Phones: Do not use corded phones during a thunderstorm, as lightning can cause electrical surges through the phone lines.
Safety in Vehicles: Stay Inside the Vehicle:
Seek Shelter in a Car: If you are driving or outside, your vehicle can provide protection from lightning. The metal frame of the car acts as a Faraday cage, directing electrical charge around the occupants and into the ground.
Avoid Touching Metal Parts: While in the car, avoid touching metal parts of the vehicle to minimize the risk of electric shock.
Pull Over Safely:
Find a Safe Spot: If you are driving, pull over to the side of the road in a safe area away from trees and overpasses. Remain in the car until the storm passes.
Safety Outdoors
Avoid Tall Objects:

Stay Away from Trees: Do not seek shelter under trees or tall structures, as they are more likely to be struck by lightning.
Avoid Metal Objects: Stay away from metal objects such as fences, poles, and golf clubs, as metal conducts electricity.
B. Stay Low:
Avoid Open Fields: If you are caught in an open area, crouch down with your feet close together to reduce your profile and minimize the risk of being struck by lightning.
Avoid Water: Do not swim or bathe during a thunderstorm, as water conducts electricity.
Safety at Home
Secure Outdoor Items:
Bring Items Inside: Bring in or secure outdoor furniture, garden tools, and other items that can become projectiles in strong winds.
Close Garage Doors: Ensure garage doors are closed to protect vehicles and equipment from flying debris.
Check for Flooding:
Monitor Water Levels: Be aware of local flood warnings and monitor water levels around your property. Avoid driving or walking through flooded areas.
Lightning Safety
Follow the 30-30 Rule:
30-Second Rule: If you hear thunder within 30 seconds of seeing lightning, seek shelter immediately. This indicates that the lightning strike is close.
30-Minute Wait: Wait for at least 30 minutes after the last thunderclap before leaving your shelter to ensure the storm has passed.

B. **Use Lightning Protection Systems:**
Install Lightning Rods: Ensure that your home is equipped with a lightning protection system, including lightning rods, conductors, and grounding systems, to minimize the risk of damage.
Emergency Preparedness
Emergency Kit:
Assemble Supplies: Keep an emergency kit with essentials such as flashlights, batteries, first aid supplies, and non-perishable food items.
Stay Informed: Have a battery-powered weather radio or a fully charged phone to receive weather alerts and updates.
B. Family Plan:
Create a Plan: Develop a family emergency plan that includes a designated shelter area and communication plan.

Educate Family Members: Ensure that all family members are aware of safety procedures and know what to do during a thunderstorm.

After the Storm

Inspect Your Property:

Check for Damage: After the storm, inspect your property for any damage caused by lightning, wind, or hail. Look for fallen trees, broken branches, and structural damage.

Report Hazards: Report any downed power lines or hazards to local authorities immediately.

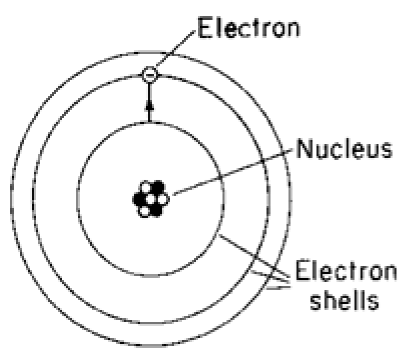
Avoid Downed Power Lines:

Stay Clear: Keep a safe distance from downed power lines and report them to the utility company. Do not attempt to move them yourself.

Safety during thunderstorms involves proactive measures to protect yourself, your family, and your property. By seeking shelter indoors, avoiding dangerous outdoor activities, securing your home, and preparing for emergencies, you can minimize the risks associated with thunderstorms and ensure a safer environment during severe weather conditions.

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

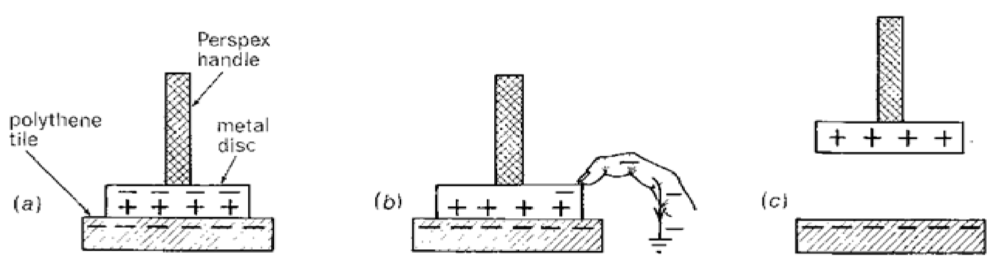
When two bodies are rubbed together, work is done, transfer of electrons from one body to another occurs. This results into two bodies acquiring opposite charges.

Law of Electro statics

Like charges repel each other.

Unlike charges attract each other.

Electrification by conduction

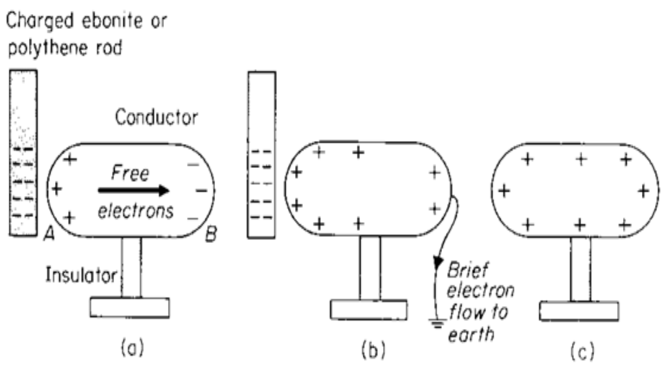


- Support the uncharged conductor on an insulated stand.
- Put a positively charged rod in contact with the conductor.
- Earth the conductor by touching
- Remove the earthing
- When the conductor is removed from the rod, it is obtained to be positively charged.

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



Charging the body positively.

Procedure

Put the conductor on an insulated stand as in (a)

Bring a negatively charged rod near the conductor.

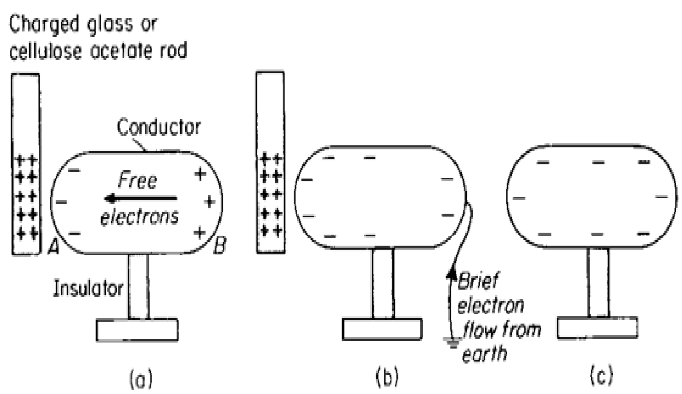
The positive and negative charges separate as shown in (a)

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 obtained to be positively charged.

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.

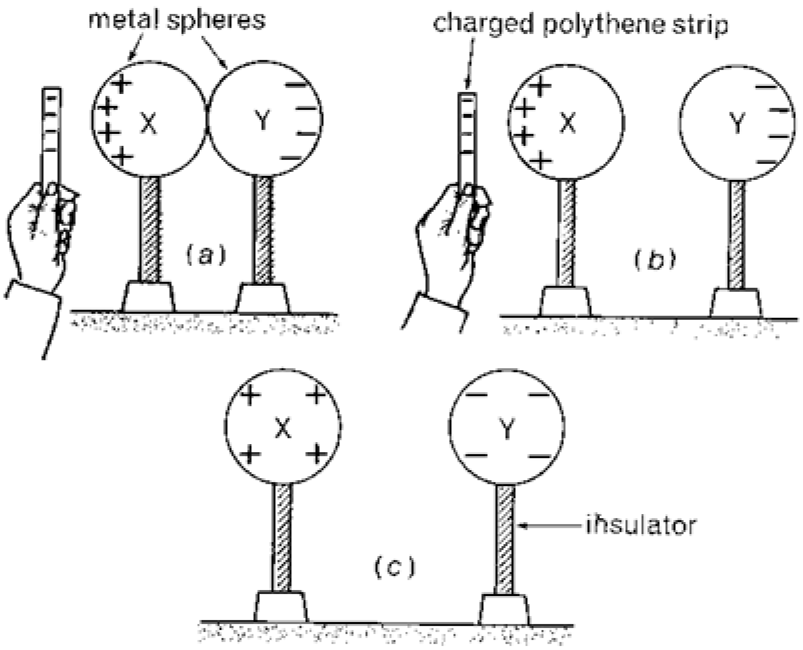
The positive and negative charges separate as shown in (a)

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 obtained to be negatively charged.

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

Conductors and insulators are two categories of materials that differ in their ability to allow the flow of electric charges (electrons) or heat. Understanding the distinction between them is essential in fields such as electricity, electronics, and thermodynamics.

Conductors: Conductors are materials that allow the flow of electric charges (usually electrons) or heat through them easily. They have free-moving charge carriers, which can be electrons or ions that enable electricity or heat to pass through.

Characteristics of Conductors:

Free Electrons: Conductors have many free electrons (delocalized electrons) in their atomic structure. These electrons are loosely bound to their atoms and can move freely when an electric field is applied.

Low Electrical Resistance: Conductors offer very little resistance to the flow of electric current because the free electrons can move with minimal hindrance. This makes them highly efficient at transmitting electricity.

Heat Conductivity: In addition to conducting electricity, conductors can also efficiently transfer heat. Metals, for instance, can quickly transfer thermal energy from one part of the material to another.

Examples:

Metals: Copper, aluminum, gold, and silver are excellent electrical conductors because they have free-moving electrons.

Graphite: While non-metallic, graphite is a good conductor due to the presence of free electrons in its structure.

Plasma: Ionized gases in the plasma state (e.g., in stars or neon signs) can conduct electricity due to the presence of free-moving ions and electrons.

Applications of Conductors:

Wiring: Copper and aluminum are commonly used in electrical wiring and power lines because of their excellent conductivity.

Electronic Components: Conductors are used in circuit boards, connectors, and various electrical components.

Heat Sinks: Metal conductors like aluminum are used in heat sinks to dissipate heat from electronics like CPUs and GPUs.

Insulators: Insulators are materials that resist the flow of electric charges or heat. They do not allow electrons or ions to move freely, which makes them poor conductors of electricity or heat.

Characteristics of Insulators

Tightly Bound Electrons: In insulators, the electrons are tightly bound to their respective atoms and cannot move freely. This prevents the movement of electric charges and stops the flow of current.

High Electrical Resistance: Insulators have very high resistance to electric current. This makes them effective at blocking or containing electrical charges.

Poor Heat Conductivity: Insulators are also poor conductors of heat. They resist the transfer of thermal energy, making them good for thermal insulation.

Examples:

Non-metals: Materials such as rubber, glass, wood, plastic, and ceramics are excellent insulators of electricity and heat.

Air: Although technically a gas, air acts as an insulator, preventing the free flow of electricity (which is why air gaps are used in electrical insulators).
Paper: Dry paper is a good insulator and is used in various applications where electrical insulation is necessary.

Applications of Insulators:
Electrical Insulation: Plastic and rubber are often used to coat electrical wires to prevent accidental contact with live conductors and to contain electrical energy within the system.
Thermal Insulation: Insulators such as fiberglass, foam, and wool are used in building construction to prevent the loss of heat in homes and offices.
Dielectric Materials: Insulators are used in capacitors as dielectric materials, which can store electrical energy.

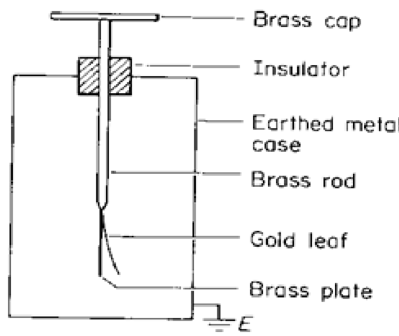
Comparison between Conductors and Insulators

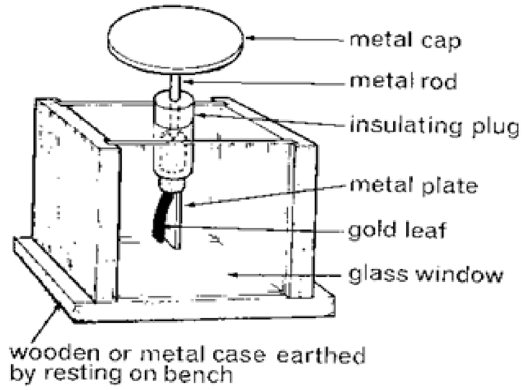
Property	**Conductors**	**Insulators**
Electrical Conductivity	High (due to free electrons)	Low (due to tightly bound electrons)
Resistance	Low (minimal resistance to current flow)	High (resist the flow of current)
Heat Conductivity	Good (thermal energy transfers easily)	Poor (resist the transfer of heat)
Examples	Copper, aluminum, gold, silver	Rubber, glass, plastic, wood
Electron Movement	Free electrons move easily	Electrons are tightly bound and immobile

Semiconductors:
In addition to conductors and insulators, semiconductors represent a special class of materials that have properties between conductors and insulators. Their conductivity can be controlled or modified by adding impurities (a process called doping), applying voltage, or changing temperature. Semiconductors are the foundation of modern electronics, used in devices like transistors and diodes.

Examples of Semiconductors: Silicon and germanium.
Applications: Semiconductors are the building blocks of computer chips, solar cells, and other electronic devices.

The gold leaf electroscope

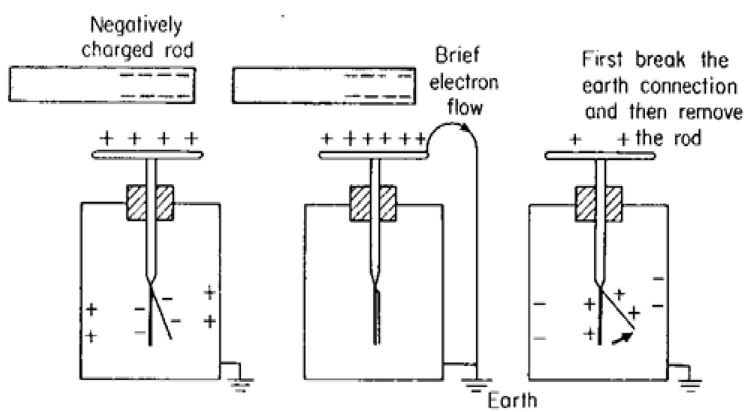




It consists of a brass cap and brass plate connected by a brass rod.
A gold leaf is fixed together with a brass plate
The brass plate, gold leaf and part of brass rod are put inside a metallic box which is enclosed with glass windows.

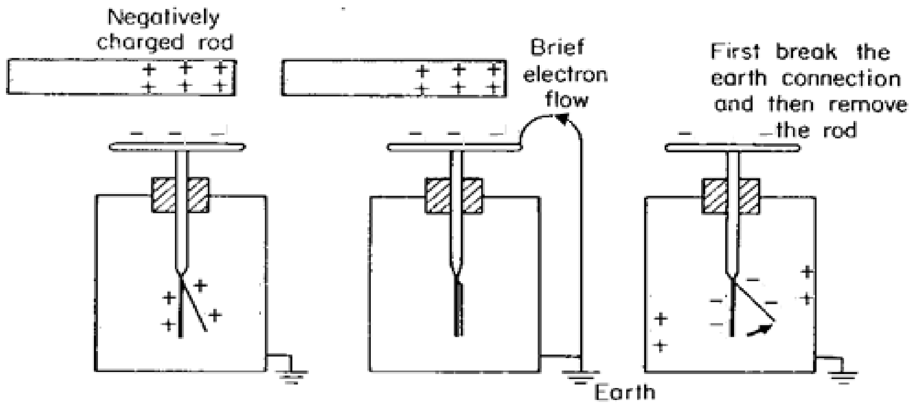
CHARGING A GOLD LEAF ELECTROSCOPE BY INDUCTION

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.

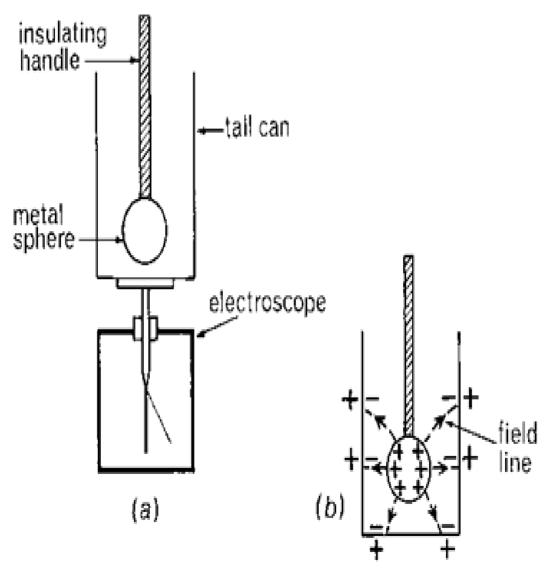
Charging it negatively.



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

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.

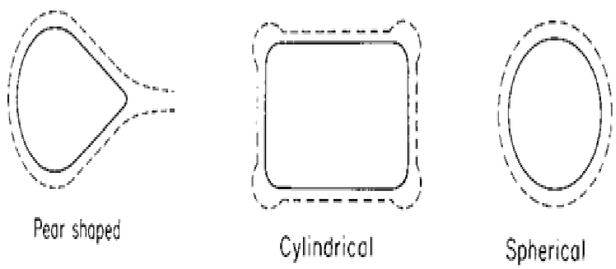
Curved bodies

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;

Spray off' of its own charge in form of electric wind.

Collector of unlike charges.

The spray off and collecting of charges by the sharp points is known as **corona discharge**.

Application of action of points (corona discharge)

Used in a lightening conductor**.**

Used in electrostatics generators.

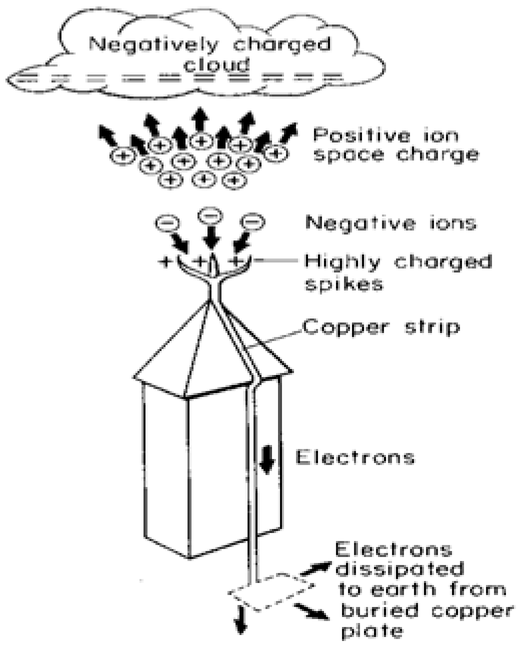
Electrostatic photocopying machines.

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 lightning.

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.

Electric fields

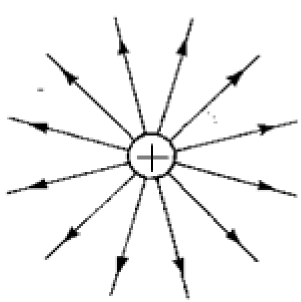
This is a region around a charged body where electric forces are experienced. Electric fields may be represented by field lines. Field lines are lines drawn in an electric field such that their directions at any point give a direction of electric field at that point. The direction of any field at any given point is the direction of the forces on a small positive charge placed at that point.

Properties of electric field lines

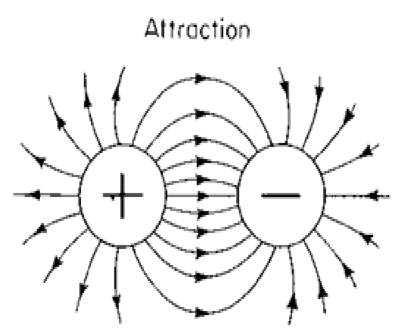
They begin and end on equal quantities of charge.
They are in a state of tension which causes them to shorten.
They repel one another side ways.

Field patterns

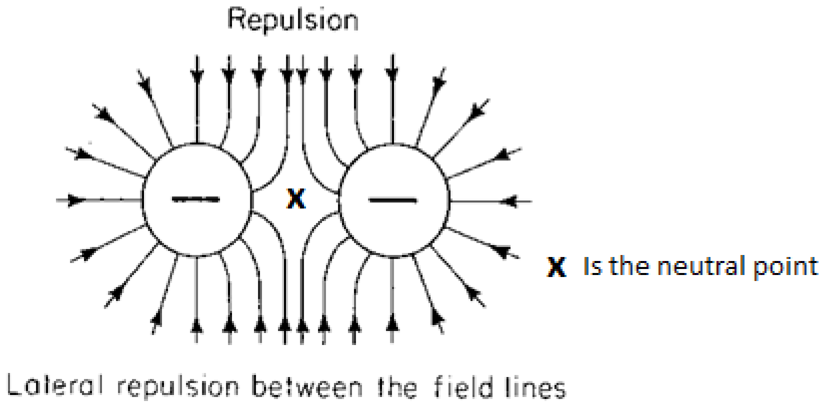
(a) Isolated charge



Unlike charges close together



(b) 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.

2.8 The solar system

Learning Outcomes

a) Know the relative sizes, positions, and motions of the earth, sun and moon (k, u)
b) Understand how day and night occur and demonstrate the phases of the moon(u, s)
c) Understand the roles of the sun, earth and moon in explaining time, seasons, eclipses, and ocean tides (k, u,gs)
d) Know the components of the solar system and their positions(k)
e) Know the main characteristics of the inner and outer planets in the solar system(k)f. Understand the various views about the origin and structure of the universe(k, v/a)

EARTH AND SPACE SYSTEM

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.

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.

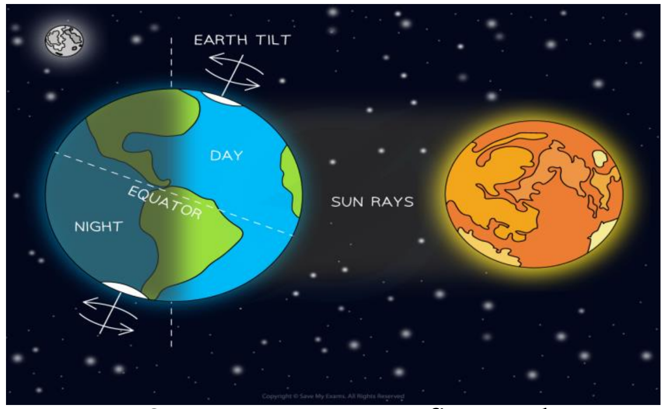
The Earth has the right distance from the Sun; it is protected from harmful solar radiation by its magnetic field. It is also kept warm by an insulating atmosphere, and it has the right chemical ingredients for life, including water and carbon. Earth is able to support life because it has a suitable 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 the Earth is able to support life in it.

The ASTEROID BELT and where it's obtained

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.

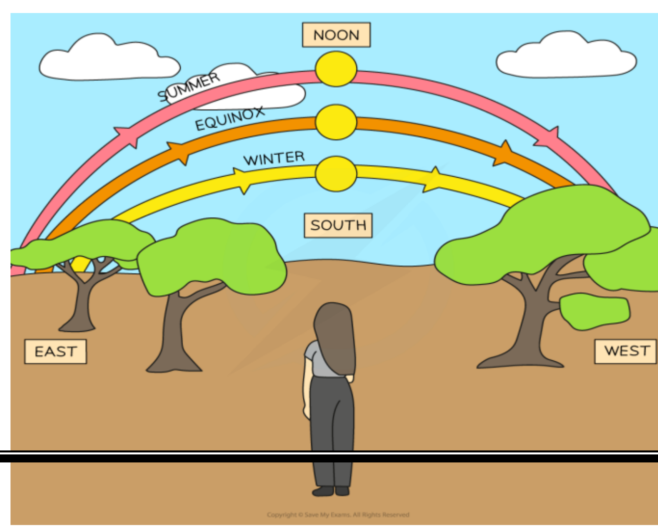


Origin and structure universe

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 solasystems 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 infinitelydense 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*

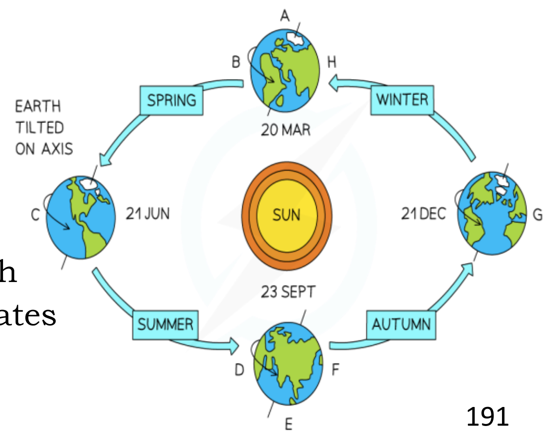
Rising and Setting of the Sun

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.

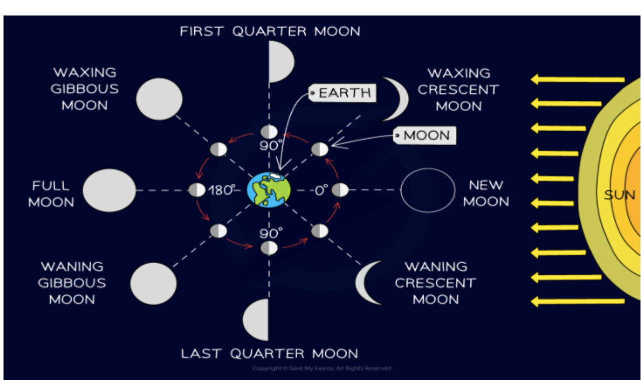
Moon & Earth

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 2πr where r is the radius a circle.

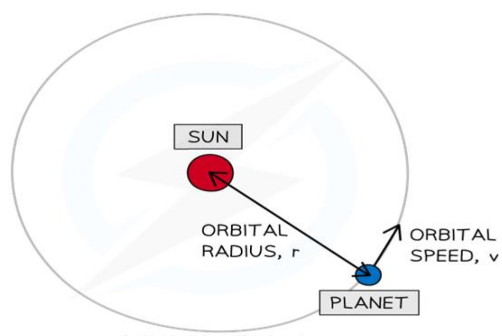
The relationship between speed, distance and time is: the average orbital speed of an object can be defined by the equation: $v = \frac{2\pi r}{T}$

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.



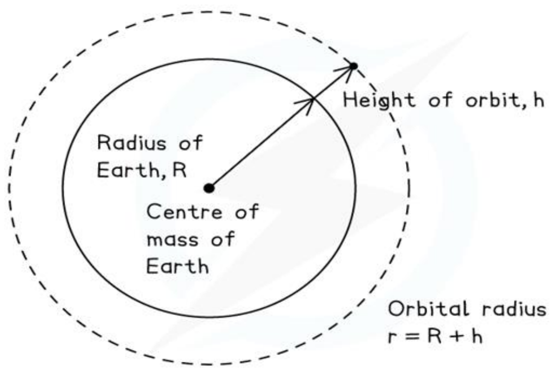
Orbital radius and orbital speed of a planet moving around a Sun

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



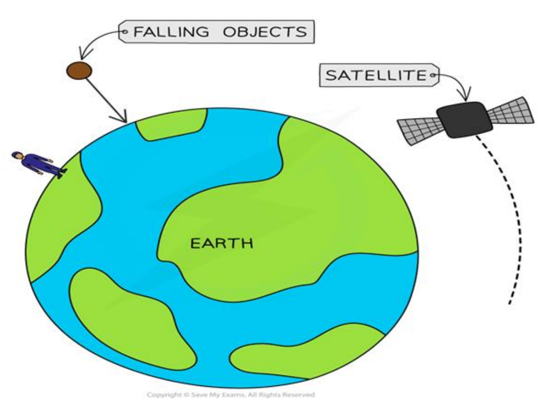
Step 4: Convert any units
The time period needs to be in seconds
The radius needs to be in metres
Step 5: Substitute values into the orbital speed equation

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 Field Strength

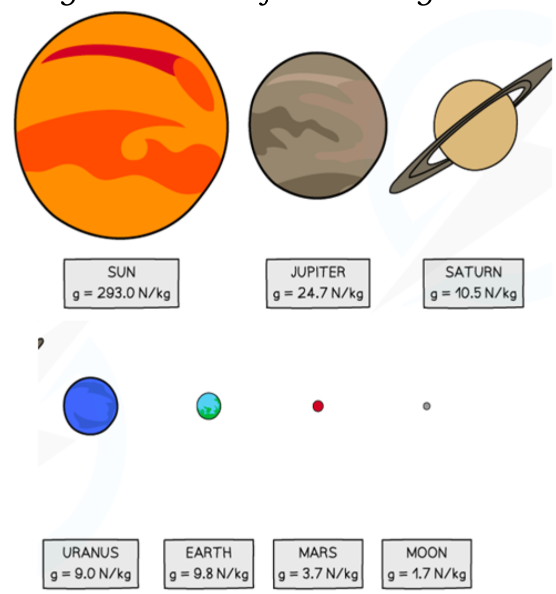
The strength of gravity on different planets affects an object's weight on that planet.
Weight is defined as the force acting on an object due to gravitational attraction.
Planets have strong gravitational fields. Hence, they attract nearby masses with



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.

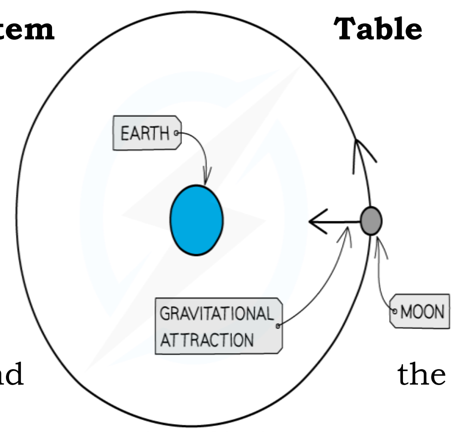
However, their weight will be a lot greater meaning for example; a human will be unable to fully stand up.
A person's weight on Jupiter would be so large a human would be unable to fully stand up.

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.

Body or Object	What it Orbits
Planet	Sun
Moon	Planet
Comet	Sun
Asteroid	Sun
Artificial satellite	Any object or body in solar system

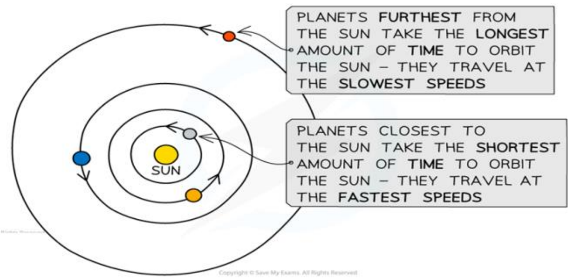
Gravitational Attraction of the Sun
There are many orbiting objects in our solar system and they each orbit a different type of planetary body.

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;
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 a circular path. 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.

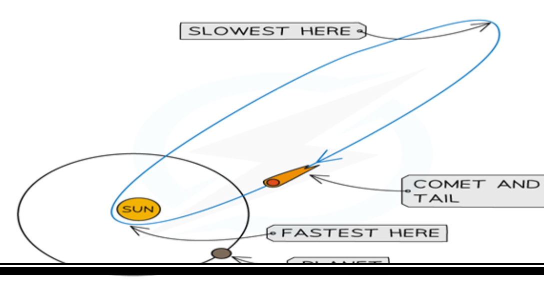
This can be seen from data collected for a planet's orbital distance against their orbital speed. E.g. Neptune travels much slower than Mercury.

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.*

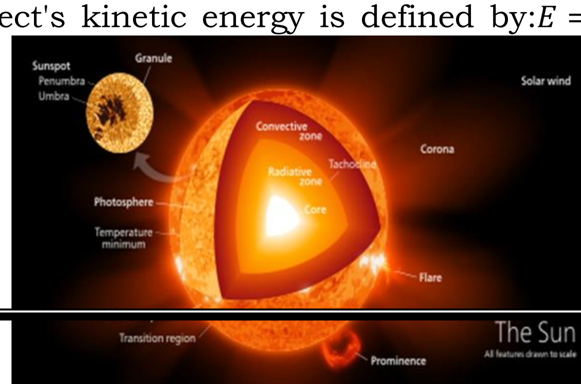
As the comet approaches the Sun:
The radius of the orbit decreases
The orbital speed increases due to the Sun's strong gravitational pull
As the comet travels further away from the Sun:
The radius of the orbit increases
The orbital speed decreases due to a weaker gravitational pull from the Sun
Comets 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*

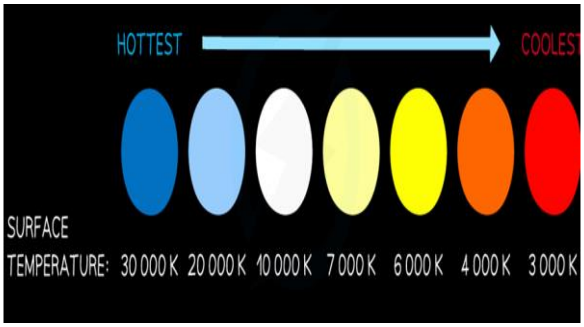


energy. Its gravitational potential energy therefore must decrease for energy to be conserved.

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 energy in the infrared, visible and ultraviolet regions 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.

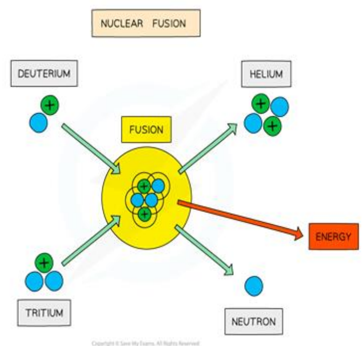
Therefore, *the colour they emit depends on how hot they are.*

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 shown here:

Deuterium and tritium are both isotopes of hydrogen.

$$^{2}_{1}H + ^{3}_{1}H \longrightarrow ^{4}_{2}He + ^{1}_{0}n$$

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

Senior Three

3.1 Linear and non-linear motion

Learning Outcomes

a) Understand and apply the relationship between speed, distance, and time (u, s)
b) Understand the terms: linear motion, speed, average speed, acceleration, and be able to investigate resistance to motion (u,s)
c) Know and use the equations of motion (u,s)
d) Understand the acceleration of bodies moving in a circle and the effect of gravity and air resistance on moving bodies (u,s)
e) Understand linear momentum and that it is conserved during collisions (u,s)
f) Understand that momentum is conserved during a collision and the implication of this (u, s,v/a)
g) Understand and apply newton's laws of motion (u,s,v/a)
h) Understand the differences between vector and scalar quantities, and give examples of each(u)
i) Understand that a number of forces acting on a body can be represented by a sign.

Linear motion refers to the movement of an object along a straight path in one dimension. It is the simplest type of motion, involving objects moving in a straight line, either at a constant speed or accelerating. Linear motion can be described using concepts such as velocity, acceleration, displacement, and time. It is a fundamental concept in classical mechanics and is governed by Newton's laws of motion.

Quantities in Linear Motion:

Displacement (s): *Displacement is the change in position of an object along a straight line.* It is a **vector quantity,** meaning it has both magnitude (distance) and direction. Example: If a car moves 5 km east, its displacement is 5 km to the east, regardless of the path taken.

The SI unit of displacement is the meter (m).

Distance: *Distance is the total length of the path traveled by an object, irrespective of direction.* Unlike displacement, distance is a **scalar quantity**; it only has magnitude, not direction.

Example: If a person walks 5 meters forward and then 5 meters back, the total distance is 10 meters, but the displacement is 0 meters.
Velocity (v): *Velocity is the rate of change of displacement with respect to time*. It is a **vector quantity,** meaning it describes both speed and direction.
Average velocity (V_{avg}) is calculated as: $V_{avg}=\frac{\Delta s}{\Delta t}$, where Δs = change in displacement, Δt = change in time
Instantaneous velocity is the velocity of an object at a particular moment in time.
The SI unit of velocity is the meter per second (m/s).

Speed: *Speed is the rate at which an object covers distance.* It is a *scalar quantity and only has magnitude.* Speed is the total distance traveled divided by the time taken: Speed=Total distance/Time taken
The SI unit of speed is also meters per second (m/s).
Acceleration (a): *Acceleration is the rate of change of velocity with respect to time.* It is a vector quantity and can describe changes in speed or direction.
Uniform acceleration occurs when the velocity of an object changes by the same amount each second.
Average acceleration is given by: $a = \frac{\Delta v}{\Delta t}$, where: Δv = change in velocity, Δt = time interval. The SI unit of acceleration is meters per second squared (m/s^2).
Time (t): *Time measures the duration of motion.* It is a **scalar quantity** and is usually measured in seconds (s).
Types of Linear Motion:
Uniform Linear Motion: This occurs when an object moves along a straight path at a constant velocity, meaning it covers equal distances in equal time intervals. In this type of motion, acceleration is zero because the velocity does not change.
Equations:
Displacement: s=v·t, where v is constant velocity, and t is the time.
Non-Uniform Linear Motion: This type of motion occurs when an object moves along a straight path but with changing velocity. It experiences acceleration or deceleration. The velocity changes with time due to the influence of forces such as gravity, friction, or external applied forces.
Equations of Motion for Uniformly Accelerated Linear Motion:
These equations are crucial for solving problems involving linear motion with constant acceleration. They relate displacement, velocity, acceleration, and time:
1st Equation (velocity-time relationship): $v = u + at$
Where: v = final velocity, u = initial velocity, a = acceleration and t = time
2nd Equation (Displacement-Time Relationship):

$s = ut + \frac{1}{2}at^2$, where: s = displacement, u= initial velocity, t = time, and a = acceleration

3rd Equation (velocity-displacement Relationship):

$v^2 = u^2 + 2as$, where: v = final velocity, u = initial velocity, a = acceleration and s = displacement

These equations assume that acceleration is constant and the motion occurs in a straight line.

Examples of Linear Motion in Real Life:

Free Fall:

When an object falls under the influence of gravity, it experiences linear motion with constant acceleration (due to gravity, $g \approx 9.8\ m/s^2$. The motion of the object can be described using the equations of motion, where: u=0, (when starting from rest), a=g, t = time taken to fall.

A Car on a straight road:

If a car is moving at a constant speed along a straight road, it is in uniform linear motion. If the car accelerates or decelerates (e.g., during braking), it is in non-uniform linear motion.

Motion of a Train:

A train moving between stations experiences both uniform and non-uniform linear motion. It accelerates when leaving the station, travels at constant speed, and decelerates when approaching the next station.

Projectile Motion (Horizontal Component):

In projectile motion, the horizontal component of motion (if air resistance is neglected) is uniform linear motion, as no force acts horizontally after the object is launched.

Graphical Representation of Linear Motion:

Displacement-Time Graph:

For uniform motion, the graph is a straight line with a constant slope (slope = velocity).

For non-uniform motion, the graph is curved, indicating changing velocity.

Velocity-Time Graph:

For uniform motion, the velocity-time graph is a horizontal line, indicating constant velocity.

For uniform acceleration, the graph is a straight line with a positive or negative slope (slope = acceleration).

The area under the velocity-time graph represents the displacement.

Acceleration-Time Graph:

For constant acceleration, the acceleration-time graph is a horizontal line.

If acceleration is zero, the graph lies on the time axis.

Summary:

Linear motion is the movement of an object along a straight path.

The key variables in linear motion are displacement, velocity, acceleration, and time.

Uniform linear motion involves constant velocity, while non-uniform linear motion involves acceleration.

The equations of motion allow for calculations of displacement, velocity, and time when acceleration is constant.

Linear motion is common in everyday life, such as cars traveling on roads, objects in free fall, and horizontal components of projectile motion.

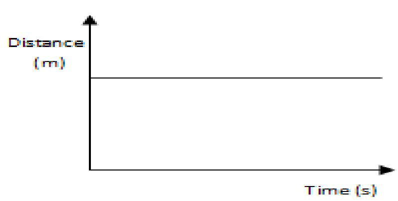
Example

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.
2. A car accelerates uniformly at a speed of 20m/s for 4 seconds. Find final velocity if acceleration is 2 m/s^2 and distance traveled.
3. A body moving with velocity of 20 m/s accelerates to a velocity of 40m/s in 5 seconds. Find the acceleration and the distance traveled in 5s.
4. A body at rest at height of 20m falls freely to the ground. Calculate the velocity with which it hits the ground and the time before striking the ground.

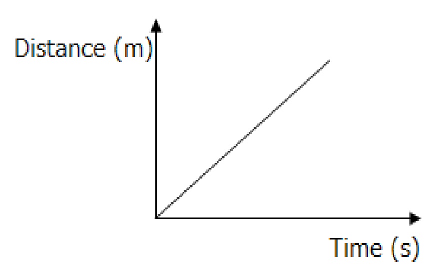
Graphs of motion

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

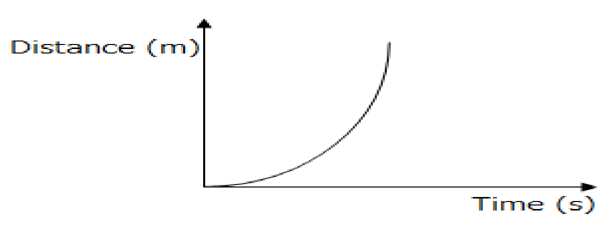


ii) For a body moving with uniform velocity



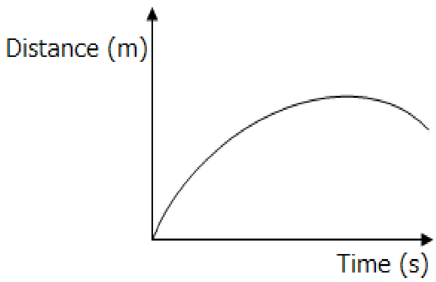
If a body is moving with the same velocity it travels equal distance in equal intervals of time i.e. the object distance increases by equal increase in time.

iii) Body moving with non-uniform velocity



Varying distances are moved in equal intervals of time

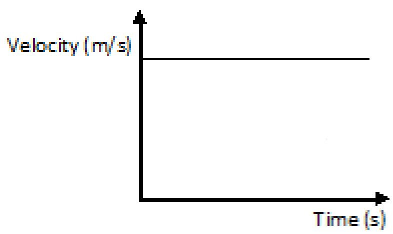
iv) Body moving with decreasing acceleration (retardation)



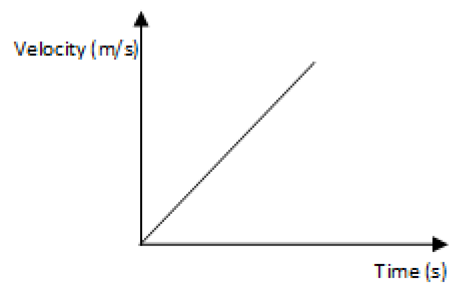
For a body whose velocity is decreasing the graph bends towards the horizontal. Velocity decreasing (retardation)

Velocity time graphs

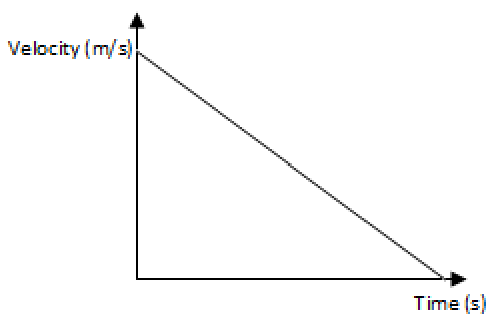
i) Body moving with uniform velocity



ii) Body moving with uniform acceleration



iii) Body moving with uniform deceleration.



Note

The area under a velocity time graph gives the distance covered by the body.
The slope of a uniform velocity time graph gives the uniform acceleration.

Activity

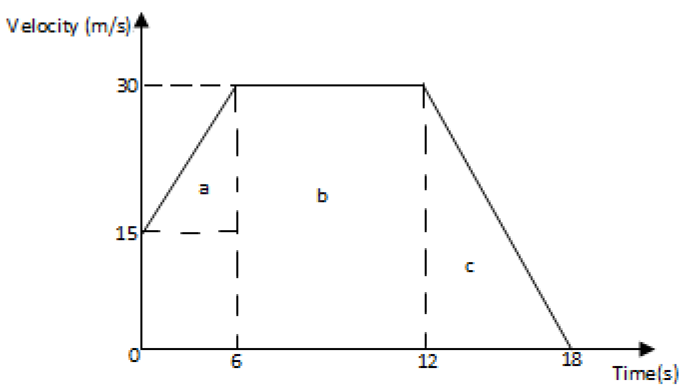
1. A car starts from rest and steadily accelerates for 10s to a velocity of 20m/s. It continues with this velocity for a further 20s before it is brought to rest in 20s

a) Draw a velocity time graph to represent this motion.
b) Calculate
  i) Acceleration
  ii) Deceleration
  iii) Distance travelled
  iv) Average speed

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

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

4. The graph below represents a velocity time graph of a body in motion.



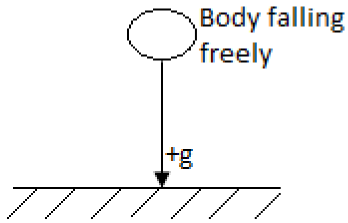
Describe the motion of the body.
Calculate the total distance travelled
Determine the average speed.

5. 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

A stone is raised from rest at point 20m above the ground so as to fall freely vertically down wards. Find time to land on the ground and the velocity with which the body lands

1. A ball is thrown vertically upwards with an initial velocity of 30m/s. Find
   a. The maximum height reached
   b. Time taken to reach the maximum height
   c. Time taken to return to the starting point.

2.A stone thrown vertically upwards with an initial velocity of 14m/s neglecting air resistance, find

   i. The maximum height reached
   ii. The time taken before it reached the ground

Acceleration of free fall is constant for a body falling from rest

$S = u\,t + \frac{1}{2}gt^2$

$S = \frac{1}{2}gt^2$

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. Vertical motion, distance is $s = h$, $h = \frac{1}{2}gt^2$

Where v_x is horizontal velocity of a given body and t is the time of flight.

Activity

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

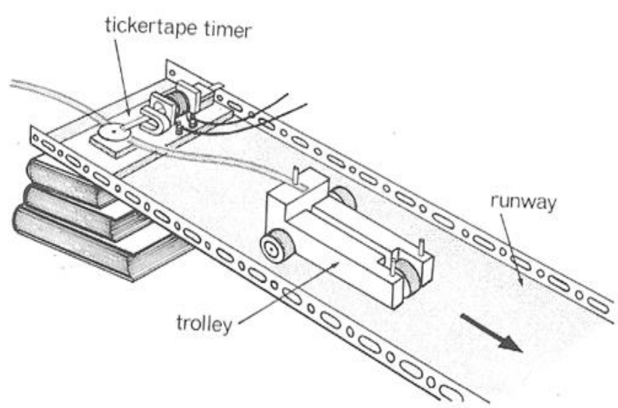
2. An object is dropped from helicopter at a height of 45m above the ground.
   a) If the helicopter is at rest, how long does the object take to reach the ground and what is its velocity on arrival.
   b) If the helicopter falls with a velocity of 1m/s when the object is released, what would be the final velocity of the object?

3.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.

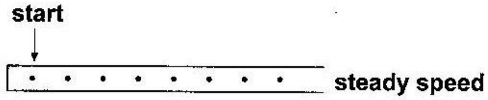
Experiment with a ticker – timer



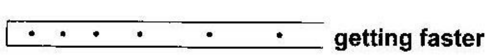
The paper tape is pulled by a trolley moving down an inclined plane as shown above.
Different results are obtained on the speed of the trolley.

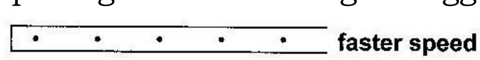
Typical results

Trolley moving with uniform speed, spacing between successive dots is the same throughout.

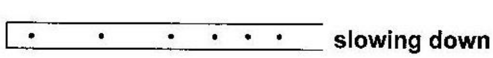


- The trolley is accelerating, the spacing between dots gets bigger and bigger.



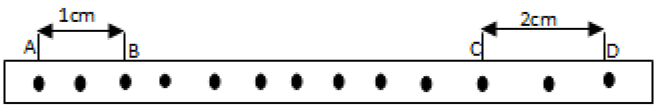


- Trolley decelerating, the spacing between successive dots gets smaller and smaller.



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

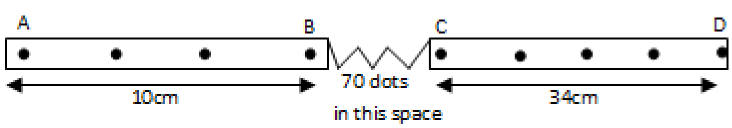
Time taken a long CD = =0.02s

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

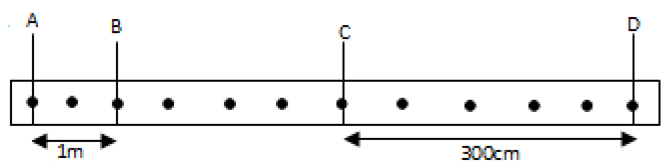
t= 1 .46s

a= 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

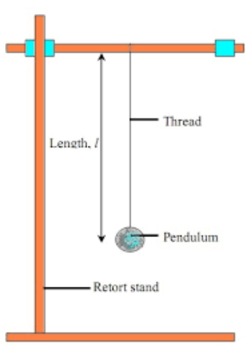
ii) Time taken a long CD = 0.25s
 Final velocity or speed = 12m/s

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.

To determine the acceleration due to gravity (g), you can perform a simple pendulum experiment.



Set up: Attach a small, dense bob to a string of length L and suspend it from a fixed point.

Measure the length (L): Measure the length of the string from the point of suspension to the center of the bob.

Release the pendulum: Displace the bob slightly and release it to swing back and forth as a pendulum.

Time the oscillations: Using a stopwatch, measure the time (T) it takes for the pendulum to complete 10 oscillations. Divide the total time by 10 to get the period (T) for one oscillation.

Calculate g: The formula for the gravity of a pendulum is given by: $\boldsymbol{g} = \frac{4\pi^2 l}{T^2}$

Results: Plug in the values of L and T to calculate the acceleration due to gravity.

This method gives an approximation of g based on the length of the pendulum and the period of oscillation.

NEWTON'S LAWS OF MOTION

Isaac Newton's three laws of motion form the foundation of classical mechanics, describing the relationship between the motion of an object and the forces acting on it.

1. Newton's First Law of Motion (Law of Inertia)

A body at rest will remain at rest, and a body in motion will remain in motion with a constant velocity, unless acted upon by an external force.

Explanation: This law explains the concept of inertia, which is the tendency of an object to resist changes in its state of motion.

If no external force (like friction, air resistance, or a push/pull) acts on an object, it will either remain still or continue moving in a straight line at constant speed.

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.

Examples: A book on a table will remain there unless someone pushes it.

A car in motion will continue moving unless brakes (external force) are applied to slow it down or stop it.

2. Newton's Second Law of Motion (Law of Force and Acceleration)

The acceleration of an object is directly proportional to the net force acting on it and inversely proportional to its mass. The direction of the acceleration is in the direction of the net force.

Mathematically: F=ma. Where: F = net force acting on the object (in newtons, N) m = mass of the object (in kilograms, kg), a = acceleration of the object (in meters per second squared, m/s^2)

Explanation:

If a force is applied to an object, it will accelerate in the direction of the force. The larger the force, the greater the acceleration.
However, if the object is more massive (heavier), the same force will result in less acceleration. Thus, heavier objects are harder to move or stop than lighter ones.
Examples: A small car requires less force to accelerate compared to a large truck. If you push a shopping cart with a strong force, it accelerates quickly; with less force, it moves slower.

3. Newton's Third Law of Motion (Action and Reaction)

For every action, there is an equal and opposite reaction.
Explanation: When one object exerts a force on a second object, the second object exerts an equal but opposite force on the first object.
Forces always come in pairs. If you push on something, it pushes back with the same amount of force in the opposite direction.
Examples:
When you jump off a boat onto the shore, the boat moves backward. Your feet push on the boat (action), and the boat pushes back on your feet (reaction), causing it to move. A rocket works by expelling gases downward (action), and as a result, the rocket is pushed upward (reaction).

Applications of Newton's Laws:
First Law (Inertia): Seatbelts in cars are designed to protect passengers by providing an external force that stops their motion when the car suddenly decelerates, preventing them from continuing to move forward due to inertia.
Second Law (Force and Acceleration): Engineers design vehicles based on the mass and the forces needed for efficient acceleration and braking, balancing speed and control.
Third Law (Action-Reaction): Airplanes generate lift by pushing air downward with their wings (action), and the air pushes the airplane upward (reaction), allowing it to fly.

Activity:
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

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.

3.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

4. 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 (Elevator)

When a person (or any object) is inside a lift (elevator), the motion of the lift affects the forces acting on the body. Specifically, the apparent weight of the person changes depending on the motion of the lift. This phenomenon is explained by Newton's second law of motion and the concepts of weight and normal force.

The real weight of a person is the force due to gravity acting on their mass, given by: W=mg. where: W is the weight, m is the mass of the person, g is the acceleration due to gravity (approximately $9.8\,m/s^2$)

Forces Acting on the Person in the Lift:

Weight (W = mg): The gravitational force pulling the person downward.

Normal Force (N): The force exerted by the floor of the lift on the person, which opposes the weight. This is the force you feel as your "apparent weight."

Scenarios:

1. Lift at Rest or Moving with Constant Velocity

When the lift is at rest or moving at constant velocity (either upward or downward), the acceleration is zero. According to Newton’s first law, there is no change in motion, so the forces are balanced. $R = W = mg$. Apparent weight (what you feel) is equal to your actual weight.

2. Lift Accelerating Upwards

When the lift accelerates upward, there is an additional upward force due to the acceleration of the lift. The normal force (R) increases because the lift floor pushes harder against the person.

Using Newton’s second law: $R = mg + ma = m(g + a)$, where: a is the acceleration of the lift upwards. Apparent weight increases because the normal force is greater than the gravitational force alone. You feel heavier during upward acceleration.

3. Lift Accelerating Downwards

When the lift accelerates downward, the normal force decreases because the lift floor is not pushing as hard against the person.

Again, applying Newton's second law: $R = mg - ma = m(g - a)$.

Apparent weight decreases because the normal force is less than the gravitational force. You feel lighter during downward acceleration.

4. Free Fall (Lift Cable Breaks)

If the lift were in free fall (e.g., the lift cable snaps, and the lift falls under gravity alone), the acceleration of the lift would be equal to the acceleration due to gravity g.

In this case: $R = m(g - g) = 0$. Apparent weight is zero. The person would feel weightless because there is no normal force acting on them (both the person and the lift are falling at the same rate). *This is similar to the sensation astronauts experience in free fall in space.*

Summary of Apparent Weight in Different Scenarios:

Lift's Motion	Apparent Weight	Feeling
At rest or constant velocity	Apparent weight = Actual weight	Normal (as if on solid ground)
Accelerating upwards	Apparent weight > Actual weight	Heavier
Accelerating downwards	Apparent weight < Actual weight	Lighter
Free fall (cable breaks)	Apparent weight = 0	Weightless

Conclusion:

The apparent weight of a person in a lift changes depending on the motion of the lift. This change is due to the varying normal force, which either increases or decreases depending on whether the lift is accelerating upwards or downwards.

Activity:

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 $4 m/s^2$
(c) moving down wards with uniform acceleration of $4 m/s^2$

COLLISION AND LINEAR MOMENTUM

Collision and linear momentum are crucial concepts in physics, especially in mechanics. When objects collide, their motion and the forces involved are best understood using the principle of momentum.

Linear Momentum

Linear momentum (p) is the product of an object's mass (m) and its velocity (v).
p=mv, Where p is the linear momentum, m is the mass of the object (kg), v is the velocity of the object (m/s).

Characteristics of Linear Momentum:

Vector quantity: Momentum has both magnitude and direction, which is the same as the direction of the velocity.
Conserved in isolated systems: The total linear momentum of a system remains constant if no external forces act on it (conservation of momentum).
The SI unit of momentum is kg·m/s

Momentum and Force:

Newton's second law can be written in terms of momentum. The net force acting on an object is equal to the rate of change of its momentum: $F = \frac{dp}{dt}$, where F is the net force, $\frac{dp}{dt}$ is the rate of change of momentum. This indicates that force is responsible for changing an object's momentum over time.

Collisions

A collision occurs when two or more objects come into contact with each other for a short period, exchanging forces and energy. During a collision, the momentum of the involved objects changes, but the total momentum of the system (if isolated) remains conserved. Collisions are categorized into two main types based on the conservation of kinetic energy:
a) Elastic Collision. *In an elastic collision, both momentum and kinetic energy are conserved.* The objects bounce off each other without any lasting deformation or generation of heat.
Examples:
Billiard balls colliding on a pool table.
Atoms colliding in a gas.
Mathematical representation: For two objects, 1 and 2, with masses m_1 and m_2, and initial velocities v_1 and v_2, the following conservation laws apply:

Conservation of momentum: $m_1v_1 + m_2v_2 = m_1v'_1 + m_2v'_2$, Where v_1' and v_2' are the velocities of the objects after the collision.

Conservation of kinetic energy:

$$\frac{1}{2}m_1v_1^2 + \frac{1}{2}m_2v_2^2 = \frac{1}{2}m_1v'^2_1 + \frac{1}{2}m_2v'^2_2$$

b) Inelastic Collision

In an inelastic collision, momentum is conserved, but kinetic energy is not. Some kinetic energy is transformed into other forms of energy, such as heat, sound, or deformation of the objects. In a perfectly inelastic collision, the colliding objects stick together after impact and move as a single object.

Examples:

A car crash, where the vehicles may crumple and stick together.

A lump of clay hitting and sticking to a wall.

Mathematical representation: For two objects undergoing a perfectly inelastic collision:

Conservation of momentum: $m_1v_1 + m_2v_2 = (m_1 + m_2)v_f$, where v_f is the final velocity of the combined mass after the collision.

Kinetic energy loss: Unlike elastic collisions, the kinetic energy before and after the collision is different. Some of it is lost during the collision:

$\Delta KE = \Delta KE_{initial} - \Delta KE_{final}$

Conservation of Momentum

The law of conservation of momentum is a fundamental principle in physics. It states that in an isolated system (i.e., no external forces), the total linear momentum of the system remains constant, regardless of the interactions within the system.

This is true for both elastic and inelastic collisions.

Conservation of Momentum in Collisions:

For two objects 1 and 2, with initial momenta p_1 and p_2, and final momenta p_1'and p_2', the total momentum before and after the collision is conserved: $p_1+p_2=p_1'+p_2'$. In vector form: $m_1v_1+m_2v_2=m_1v_1'+m_2v_2'$

Applications of Collisions and Momentum

a) Car Crashes

Momentum conservation helps engineers understand how forces are distributed during car crashes. In inelastic collisions, energy is absorbed through vehicle deformation, minimizing the impact on passengers.

b) Sports

In sports like pool or snooker, players rely on elastic collisions to control the balls' motion. The angles and speeds are crucial to achieve the desired outcomes based on momentum transfer.

c) Space Exploration

In space, momentum conservation is key in propulsion. Rockets expel gas backward, which provides the forward momentum needed to propel them forward (action-reaction pairs from Newton's third law).

Activity

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.

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.

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.

EXPLOSION

Explosions in Relation to Momentum Changes and Newton's Laws of Motion

Explosions can be understood through the lens of momentum changes and Newton's laws of motion. When an explosion occurs, forces are exerted, and objects are propelled in different directions, often with rapid acceleration. Key examples of these concepts include firing a gun, rocket propulsion, and a balloon releasing air.

Momentum and Explosions

Momentum is the product of an object's mass and velocity, and it is a conserved quantity in isolated systems. In the context of explosions, the total momentum before and after an explosion must remain constant (assuming no external forces act on the system). This principle is known as **the conservation of momentum.**

Before an explosion, the total momentum of the system is usually zero or some constant value.
During the explosion, forces act on different parts of the system, causing them to move in opposite directions.
After the explosion, the sum of the momenta of all the parts must equal the total momentum before the explosion.
Example of Conservation of Momentum in an Explosion:
If a firecracker explodes, the fragments move in different directions. While each fragment has its own momentum, the vector sum of the momenta of all fragments equals the momentum of the firecracker before the explosion, maintaining the system's overall momentum.

Newton's Laws of Motion and Explosions
a) Newton's First Law (Law of Inertia)
Newton's first law states that an object at rest will remain at rest, and an object in motion will remain in motion with a constant velocity unless acted upon by an external force.
Application to Explosions: Before an explosion, all parts of the object (e.g., gun, rocket, and balloon) are at rest or moving with constant velocity. The explosion introduces a force, overcoming the inertia of the object and causing its parts to move rapidly. Without the explosion, the object would remain at rest.
b) Newton's Second Law (Law of Force and Acceleration)
Newton's second law explains how the force applied to an object is directly proportional to the acceleration it experiences and inversely proportional to its mass:
$F=ma$
In the context of explosions, the rapid release of energy exerts large forces on the object, causing a dramatic acceleration of its parts.

Application to Explosions:
In a gun, the expanding gases from the explosion inside the barrel exert a force on the bullet, accelerating it out of the barrel. The greater the force applied to the bullet (which is proportional to the energy of the explosion), the greater the acceleration, and the faster the bullet will move.
In a rocket, the combustion of fuel generates a high-pressure gas that accelerates out of the rocket's engine, pushing the rocket in the opposite direction.

c) Newton's Third Law (Action-Reaction Law)

Newton's third law states that for every action, there is an equal and opposite reaction.

Application to Explosions: This law is critical in understanding how explosions cause movement. When a force is exerted on one part of the system, an equal and opposite force is exerted on another part. These forces lead to changes in momentum, propelling objects in different directions.

Examples of Newton's Third Law in Explosions:

Firing a Gun:

Action: The exploding gunpowder exerts a force on the bullet, propelling it forward.

Reaction: The gun exerts an equal and opposite force on the shooter (recoil), pushing the gun backward.

Momentum: Before the shot, the gun-bullet system has zero momentum (if at rest). After firing, the momentum of the bullet moving forward is equal and opposite to the momentum of the gun recoiling backward.

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.

Rocket Propulsion:

Action: The rocket engine expels gases downward at high speed due to the combustion of fuel.

Reaction: An equal and opposite force pushes the rocket upward.

Momentum: Before ignition, the rocket and gases are stationary, so the total momentum is zero. After ignition, the upward momentum of the rocket is balanced by the downward momentum of the expelled gases, conserving the total momentum of the system.

Balloon Releasing Air:

Action: When a balloon is released, the air inside rushes out through the opening.

Reaction: The balloon moves in the opposite direction as a response to the force exerted by the escaping air.

Momentum: The total momentum before the balloon is released is zero. Once the air escapes, the momentum of the air rushing out is balanced by the momentum of the balloon moving in the opposite direction.

Conservation of Momentum in Explosions

In all explosions, the law of conservation of momentum applies. This means that the total momentum of the system before the explosion must equal the total momentum after the explosion, provided no external forces are involved.

Before the Explosion: The system (e.g., gun and bullet, rocket and gases, balloon and air) may have zero momentum if at rest or some constant momentum if in motion.

After the Explosion: The different parts of the system move in different directions, but the vector sum of all the momenta remains equal to the initial momentum.

In an isolated system, no momentum is gained or lost during an explosion, but the energy from the explosion redistributes the momentum among the system's components.

Energy in Explosions

While momentum is conserved in explosions, kinetic energy often changes. In most explosions, energy stored in the form of chemical or nuclear potential energy is rapidly converted into kinetic energy and heat. This release of energy is responsible for the high velocities and large forces associated with explosions.

In a gun firing, the chemical energy in the gunpowder converts into the kinetic energy of the bullet.

In rocket propulsion, the chemical energy from burning fuel converts into the kinetic energy of the expelled gases and the rocket.

Activity

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.
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

3. (a) Outline the similarities and the differences between elastic and inelastic collisions

   b) Fatimah of mass 60kg running at 64 km/h jumps on a stationary trolley of mass 20kg.If the collision is perfectly inelastic; Find the Loss in kinetic energy and the final kinetic energy

MOTION IN FLUIDS: ARCHIMEDES AND FLOATATION

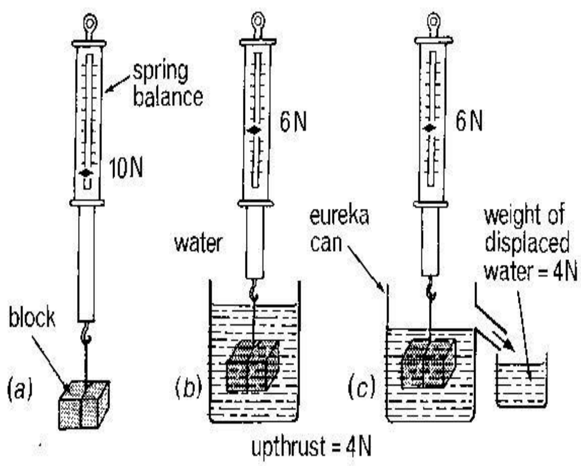
Archimedes' Principle

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' principle: 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' principle



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 obtained 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

Activity(In groups)

2. A glass block weighs 25N. When wholly immersed in water, the block appears to weigh 15N, calculate the up thrust.

2.A body weighs 1N in air and 0.3N when wholly immersed in water. Calculate the weight of water displaced

3.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.

Application of Archimedes' principle

3. Measurement of relative density of solids
4. 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

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 Ww
- Find the up thrust in liquid $= Wa - W_1$
- Find the up thrust in water $= Wa - Ww$
- Obtain RD of a liquid from $R.D = \frac{Wa - W_1}{Wa - Ww}$

Activity

3. 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.
4. An object weighs 100N in air and 20N in a liquid of RD 0.8. Find its weight in water.

3.2 Refraction, dispersion, and colour

Learning Outcomes

b) Understand that light may be refracted as it passes from one medium to another and that this has both consequences and uses (u, s,v/a)
c) Understand the concept of refractive index (u,s)c. Understand the concept of total internal reflection(u)
d) Know that white light can be split into coloured light by refraction (k,s)
e) Know that white light results from the superimposition of light of all colours of the visible spectrum (u,k)f. Determine refractive index of glass (s, gs)

Refraction of Light:

Refraction is the bending or change in direction of a ray of light as it passes from one transparent medium into another medium with a different optical density. This phenomenon occurs due to the change in the speed of light when it moves from one medium to another. Refraction is a fundamental concept in optics and is responsible for many optical phenomena and devices such as lenses, prisms, and magnifying glasses.

Concepts in Refraction:

Optical Density: Optical density refers to how much a medium slows down light as it passes through. The denser the medium, the more it slows light. Light travels fastest in a vacuum and slower in materials like air, water, or glass.

Speed of Light: The speed of light in a vacuum is approximately $3\times10^8\ m/s^3$ When light enters a denser medium (like water or glass) from a less dense medium (like air), its speed decreases, and it bends toward the normal. Conversely, when light enters a less dense medium from a denser one, its speed increases, and it bends away from the normal.

The Normal Line:

The normal is an imaginary line perpendicular to the boundary between two media at the point where the light ray strikes the surface.

Refraction is measured with respect to this normal line.

1. Snell's Law of Refraction:

The amount of bending (refraction) of light as it passes from one medium to another is governed by Snell's Law, which is mathematically expressed as:

$n_1 sin\theta_1 = n_2 sin\theta_2$.

Where:

- n_1 is the refractive index of the first medium,
- n_2 is the refractive index of the second medium,

- θ_1 is the angle of incidence (the angle between the incident ray and the normal),
- θ_2 is the angle of refraction (the angle between the refracted ray and the normal).

The refractive index (n) is a measure of how much light slows down in a given medium and is defined as: $n = \frac{c}{v}$; where: c is the speed of light in a vacuum, v is the speed of light in the medium. A medium with a higher refractive index has a lower light speed, causing more bending of light.

2. **Refraction at an Interface:** When light passes through the interface of two materials, the following scenarios occur:

a) Light Passing from a Less Dense to a Denser Medium (e.g., Air to Water):

Light slows down when it enters a denser medium, causing it to bend toward the normal. Example: A pencil partially submerged in water appears bent or broken at the water's surface because the light rays refract as they move from water (denser) to air (less dense).

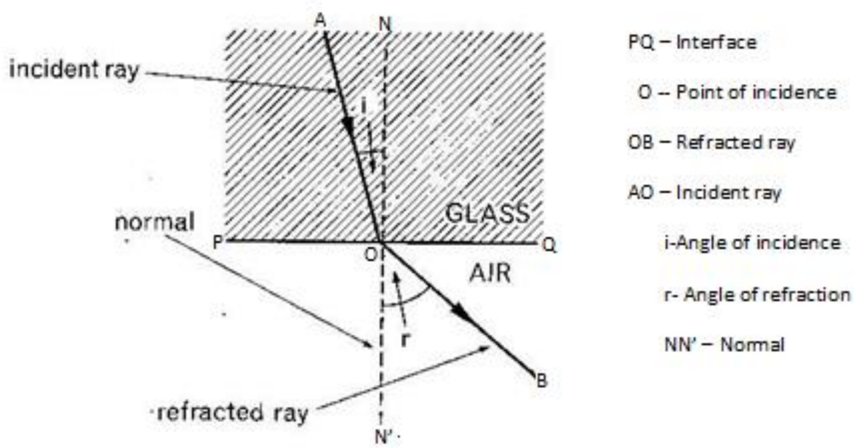
b) Light Passing from a Denser to a Less Dense Medium (e.g., Water to Air):

Light speeds up when it moves into a less dense medium, causing it to bend away from the normal.

Example: When you look at a coin at the bottom of a pool, it appears shallower than it actually is due to the refraction of light as it exits the water.

REFRACTION AT PLANE SURFACES

This is the bending of light rays when it passes from one medium to another of different optical densities



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

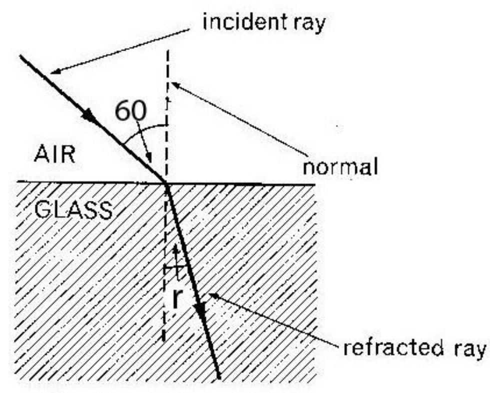
1. The incident ray, the refracted ray and the normal at the point of incidence all lie in the same plane
2. The ratio sine of angle of incidence to the sine of angle of refraction is constant for any given pair of media (Snell's law)
   i.e. $\frac{sini}{sinr} = n$,constant (n) where n – refractive 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

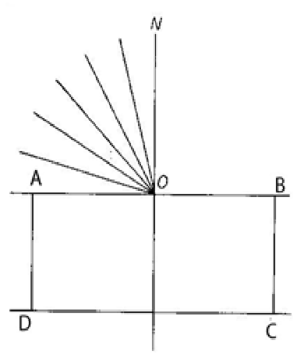
Example

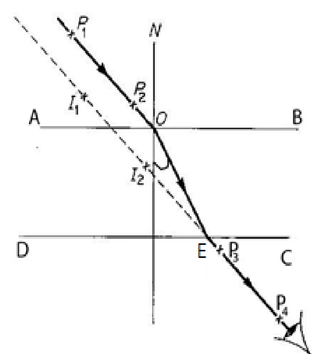
A glass material has a refractive index n= 1.5. Find the angle of refraction, if the ray of light moves from air to glass as shown below



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 =refractive index

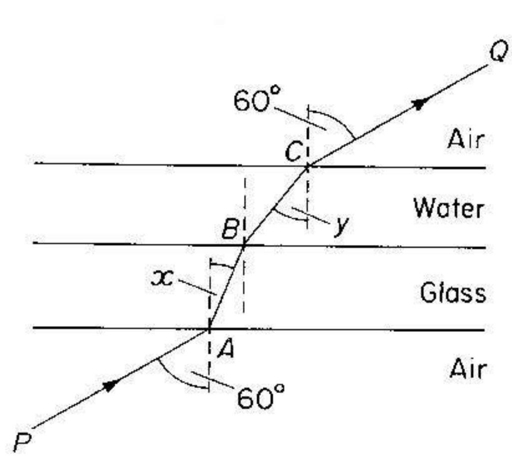
Absolute refractive index

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.

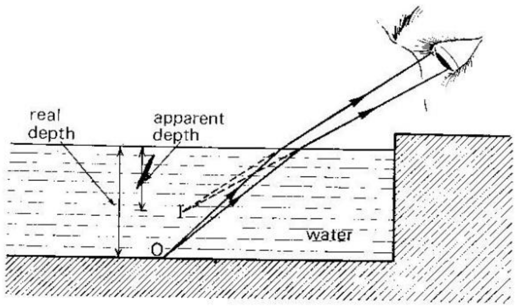
REFRACTION ON PLANE PARALLEL BOUNDARIES

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 ${}_1n_2$ = =

$n_1 \sin i = n_2 \sin r$



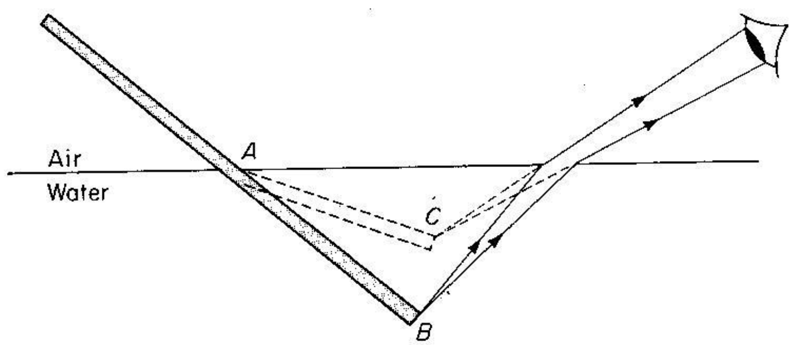
EFFECTS OF REFRACTION ON PLANE SURFACES
Refraction on plane surface causes
A partially immersed stick in water at an angle to appear bent at the boundary between air and water.
A stick placed upright in water appears shorter
A swimming pool or well or pond appears shallower than its actual size



- An object placed under the glass block appears nearer

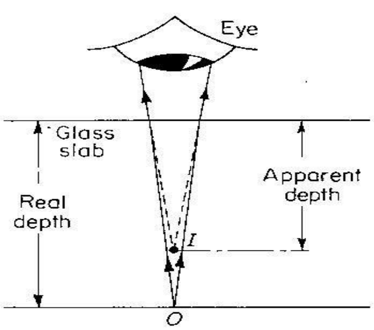
Explanation of the effects of refraction

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.

Determination of refractive index by real and apparent depth method

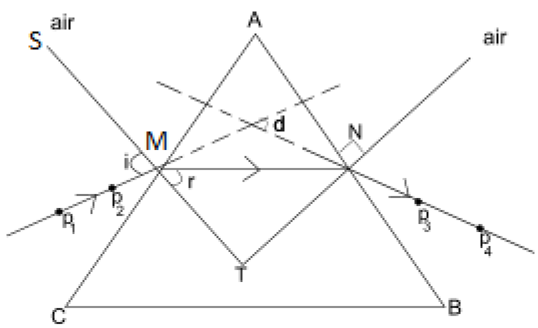
A glass block placed vertically over a cross (x) drawn on a white sheet of paper as shown above

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

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

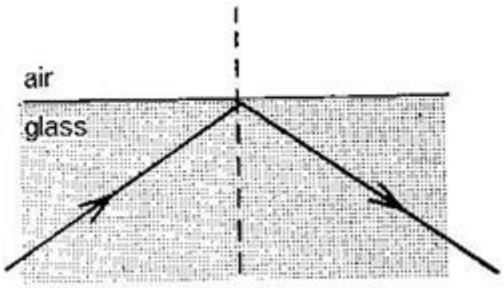
The procedure is repeated to obtain different values of i and r and the results tabulated as shown

$i(^0)$	$r(^0)$	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

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

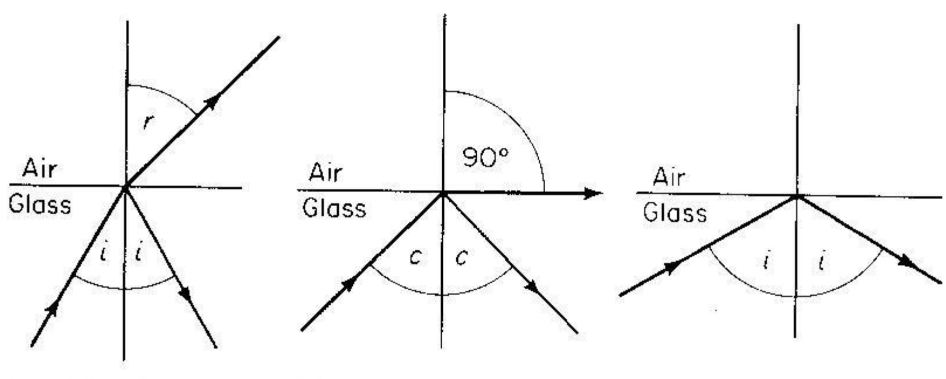
Light should travel from an optically dense medium to a less dense medium

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)

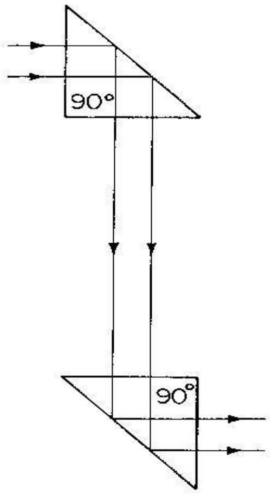
APPLICATION OF TOTAL INTERNAL REFLECTION

In refracting prisms which are in binoculars, periscopes and cameras

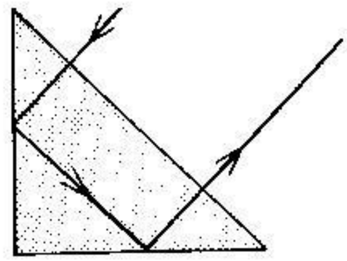
Examples

1. Turning a ray through 90^0

Prism periscope

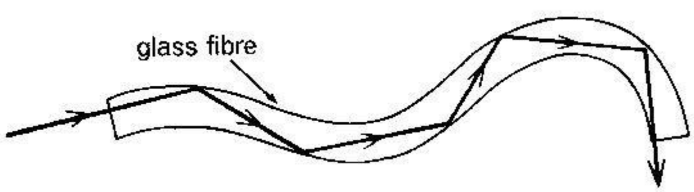


2. Turning a ray through 180^0

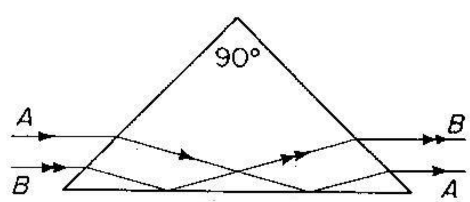


3. Turning a ray through 360^0

Optical light pipes



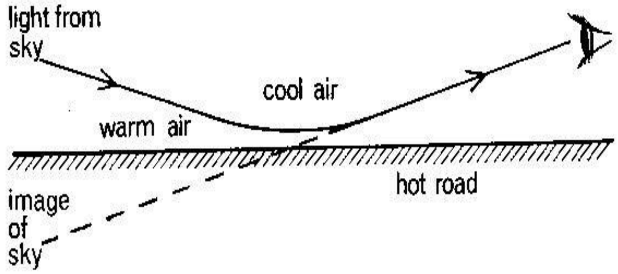
The inner surface has slightly higher refractive index than the outer surface making it slightly denser medium. Light can be trapped by total internal reflection inside a bent glass rod and piped along a curved path as shown above. Optical fibres can be used by doctors and engineers to light up some awkward spot for inspection Modern telephone cables are optical fibres using laser light



EFFECTS OF TOTAL INTERNAL REFLECTION

The mirage

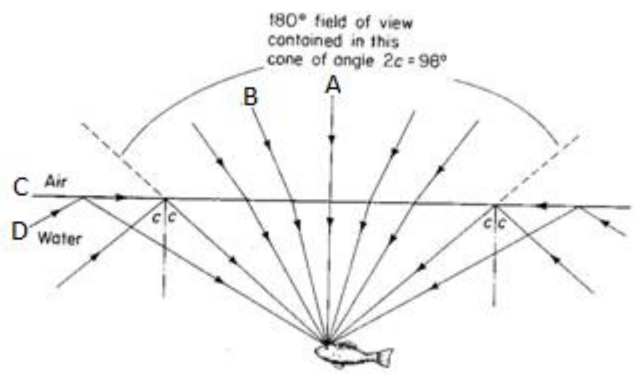
This can happen when the air nearer the surface of the ground is less dense than that above. Cool air is dense than warm air.



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



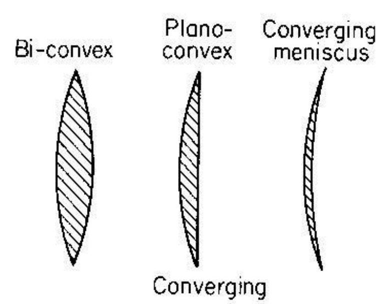
Fish's eye view

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.

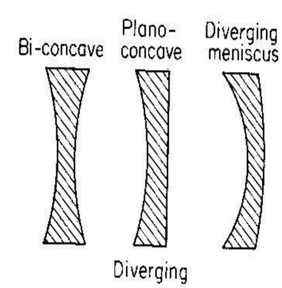


LENSES

These are two types:

(i) Convex/converging lenses

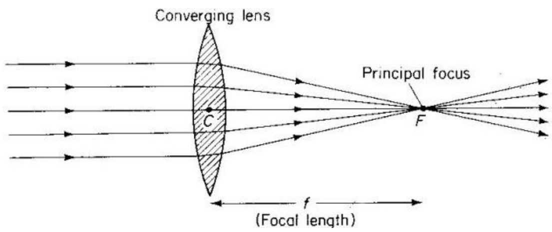
(ii) Concave/diverging lenses

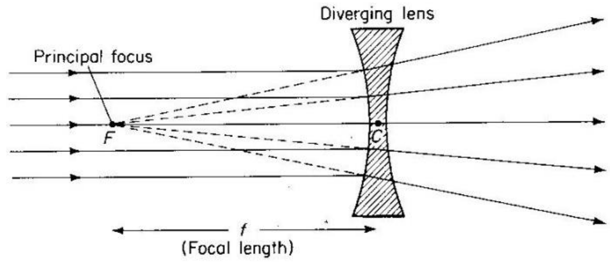


Convex lens

Concave lens

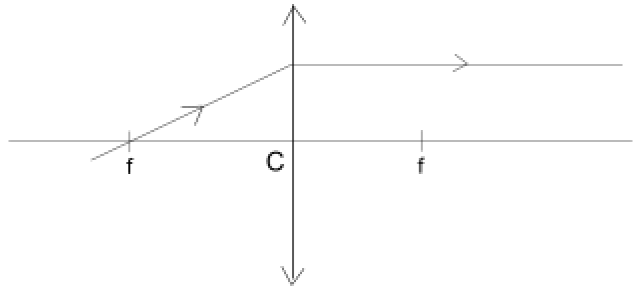
Terms used:





Principal axis: is a line joining the principal focus and the optical Centre

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



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

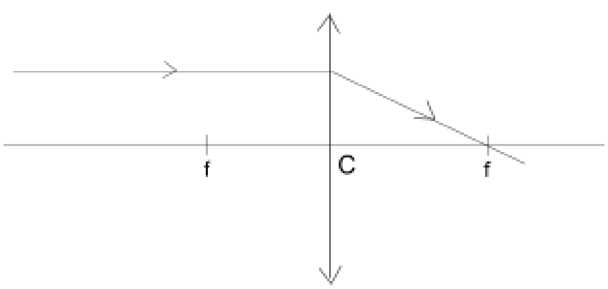
Focal length: this is the distance between the principal focus and the optical centre

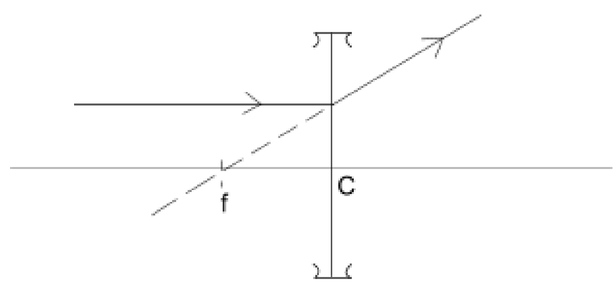
Optical centre: this is the centre of the lens at which rays pass undeviated.

CONSTRUCTION OF RAY DIAGRAM

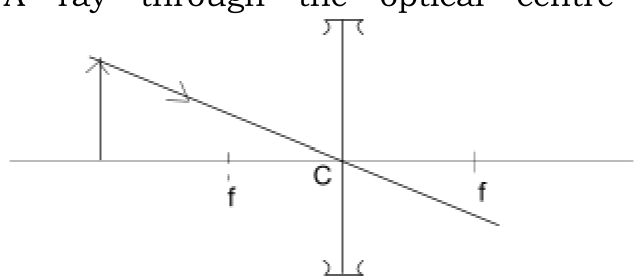
In constructing ray diagrams, 2 of the 3 principal rules are used.

1. A ray parallel to the principal axis is refracted through the focal point

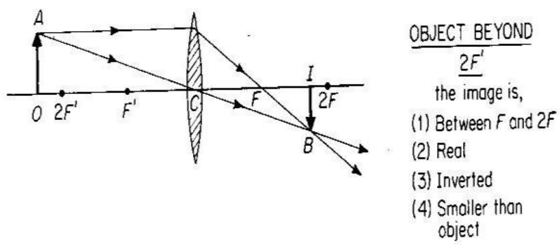


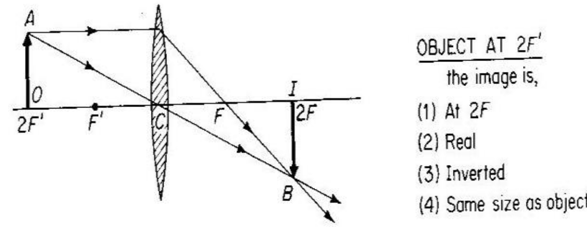


2. A ray through the optical centre passes through undeviated



3. A ray through the principal focus emerge parallel to the principal axis after refraction





Images formed by convex lenses

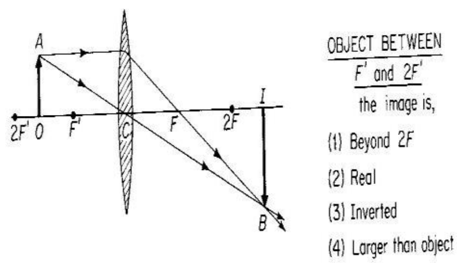
The nature of the image formed in a convex lens depends on the position of the object from the lens

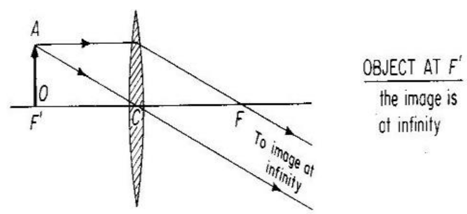
Object beyond 2f

Object at 2f

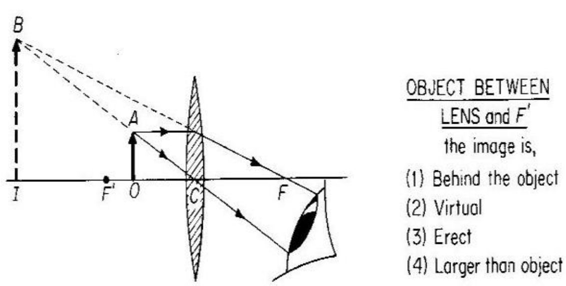
Object between f and 2f

Object at f





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

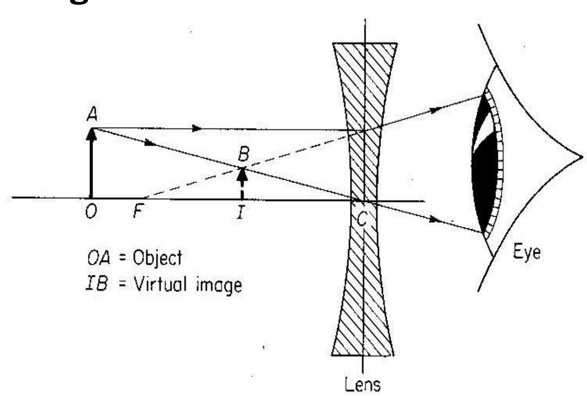
Image Formation in a Concave Lens

Power of a lens

It is defined as the reciprocal of focal length in metres

Power of lens $P = \frac{1}{f}$ where f is focal length of the lens in metres

S.I units of power of the lens is dioptres (D)



Activity

1. Calculate the power of the focal length 10cm.
2. Find the power of the lens whose focal length is 20cm

Magnification of the lens

It is defined as the ratio of the image height to object height

OR

It is the ratio of image distance to object distance from the lens

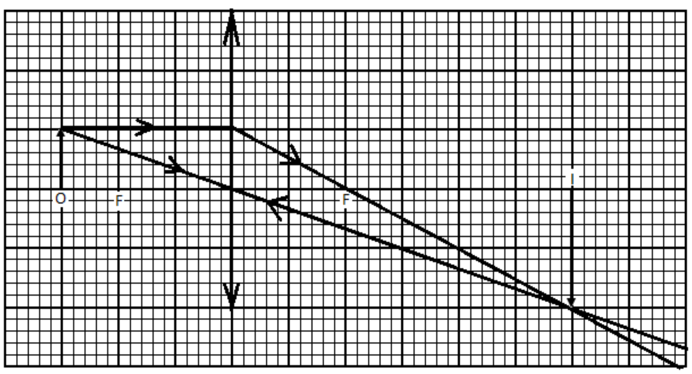
Determination of image position by graphical method

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)

Activity

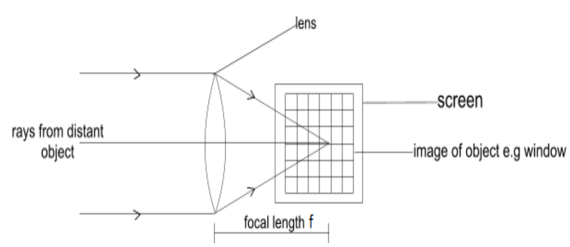
1. A simple magnifying glass of focal length 5cm forms an erect image of the object 25cm from the lens. By graphical method
    a. Find the distance between the object and image
    b. Calculate the magnification
2. An erect object 5cm high is placed at a point 25cm from a convex lens. A real image of 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

Method 1: Rough method

Procedure

A converging lens with a screen on one

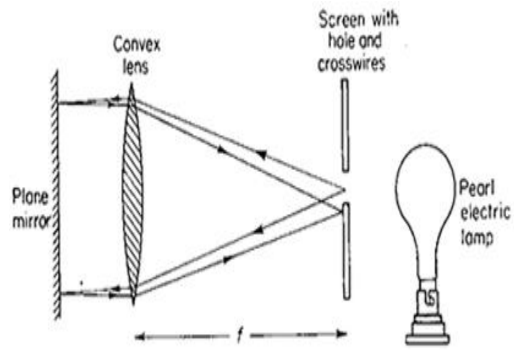


side is placed some distance from the distant object e.g. a window as shown. The screen is moved away or towards the lens until a clear image of the window is formed on the screen

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.

Determination of focal length using on illuminated object



Procedure

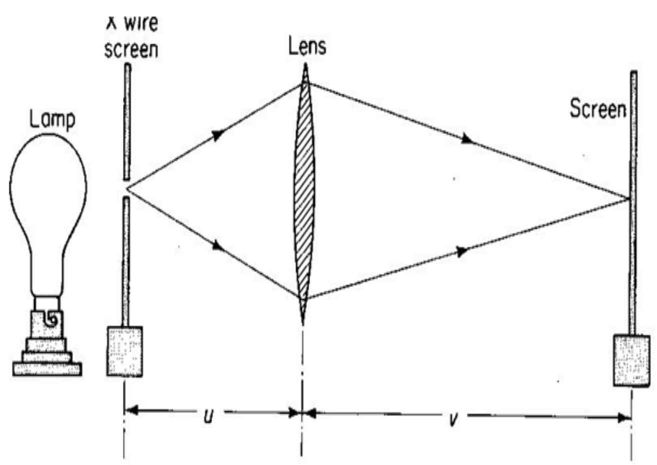
A lens is set up in a suitable holder with a plane mirror behind it so that light passing through the lens is reflected back as shown above

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

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 obtained and the results entered in a suitable table, including values of $\frac{1}{u}$ *and* $\frac{1}{v}$, the mean value of intercepts c= $\frac{1}{2}(\frac{1}{c_1}+\frac{1}{c_2})$ determined.

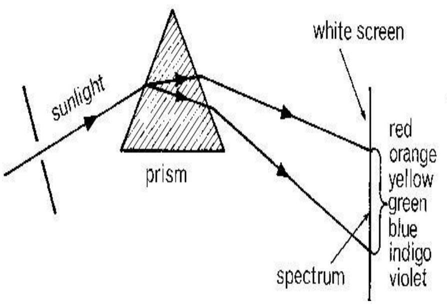
Focal length is calculated from: f = c

Application of lenses

- Lens camera
- Slide projectors
- Spectacles (used by people with eye defects)
- Microscopes and telescopes.

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.

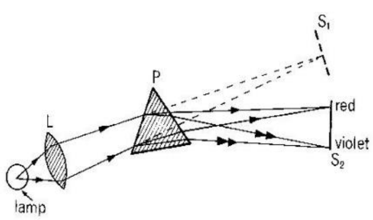


Dispersion occurs because each colour is refracted in glass by different amount i.e. each colour has different refractive index. So red is refracted least and violet is refracted most.

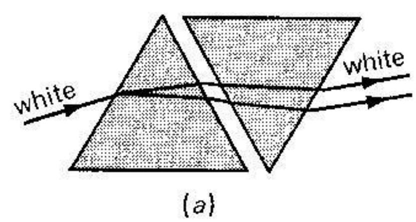
HOW TO OBTAIN A PURE SPECTRUM

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.



(a)

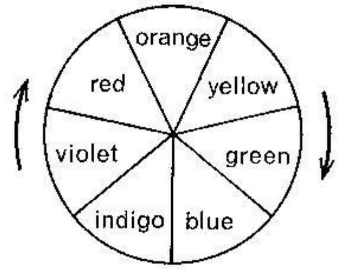
Lens B collects the different coloured lines so that the parallel beam of each separate colour is focused on the screen.

RECOMBINATION OF THE SPECTRUM:

The colours of the spectrum can be recombined by;

Arranging a second prism so that the light is deviated in the opposite direction,

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.

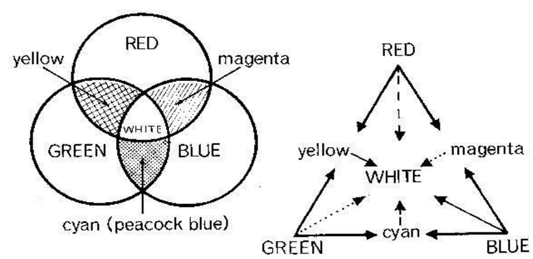
The colour it transmits or reflects e.g. an object appears blue because it reflects blue light into the eyes and absorbs the other colours of the spectrum. Similarly, an object appears red because it reflects red light into the eyes and absorbs all other colours.

A white object reflects all the colours of the spectrum into the eyes and absorbs none.

Types of colours:

Primary colours

These are colours that can't be obtained by adding two different colours of light. They include red, blue and green



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.

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

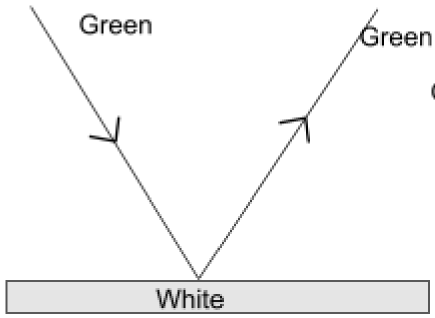
Blue + yellow → white light

From the complementally colours it is noted that when the three primary colours are joined, they produce white light.

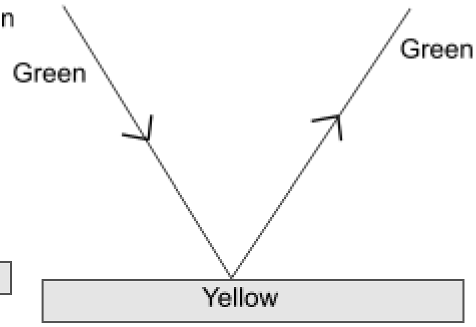
SUMMARY OF COLOURED LIGHTS

Coloured objects in white light

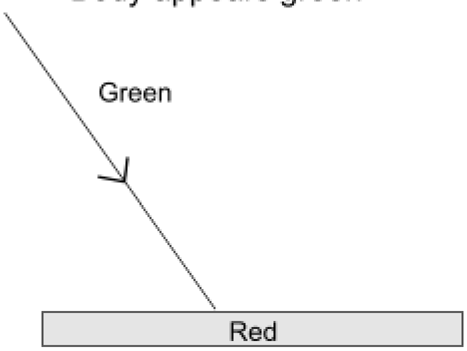
A coloured object reflects and transmits its own colour and absorbs other colour incident on it. **Examples:**



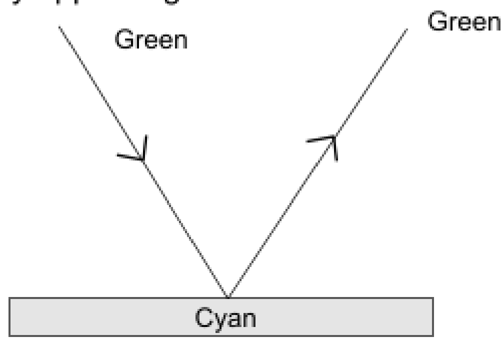
Body appears green



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.

Activity

Describe and explain the appearance of a red tie with blue spots when observed in;

a. Red light
b. green light

Solution

Green light – the red tie appears black because both colours are primary colours and non is reflected

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.

A plant with green leaves and red flowers is placed in

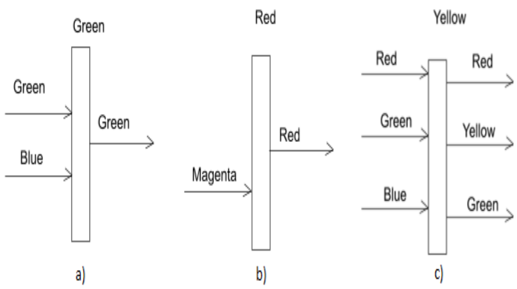
a) green
b) blue
c) Yellow

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 $\rightarrow$ green

Yellow + orange $\rightarrow$black

Green + indigo $\rightarrow$ blue

The blue reflects indigo and green, its neighbor 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

To understand how a colour pigment appears in white light, it's essential to explore the interactions between the pigment, which absorbs and reflects light, and white light, which contains all visible colours.

White Light Composition:

White light consists of the entire visible spectrum of colours: red, orange, yellow, green, blue, indigo, and violet. When all these wavelengths are combined, the result is white light.

When white light strikes an object, some wavelengths are absorbed, and others are reflected. The reflected wavelengths determine the colour that we perceive.

Colour Pigments:

Pigments are substances that selectively absorb some wavelengths of light and reflect others. The colour of the pigment is determined by the wavelengths it reflects.
For example, a red pigment absorbs all other colours except red, which it reflects, making it appear red to our eyes.

Appearance of Different Colour Pigments in White Light:

Red Pigment in White Light:

A red pigment absorbs most wavelengths in the white light spectrum except for red. It reflects the red wavelengths, and this reflected red light reaches our eyes, making the object appear red.
Example: A red apple appears red because it reflects the red wavelengths of white light and absorbs the others.

Blue Pigment in White Light:

A blue pigment absorbs all other colours except blue. It reflects the blue wavelengths of the white light, and we perceive the object as blue.
Example: A blue cloth absorbs all non-blue wavelengths but reflects the blue component, making it look blue under white light.

Green Pigment in White Light:

A green pigment absorbs most wavelengths except green. The green component of the white light is reflected, making the object appear green.
Example: Green leaves absorb most of the light except for the green portion, which is reflected, giving them their green appearance.

Yellow Pigment in White Light:

Yellow is typically a result of the reflection of both red and green light. A yellow pigment absorbs other wavelengths and reflects red and green light, which combine to form the perception of yellow.
Example: A sunflower appears yellow because its pigments reflect both red and green light, which combine to give the yellow hue.

Magenta Pigment in White Light:

Magenta reflects red and blue wavelengths while absorbing green. The combination of red and blue wavelengths reflected from white light gives the perception of magenta.
Example: A magenta flower reflects red and blue light, making it look magenta under white light.

Cyan Pigment in White Light:

Cyan reflects blue and green wavelengths while absorbing red. The combination of blue and green wavelengths reflected from white light makes the object appear cyan.

Example: Cyan-coloured objects reflect both blue and green light, giving them a cyan appearance in white light.

White Pigment in White Light:

A white pigment reflects all wavelengths of light, so it appears white. None of the light is absorbed, and all of it is reflected.

Example: A white sheet reflects the entire spectrum of white light, appearing white to our eyes.

Black Pigment in White Light:

A black pigment absorbs all wavelengths of light and reflects none, which is why it appears black. No light reaches our eyes from the pigment.

Example: A black T-shirt absorbs all the light falling on it, so it appears black under white light.

How Mixing Pigments Affects Appearance:

Primary Pigments:

The primary pigments are cyan, magenta, and yellow. These pigments can mix to create other colours by absorbing different wavelengths of white light.

Cyan absorbs red and reflects blue and green.

Magenta absorbs green and reflects red and blue.

Yellow absorbs blue and reflects red and green.

Secondary Colours:

Mixing two primary pigments results in a secondary colour.

Cyan + Magenta reflects blue light (since both absorb green and red), making the resulting pigment appear blue.

Magenta + Yellow reflects red light (since both absorb green and blue), making the pigment appear red.

Cyan + Yellow reflects green light (since both absorb red and blue), making the pigment appear green.

Conclusion:

The appearance of a pigment in white light is determined by the specific wavelengths it reflects. When illuminated with white light, a pigment absorbs certain colours and reflects others, creating the perception of its colour. This interaction between the pigment and the various wavelengths in white light allows us to see the pigment in its characteristic hue.

A colour pigment reflects only one colour

APPEARANCE A COLOUR PIGMENT IN COLOURED LIGHT

The Appearance of a Colour Pigment in Coloured Light

Colour pigments, such as those found in paints, fabrics, or dyes, appear coloured because they absorb certain wavelengths of light and reflect others. The perceived colour of an object is due to the light wavelengths that are reflected into our eyes. When an object is viewed under coloured light, its appearance can change based on the interaction between the pigment and the wavelength of the light.

White Light and Pigments:

White light is a combination of all the colours in the visible spectrum (red, orange, yellow, green, blue, indigo, and violet).

A pigment appears a certain colour because it absorbs all the other colours and reflects only the colour it appears to be. For example, a red pigment absorbs all wavelengths except red, which it reflects.

Coloured Light:

Coloured light contains only specific wavelengths, not the full spectrum of white light. For example, red light only contains red wavelengths, and blue light only contains blue wavelengths.

The Interaction of Colour Pigments with Coloured Light:

Pigment in Red Light:

Red Pigment: In red light, a red pigment will still appear red because it reflects the red light and absorbs everything else. Since the light source is red, the pigment reflects that red light back.

Blue Pigment: A blue pigment will appear black or very dark in red light because there is no blue light to reflect. The pigment absorbs the red light, and since no blue light is present, no light is reflected, making the object look black.

Green Pigment: Similarly, a green pigment will appear black in red light, as green pigments absorb red light and reflect green. Since no green light is present, no light is reflected.

Pigment in Blue Light:

Red Pigment: A red pigment will appear black in blue light because it absorbs blue light and reflects only red. Since there is no red light to reflect, it appears black.

Blue Pigment: A blue pigment will appear blue in blue light because it reflects blue light and absorbs other colours.

Green Pigment: A green pigment will also appear black in blue light, as it reflects green light, which is absent in this case.

Pigment in Green Light:

Red Pigment: A red pigment will appear black in green light because it absorbs green light and reflects only red, which is not present.
Green Pigment: A green pigment will appear green in green light because it reflects green light and absorbs the rest.
Blue Pigment: A blue pigment will appear black in green light because it absorbs green light and does not reflect it.

Pigment in Yellow Light:

Red Pigment: Yellow light consists of both red and green light. A red pigment will reflect the red portion of yellow light, making it appear red.
Blue Pigment: Since blue pigments absorb both red and green light, a blue pigment will appear black in yellow light.
Green Pigment: A green pigment will reflect the green component of yellow light and appear green.

White Pigment:

A white pigment reflects all wavelengths of light. In coloured light, a white pigment will appear the same colour as the light shining on it. For example, in red light, a white pigment will appear red, and in blue light, it will appear blue.

Black Pigment:

A black pigment absorbs all wavelengths of light and reflects none. Regardless of the coloured light shining on it, a black pigment will always appear black because no light is reflected.

Practical Examples:

Red Pigment under Green Light: A red pigment will absorb green light and appear black.
Blue Pigment under Red Light: A blue pigment will absorb red light and appear black.
Yellow Pigment under Blue Light: Yellow pigments are typically made by mixing red and green pigments. Under blue light, a yellow pigment will appear black because there is no red or green light to reflect.
Conclusion:
The appearance of a pigment in coloured light depends on the relationship between the light's wavelength and the pigment’s reflective properties. If the pigment reflects the wavelength of the coloured light, it will appear its normal colour. If the pigment absorbs the wavelength, it will appear black or very dark because no light is reflected back to the observer.

3. Critical Angle and Total Internal Reflection:

When light travels from a denser medium to a less dense medium, there is a special angle of incidence called the critical angle. At this angle, the refracted ray travels along the boundary between the two media. If the angle of incidence exceeds the critical angle, light undergoes total internal reflection and does not pass into the second medium.

a) **Critical Angle (θ_c):** The critical angle is the angle of incidence beyond which light is totally reflected within the denser medium. It can be calculated using the formula: $\theta_c = \frac{n_2}{n_1}$, Where $n_1$is the refractive index of the denser medium, and n_2 is the refractive index of the less dense medium.

b) **Total Internal Reflection:** This occurs when light tries to move from a denser medium to a less dense medium at an angle greater than the critical angle. Instead of refracting, the light is reflected back into the denser medium. Total internal reflection is the basis for optical fiber technology and devices like binoculars and periscopes.

4. Refraction in Lenses: Refraction is responsible for the focusing power of lenses, which are designed to bend light rays in a controlled manner.

a) Converging (Convex) Lenses: Convex lenses cause light rays to converge at a focal point. They are thicker at the center and thinner at the edges.

Parallel rays of light refract through the lens and meet at a point on the other side of the lens (the focal point). This is used in magnifying glasses, cameras, and eyeglasses for farsightedness.

b) Diverging (Concave) Lenses: Concave lenses cause light rays to diverge away from each other. They are thinner at the center and thicker at the edges. Parallel light rays refract through the lens and diverge as if they are originating from a focal point on the same side of the lens. This is used in glasses for nearsightedness.

5. Applications of Refraction:

Refraction plays a key role in various real-world applications, including:

a) **Optical Instruments:** Lenses used in microscopes, telescopes, and cameras depend on the refraction of light to magnify or focus images. Eyeglasses use refraction to correct vision by altering the path of light entering the eye.

b) **Prisms:** A prism refracts light in such a way that it splits white light into its component colors (a spectrum) due to different colors of light having different refractive indices. This is known as dispersion.

c) **Mirages:** Mirages are optical illusions caused by the refraction of light in layers of air with varying temperatures. Light bends when it moves through air layers of different densities, creating the illusion of water on the road on a hot day.

d) **Fiber Optics:** Fiber optics relies on total internal reflection. Light signals travel through a glass or plastic fiber, staying inside the fiber due to continual total internal reflection.

6. Real-World Examples of Refraction:

a) **The Bending of a Straw in Water**: A straw in a glass of water appears bent or broken at the water's surface because the light coming from the submerged portion of the straw bends as it moves from the water to the air.

b) **Stars Twinkling:** Twinkling of stars is due to the refraction of starlight as it passes through different layers of the Earth's atmosphere, which have varying densities and temperatures.

c) **Lenses in Eyeglasses and Contact Lenses:** Eyeglasses and contact lenses correct refractive errors in the eye by bending light rays so that they properly focus on the retina.

Refraction is a vital concept in understanding how light interacts with different materials. It explains why objects appear distorted when viewed through water, how lenses work to focus or disperse light, and why phenomena like mirages and rainbows occur. By applying Snell's Law and the principles of refraction, we can design powerful optical instruments and technologies that rely on the predictable bending of light.

Refractive Index: The refractive index (also called the *index of refraction*) is a fundamental property of materials that describes how light behaves when it passes from one medium to another. It quantifies how much the light slows down and bends (refracts) when it enters a different medium.

The refractive index is a dimensionless number and is crucial in understanding optical phenomena such as refraction, reflection, and dispersion. It plays a key role in optics, helping us understand the behavior of lenses, prisms, and various optical instruments.

1. Definition of Refractive Index:

The refractive index (n) of a medium is defined as the ratio of the speed of light in a vacuum (or air) to the speed of light in the medium. Mathematically, it is expressed as: $n = \frac{c}{v}$, Where: n is the refractive index, c is the speed of light in a vacuum ($c \approx 3\times10^8$ m/s), v is the speed of light in the medium.

2. Interpretation of Refractive Index: A higher refractive index means that light travels more slowly in the medium, indicating the medium is optically denser. A lower refractive index means that light travels more quickly in the medium, indicating the medium is optically less dense.

For example: The refractive index of air is approximately 1.0003 (close to 1, as the speed of light in air is nearly the same as in a vacuum). The refractive index of water is about 1.33, meaning light travels 1.33 times slower in water than in a vacuum. The refractive index of glass is typically around 1.5, depending on the type of glass.

3. Snell's Law and Refractive Index:

The refractive index plays a critical role in Snell's Law, which describes the relationship between the angles of incidence and refraction when light passes from one medium to another.

Snell's Law: $n_1 sin\theta_1 = n_2 sin\theta_2$. Where: n_1 and n_2 are the refractive indices of the two media, θ_1 is the angle of incidence (the angle between the incident ray and the normal), θ_2 is the angle of refraction (the angle between the refracted ray and the normal). The refractive index determines how much the light ray will bend when passing between media with different refractive indices:

If light passes from a less dense medium (lower refractive index) to a denser medium (higher refractive index), it bends toward the normal.

If light passes from a denser medium to a less dense medium, it bends away from the normal.

4. Refractive Index and Light Wavelength:

The refractive index of a material is wavelength-dependent, meaning it varies with the color (wavelength) of light. This phenomenon is called dispersion. Shorter wavelengths (e.g., blue light) are bent more than longer wavelengths (e.g., red light). This is why when white light passes through a prism, it separates into its constituent colors (a spectrum), forming a rainbow. The variation of refractive index with wavelength is the reason for the rainbow effect in prisms and is also important in lens design, where it causes chromatic aberration.

5. Types of Refractive Indices:

Absolute Refractive Index (n): This refers to the refractive index of a material with respect to a vacuum (or air). For example, the absolute refractive index of glass is approximately 1.5, meaning light travels 1.5 times slower in glass than in a vacuum.

Relative Refractive Index: This is the ratio of the refractive indices of two media, and it is used when light passes between two non-vacuum mediums. It is given by: $n_{rel} = \frac{n_2}{n_1}$. This can be used to determine how light bends at the boundary between two media.

6. Factors Affecting Refractive Index:

Several factors influence the refractive index of a material:

Material Composition: Different materials have different molecular structures, which affect how they slow down light. For example, diamond has a much higher refractive index (around 2.42) compared to water (1.33) because of its denser molecular structure.

Wavelength of Light: As mentioned earlier, the refractive index is higher for shorter wavelengths. Thus, blue light bends more than red light when passing through a material.
Temperature: The refractive index of liquids and gases can change with temperature. For example, the refractive index of water decreases as the temperature increases, because the density of the water decreases.
Pressure: For gases, the refractive index increases with pressure because the density of the gas increases.
7. Applications of Refractive Index:
The refractive index has numerous practical applications in everyday life, science, and technology:
a) **Lenses and Optics:** Lenses used in glasses, microscopes, cameras, and telescopes rely on precise control of refractive indices to bend and focus light. The design of lenses is based on their refractive index to correct vision or magnify objects.
b) **Fiber Optics:** Optical fibers used in telecommunications rely on total internal reflection, which depends on the refractive index of the fiber's core and cladding to keep light signals within the fiber.
c) **Prisms and Dispersion:** The refractive index is responsible for splitting white light into a spectrum of colors when it passes through a prism. This phenomenon is used in spectroscopy and optical instruments.
d) **Refractive Index Matching:** In forensic science, the refractive index is used to match materials like glass fragments by comparing their refractive indices. If two samples have the same refractive index, they could be part of the same material.
e) **Measurement of Purity:** Refractive index measurements are used to check the purity of liquids in industries like food and beverage, pharmaceuticals, and petroleum. The refractive index changes with the concentration of substances dissolved in a liquid.
f) **Mirages and Atmospheric Refraction**: The refractive index of the atmosphere changes with temperature, causing light to bend and form mirages on hot days. Similarly, stars appear to twinkle due to atmospheric refraction.
8. Real-World Examples:
Air and Water: The refractive index of air is close to 1, while the refractive index of water is about 1.33. This explains why objects submerged in water appear bent or displaced when viewed from above the water surface. This bending is due to the difference in refractive indices.
Diamond: Diamonds have a high refractive index (~2.42), which makes them sparkle when cut properly. Light entering a diamond slows down significantly,

bends sharply, and undergoes total internal reflection, contributing to the gemstone's brilliance.

Conclusion:

The refractive index is a crucial concept in understanding how light interacts with different materials. It explains why light bends when moving between mediums of different optical densities and is a key parameter in the design of lenses, optical devices, and communication systems. By measuring and utilizing refractive indices, we can control and manipulate light for various practical applications, from correcting vision to transmitting data across the world.

Total Internal Reflection

Total Internal Reflection (TIR) is an optical phenomenon that occurs when a light ray traveling within a denser medium hits the boundary of a less dense medium at an angle greater than a critical angle, causing the light to be completely reflected back into the denser medium, instead of refracting into the less dense medium. This phenomenon is crucial in fields like fiber optics, binoculars, and various optical instruments.

1. Conditions for Total Internal Reflection:

For total internal reflection to occur, two conditions must be met:

a) *Light Must Travel from a Denser Medium to a Less Dense Medium:* The light ray must be moving from a medium with a higher refractive index (denser medium, like glass or water) to a medium with a lower refractive index (less dense medium, like air or a vacuum). Example: Light traveling from water ($n \approx 1.33$) to air ($n \approx 1.00$) or from glass ($n \approx 1.5$) to air.

b) The Angle of Incidence Must Be Greater Than the Critical Angle: The angle of incidence (the angle at which the light ray strikes the boundary) must exceed a certain threshold called the critical angle. The critical angle depends on the refractive indices of the two media and can be calculated using Snell's Law. If these conditions are met, instead of being refracted into the second medium, the light is completely reflected back into the original medium.

2. Critical Angle and Its Calculation:

The critical angle (θ_c) is the angle of incidence beyond which total internal reflection occurs. It is the minimum angle at which light is no longer refracted but instead reflected entirely back into the denser medium.

The critical angle can be calculated using Snell's Law when the angle of refraction is 90° (the refracted ray is along the boundary). The formula for the critical angle is: $sin\theta_c = \frac{n_2}{n_1}$, where: θ_c is the critical angle, n_1 is the refractive index of the denser medium, and n_2 is the refractive index of the less dense medium. For a ray traveling from glass to air, $\sin\theta_c = \frac{1}{n_g}$

Example: *For light traveling from water (n_1=1.33) to air (n_2=1.00): $\sin\theta_c$=1.00/1.33=0.7519. $\theta_c=\sin^{-1}(0.7519)\approx 48.6^\circ$ So, the critical angle for light passing from water to air is approximately 48.6°. Any angle of incidence greater than this will result in total internal reflection.*

3. How Total Internal Reflection Occurs:

When light hits the boundary between a denser and a less dense medium:

For angles of incidence smaller than the critical angle, light will partially refract into the less dense medium and partially reflect back into the denser medium.

For angles of incidence equal to the critical angle, light refracts at an angle of 90° (along the surface), and no light enters the less dense medium.

For angles of incidence greater than the critical angle, light undergoes total internal reflection and is reflected entirely back into the denser medium.

This complete reflection occurs because light is unable to refract out of the denser medium, as it "misses" entering the less dense medium at angles greater than the critical angle.

4. Examples of Total Internal Reflection in Daily Life:

a) Mirages: Mirages are optical illusions caused by the total internal reflection of light in layers of air at different temperatures. On a hot day, light from the sky may be totally internally reflected by layers of warm air near the surface, creating the illusion of water or a reflective surface on the road.

b) Shining Light through Water: When light is directed from inside water toward the surface (from a pool or aquarium), if the angle of incidence is greater than the critical angle, all the light is reflected back into the water, making the surface act like a mirror.

5. Applications of Total Internal Reflection:

Total internal reflection is widely used in various technologies and instruments because it allows for efficient light reflection with minimal loss. Some notable applications include:

a) Optical Fibers: Fiber optics relies on total internal reflection to transmit light signals over long distances with minimal loss. The light signals bounce along the core of the fiber, which has a higher refractive index, while the cladding (outer layer) has a lower refractive index, causing the light to be totally internally reflected along the length of the fiber. This technology is used in telecommunications, internet connections, and medical instruments like endoscopes.

b) Prisms in Binoculars and Periscopes: In binoculars and periscopes, prisms are used to reflect light using total internal reflection, allowing for better image clarity and efficient light transmission. Prisms replace mirrors in these devices because TIR is more efficient and produces no image distortion.

c) Retroreflectors: Retroreflectors, which are used in road signs and bicycle reflectors, rely on total internal reflection. These devices reflect light back to the source (such as headlights) even if the light strikes them at an angle, ensuring visibility at night.

d) Diamond Sparkle: Diamonds owe much of their sparkle to total internal reflection. The high refractive index of diamonds causes light entering the stone to reflect multiple times before it exits, producing the characteristic brilliance and fire.

6. Total Internal Reflection in Rainbows: While refraction and dispersion are the primary phenomena behind rainbows, total internal reflection also plays a role. When light enters a raindrop, it refracts and disperses into its component colors, and the light that is reflected internally within the raindrop undergoes total internal reflection before exiting to form the rainbow.

7. Advantages of Total Internal Reflection: Efficient Reflection: TIR is 100% efficient, meaning no light is lost, unlike in partial reflection, where some light is refracted and escapes. No Surface Coating Needed: Unlike mirrors, which require a reflective coating to reflect light, TIR occurs naturally at the boundary between two media, without the need for any external surface treatment. No Energy Loss: since the light is completely reflected, there is any energy loss due to absorption, making TIR ideal for high-precision optical devices.

Total Internal Reflection (TIR) is a powerful optical principle that occurs when light is reflected back into a denser medium rather than refracting into a less dense medium. It has a wide range of applications in modern technology, including optical fibers, prisms, and high-quality reflective devices. TIR is favored because of its efficiency, precision, and the fact that it involves no loss of light, making it a key concept in optics and photonics.

3.3 Lenses and optical instruments

Learning Outcomes

a) Know the properties of converging and diverging lenses, and how they are used in everyday life (k,u,s)
b) Understand how lenses are used in optical systems such as the magnifying glass, correcting sight in the human eye and in camera lenses (k, u,v/a)

Lenses are optical devices that bend and focus light through the process of refraction.

There are two primary types of lenses: converging (convex) lenses and diverging (concave) lenses.

1. Converging Lenses (Convex Lenses)

Definition: A converging lens is a lens that is thicker in the center and thinner at the edges. This type of lens refracts parallel light rays coming from an object, bending them inward so that they converge (meet) at a point called the focal point.

Shape:

- Convex in shape, meaning it bulges outward.
- The middle portion is thicker than the edges.

How It Works: When parallel light rays enter a converging lens, the light slows down as it enters the lens, bending toward the normal (due to the higher refractive index of the lens material compared to air). As the light exits the lens, it bends again, focusing all the light rays at a single point on the other side of the lens, called the real focal point. The distance from the center of the lens to this focal point is called the focal length.

Image Formation: Object close to the lens: If the object is placed between the focal point and the lens, the image formed is virtual, upright, and magnified. This is the principle behind magnifying glasses. Object farther from the lens: If the object is beyond the focal point, the image is real, inverted, and its size depends on the object's distance from the lens.

Uses of Converging Lenses:

Magnifying Glasses:

Function: Converging lenses are used in magnifying glasses to enlarge the appearance of small objects by converging light rays to produce a larger, upright virtual image.

Practical Use: Used to read small text or examine tiny objects.

Cameras:

Function: Converging lenses focus light from the object onto the film or sensor, forming a sharp, inverted image of the object. The lens system allows for the adjustment of focus.

Practical Use: Almost all camera systems, whether digital or film-based, use converging lenses.

Eyeglasses for Far-Sightedness (Hyperopia):

Function: Far-sighted individuals struggle to focus on nearby objects because their eyes focus images behind the retina. Convex lenses help by converging the light before it enters the eye, enabling proper focus on the retina.

Practical Use: Corrective glasses for far-sighted individuals.

Telescopes and Microscopes:

Function: Converging lenses are used to magnify distant celestial objects (telescopes) or tiny biological samples (microscopes) by forming real or virtual magnified images.

Practical Use: Astronomers use telescopes to view distant stars and planets; scientists use microscopes to view cells and microorganisms.

Projectors:

Function: In a projector, a convex lens is used to focus and enlarge an image or video onto a large screen. The projector forms a real image by directing light through a converging lens system.

Practical Use: Used in classrooms, movie theaters, and presentations.

2. Diverging Lenses (Concave Lenses)

Definition: A diverging lens is a lens that is thinner in the center and thicker at the edges. It causes parallel light rays to spread out (diverge) as they pass through the lens. The diverging rays seem to come from a point behind the lens called the virtual focal point.

Shape:

Concave in shape, meaning it curves inward like the inside of a bowl.

The edges are thicker than the center.

How It Works:

When parallel light rays enter a diverging lens, they bend outward (away from each other) after passing through the lens.

The light rays appear to come from a virtual focal point behind the lens.

A diverging lens refracts light in such a way that it never actually converges but appears to spread apart as if originating from a common point.

Image Formation:

Diverging lenses always form a virtual, upright, and reduced image, which appears smaller than the actual object. The virtual image is located on the same side as the object, but behind the lens.

Uses of Diverging Lenses:

Eyeglasses for Near-Sightedness (Myopia):

Function: Near-sighted individuals (myopic) have trouble focusing on distant objects because their eyes focus images in front of the retina. Concave lenses spread the light rays slightly before they enter the eye, pushing the focal point back onto the retina.

Practical Use: Concave lenses are widely used in eyeglasses for people with near-sightedness to correct their vision.

Peepholes in Doors:

Function: Peepholes use diverging lenses to provide a wide-angle view of the outside. This gives the viewer a broader view of the area outside the door, despite the small size of the peephole.

Practical Use: Peepholes are commonly installed in doors to allow the user to safely view who or what is outside.

Laser Beam Expanders:

Function: Diverging lenses are used in combination with other lenses to expand or diverge a narrow laser beam. This is useful in adjusting the width and focus of laser beams for certain applications.
Practical Use: Laser optics systems, such as those in scientific instruments and medical devices.
Binoculars:
Function: In some optical devices, such as binoculars, diverging lenses are used in the eyepiece to widen the viewer's field of view while maintaining image **clarity.**
Practical Use: Enhances viewing experience by providing a wider perspective in binoculars.
Comparison between Converging and Diverging Lenses

Feature	Converging Lens (Convex)	Diverging Lens (Concave)
Shape	Thicker in the middle, thinner at edges	Thinner in the middle, thicker at edges
Light behavior	Bends light rays inward (converges)	Bends light rays outward (diverges)
Focal point	Real focal point in front of the lens	Virtual focal point behind the lens
Image formation	Real or virtual, can be magnified or reduced	Always virtual, upright, and smaller
Common uses	Magnifying glasses, cameras, far-sighted eyeglasses	Near-sighted eyeglasses, peepholes, laser expanders

Practical Use of Lenses in Everyday Life
Eyeglasses: Both converging and diverging lenses are essential for vision correction. Convex lenses help people who have difficulty seeing nearby objects (hyperopia), while concave lenses help those with near-sightedness (myopia).
Magnifying Tools: Convex lenses are used in magnifying glasses and microscopes, making tiny objects appear larger and clearer.
Optical Devices: Lenses are central to cameras, telescopes, and projectors, shaping the way we capture, magnify, and display images.
Safety Tools: Diverging lenses in peepholes provide security by offering a wide-angle view through a small aperture in doors.
Converging and diverging lenses play a critical role in optics, enabling us to manipulate light for a variety of practical purposes. Their applications in vision correction, magnification, imaging, and security are essential for daily life, scientific endeavors, and technological innovation. Understanding how these

lenses work and their uses enhances our ability to design and utilize optical systems effectively.

Optical instruments

Optical instruments are devices that process light to enhance the human ability to see or to observe objects in ways that are otherwise not possible with the naked eye. These instruments use the principles of reflection, refraction, and dispersion of light, combined with lenses or mirrors, to manipulate light and form images.

The main optical instruments include microscopes, telescopes, cameras, binoculars, and eyeglasses, each designed for a specific purpose based on optical principles.

Microscopes: A microscope is an optical instrument used to magnify small objects, making them visible to the human eye. It allows scientists and researchers to study structures that are too small to see unaided, such as cells, microorganisms, and tiny materials.

Types of Microscopes:

Compound Microscope:

Structure: Uses two or more lenses to achieve high magnification (typically an objective lens and an eyepiece lens).

Magnification: The total magnification is the product of the magnification of the objective lens and the eyepiece lens.

How it works: The objective lens creates a magnified real image of the object, which is further magnified by the eyepiece lens to form a virtual image seen by the eye.

Application: Commonly used in biology and medical laboratories to view cells, bacteria, and tissues.

Electron Microscope:

Structure: Instead of lenses, it uses electromagnetic fields to focus a beam of electrons.

Magnification: Can magnify objects up to millions of times.

How it works: Electrons are passed through or reflected off an object, and an image is formed by detecting these electrons.

Application: Used in nanotechnology, material science, and biology to view viruses, molecular structures, and atoms.

Stereo Microscope:

Structure: Provides a three-dimensional view of the specimen.

How it works: It has two separate optical paths for each eye, giving a stereoscopic image.

Application: Used for dissection, circuit board inspection, and other tasks that require 3D view.

Working Principle of a Compound Microscope:

The objective lens forms a magnified, real image of the object.

The eyepiece lens magnifies this real image to form a larger, virtual image.

The light source (usually beneath the specimen) illuminates the object for clearer observation.

Applications:

Biology and medical research for examining cells, tissues, and microorganisms

Forensic analysis to examine trace evidence like fibers, hair, and fingerprints

Quality control in industries for examining materials at microscopic levels

Telescopes

A telescope is an optical instrument that magnifies distant objects, allowing us to observe faraway objects like stars, planets, and galaxies. Telescopes play a crucial role in astronomy and space exploration.

Types of Telescopes:

Refracting Telescope:

Structure: Uses a combination of convex lenses to gather and focus light.

How it works: Light from distant objects is refracted (bent) through a large convex objective lens, which focuses the light into a small, sharp image. This image is then magnified by the eyepiece lens.

Application: Used for observing planets and stars.

Reflecting Telescope:

Structure: Uses a concave mirror to collect and reflect light onto a secondary mirror or lens.

How it works: Light from distant objects is reflected off a large concave mirror at the back of the telescope. This light is directed to an eyepiece through a secondary mirror.

Application: Used for deep space observations due to its ability to gather more light than refracting telescopes.

Catadioptric Telescope:

Structure: Combines both lenses and mirrors for optical correction.

How it works: Light passes through a corrector lens and is reflected by a concave mirror. It then passes through another lens before reaching the eyepiece.

Application: Used for both astronomical and terrestrial viewing.

Working Principle of a Refracting Telescope:

The objective lens gathers light from a distant object and focuses it to form a real image.

The eyepiece lens magnifies this real image so the viewer can see a clearer, enlarged version.

Applications:

Astronomy: Observing celestial bodies like stars, planets, and galaxies.

Space research: Telescopes like the Hubble Space Telescope are used for observing deep space phenomena.

Navigation and surveying: Telescopes are used in terrestrial navigation and land surveying.

Cameras: A camera is an optical instrument that captures light and records images, either on film (in traditional cameras) or on a digital sensor (in modern cameras). Cameras are widely used in photography, filmmaking, and surveillance.

Types of Cameras:

Film Camera:

Structure: Uses photographic film to capture images.

How it works: Light enters through the lens, and a mechanical shutter controls the amount of light that hits the film. The light-sensitive chemicals on the film react and capture the image.

Application: Analog photography, traditional filmmaking.

Digital Camera:

Structure: Uses electronic sensors (such as CCD or CMOS sensors) to capture images.

How it works: Light enters through the lens and is focused on the digital sensor, where the light is converted into electrical signals, forming a digital image.

Application: Digital photography, videography, surveillance, mobile cameras.

SLR (Single-Lens Reflex) and DSLR (Digital Single-Lens Reflex):

Structure: Uses a mirror and prism system to reflect the light into the viewfinder.

How it works: The light enters the lens, and a mirror reflects the light up into the viewfinder. When the shutter is pressed, the mirror flips up, allowing light to hit the sensor or film, capturing the image.

Application: Professional and amateur photography.

Working Principle of a Camera:

The lens system focuses light from the object onto a light-sensitive medium (film or sensor).

The aperture controls the amount of light that enters the camera.

The shutter controls the exposure time.

In digital cameras, the image is stored electronically on a memory device.

Applications:

Photography: Capturing images for personal, artistic, or commercial purposes.

Videography: Recording videos for filmmaking, news reporting, and entertainment.

Surveillance: Cameras are used for monitoring and security in public places, homes, and businesses.

Binoculars

Binoculars are handheld optical instruments with two parallel telescopic lenses that allow users to observe distant objects with both eyes, providing depth perception and a 3D view.

Structure:

Consist of two small refracting telescopes mounted side by side, one for each eye.

Objective lenses gather light from the object, and eyepiece lenses magnify the image for the viewer.

How They Work:

Light from distant objects enters the objective lenses, is focused, and then further magnified by the eyepiece lenses.

Binoculars typically include prisms (either Porro or roof prisms) to correct the orientation of the image and shorten the overall length of the instrument.

Applications:

Birdwatching: Provides a clear view of birds and wildlife without disturbing them.

Astronomy: Used to observe the moon, planets, and stars.

Sports and Theatre: Binoculars are commonly used to get a closer view of the action or performance.

Navigation: Sailors use binoculars to spot land, other vessels, or obstacles at sea.

Eyeglasses

Eyeglasses are optical instruments used to correct refractive errors in vision, such as nearsightedness (myopia), farsightedness (hyperopia), astigmatism, and presbyopia.

Types of Lenses in Eyeglasses:

Concave Lenses (Diverging lenses):

How it works: Used to correct myopia (nearsightedness). The lens diverges light before it enters the eye, allowing the image to be focused on the retina instead of in front of it.

Application: Eyeglasses for nearsighted individuals.

Convex Lenses (Converging lenses):

How it works: Used to correct hyperopia (farsightedness). The lens converges light before it enters the eye, allowing the image to focus properly on the retina.

Application: Eyeglasses for farsighted individuals.

Bifocal and Progressive Lenses:

How it works: Bifocal lenses have two different optical powers to correct both near and distance vision. Progressive lenses offer a gradual transition between different focal powers.

Application: Used for presbyopia, a condition where both near and distance vision is impaired.

Applications:

Vision correction: Eyeglasses improve vision for millions of people with refractive errors.

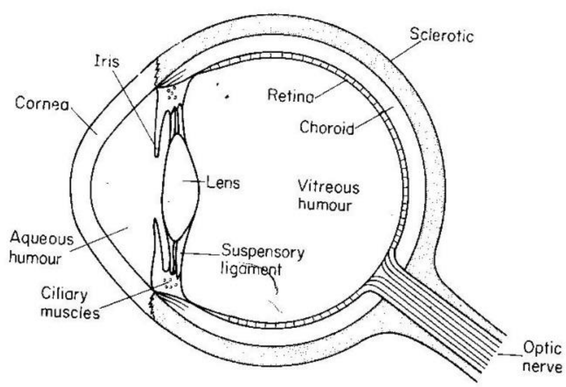
Protection: Eyeglasses can also be used to protect the eyes from harmful UV rays, dust, or debris (safety glasses).

Conclusion

Optical instruments such as microscopes, telescopes, cameras, binoculars, and eyeglasses have revolutionized the way we observe and interact with the world. From enhancing vision to exploring the microscopic and astronomical worlds, these instruments play a crucial role in science, medicine, photography, security, and everyday life. Each optical instrument is based on the fundamental principles of light, including reflection, refraction, and magnification, making them indispensable tools in both personal and professional applications.

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

1. The retina

This is a light sensitive layer at the back of the eye where the image is formed

2. The optic nerve

It is the nerve that transmits the image on the retina to the brain for interpretation

3. **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

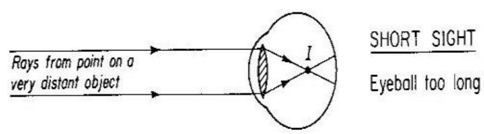
The normal eye can see objects clearly placed at infinity (far point) to see objects in greater details the eye sees it at the near point i.e. 25cm

TYPES OF EYE DEFECTS

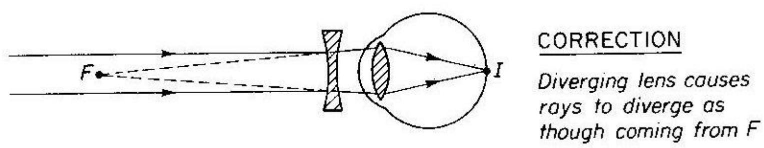
a) Short sightedness
b) Long sightedness

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.



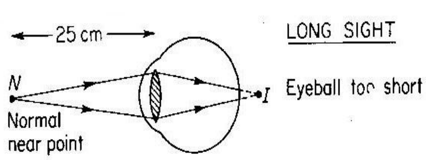
Correction of shortsightedness

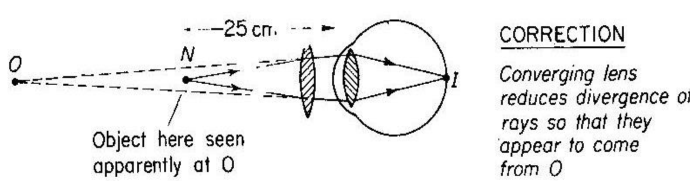


A concave lens is placed in front of the eye to make the light diverge so that it appears to come from the near point when it is actually coming far away as shown above

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

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

3.4 General wave properties

Learning Outcomes

a) Understand that energy is transferred by waves, and these may be transverse or longitudinal (k,u)
b) Know and use the relationship between velocity, frequency, and wavelength (k, s)
c) Understand the propagation, properties, and uses of electromagnetic waves, and that white light is a mixture of frequencies but that light from a laser is a single frequency (k, u,v/a)

Waves are disturbances or oscillations that transfer energy from one place to another without the transfer of matter. They occur in various forms and can be found in many aspects of daily life, including sound, light, water waves, and even seismic waves. The study of wave properties is fundamental in understanding how energy propagates through different media.

Definition of a Wave: A wave is a disturbance that travels through a medium (such as air, water, or a solid material) or through a vacuum (as in the case of electromagnetic waves) by transferring energy.

How Waves Transmit Energy

Waves are disturbances that travel through a medium (such as air, water, or solid materials) or through a vacuum (in the case of electromagnetic waves), transmitting energy from one location to another without permanently displacing the medium itself. The key concept here is that waves carry energy, not matter.

Basic Concept of Energy Transmission in Waves

Waves transmit energy by causing particles in a medium to oscillate (vibrate) around their equilibrium positions. While the particles themselves do not move along with the wave, their oscillations transfer energy from one particle to the next. This allows the wave to propagate and the energy to be transmitted over a distance.

There are two primary types of waves that transmit energy:

- Mechanical waves (require a medium for transmission)
- Electromagnetic waves (can travel through a vacuum)

Mechanical Waves and Energy Transmission

Mechanical waves require a physical medium (such as air, water, or solid materials) for energy transmission. These waves can be classified into two main types based on the motion of particles relative to the direction of wave propagation: transverse and longitudinal waves.

Transverse Waves

In transverse waves, particles of the medium oscillate perpendicular to the direction of the wave's propagation. Energy is transmitted as particles move up and down while the wave moves horizontally. Example: Waves on the surface of water, vibrations in a string (e.g., a guitar string), or light waves.

Energy Transmission: As the particles in the medium move up and down, they transfer energy to adjacent particles. The energy travels in the direction of the wave, even though the particles move perpendicularly. The amplitude of the wave (the maximum displacement of the particles from their rest position) is directly related to the energy: higher amplitude means more energy is being transmitted.

Longitudinal Waves

In longitudinal waves, particles of the medium oscillate parallel to the direction of wave propagation. Energy is transmitted through alternating regions of compression (where particles are close together) and rarefaction (where particles are spread apart). Example: Sound waves in air, seismic P-waves (primary waves), and compressional waves in a spring or slinky.

Energy Transmission: In a sound wave, for example, vibrating air molecules collide with neighboring molecules, transferring energy as the wave moves through the medium. The energy is transmitted as the particles push and pull on each other, compressing and expanding as the wave travels. The higher the amplitude (compression and rarefaction intensity), the more energy the wave transmits.

Electromagnetic Waves and Energy Transmission

Electromagnetic waves, unlike mechanical waves, do not require a medium for transmission and can propagate through a vacuum (such as space). These waves transmit energy by oscillating electric and magnetic fields.

Nature of Electromagnetic Waves

Electromagnetic waves are transverse waves where the oscillating electric field is perpendicular to the oscillating magnetic field, and both fields are perpendicular to the direction of wave propagation. Examples: Light waves, radio waves, X-rays, microwaves.

Energy Transmission: The oscillating electric and magnetic fields in electromagnetic waves carry energy across space. The energy carried by an electromagnetic wave is proportional to the wave's frequency and intensity. Higher-frequency waves (like X-rays or ultraviolet light) carry more energy than lower-frequency waves (like radio waves

Types of Waves

Transverse Waves: In a transverse wave, the oscillations of the particles of the medium are perpendicular to the direction of the wave's propagation. Examples include:

- Light waves (electromagnetic waves)
- Water waves (surface waves)

Characteristics:

- Particles move up and down or side to side, while the wave travels forward.
- Has crests (the highest points) and troughs (the lowest points).

Longitudinal Waves: In a longitudinal wave, the oscillations of the particles of the medium are parallel to the direction of the wave's propagation. Examples include:

- Sound waves in air
- Seismic P-waves

Characteristics:

- Particles of the medium move in compression and rarefaction as the wave moves forward.
- Compression: Regions where particles are close together.
- Rarefaction: Regions where particles are spread apart.

Surface Waves: These waves occur at the interface of two different mediums, such as water and air, combining characteristics of both transverse and longitudinal waves. An example is a water wave.

Characteristics:

- Particles move in a circular motion.
- Found on the surface of liquids like water.

General Wave Properties

Waves exhibit a set of fundamental properties that describe their behavior and characteristics. These properties are applicable to both mechanical and electromagnetic waves.

Wavelength (λ): The wavelength is the distance between two consecutive points that are in phase on a wave. This could be the distance between two crests (in transverse waves) or two compressions (in longitudinal waves).

Unit: **Meters (m)** Symbol: **λ (lambda)**. Formula: For waves traveling at a speed v, the wavelength is related to the frequency f by: $v=f\lambda$, where: v is the wave speed, f is the frequency, and λ is the wavelength

Frequency (f): The frequency of a wave is the number of oscillations or cycles the wave completes per second. It describes how often the wave's peaks pass a particular point.

Unit: Hertz (Hz). Symbol: f Formula: Frequency is related to the period T by: $T = \frac{1}{f}$, Where T is the time for one complete oscillation.

Period (T): The period is the time it takes for one complete cycle of the wave to pass a given point. Unit: ***Seconds (s)*** Symbol: T Formula: Period is the reciprocal of frequency: $f = \frac{1}{T}$

Amplitude (A): The amplitude of a wave is the maximum displacement of particles from their equilibrium position. It is a measure of the wave's energy.

Unit: ***Meters (m)*** or any unit of displacement (for sound, it could be decibels for pressure variations). **Symbol: A:** The greater the amplitude, the more energy the wave carries.

Wave Speed (v): The wave speed is the rate at which the wave travels through a medium. For mechanical waves, it depends on the properties of the medium (such as density and elasticity).

Unit: ***Meters per second (m/s)*** Symbol: v Formula: The speed of a wave is the product of its frequency and wavelength: $v = f\lambda$

Phase: The phase of a wave describes the position of a point within a wave cycle. Two points that have the same phase have identical displacements and are moving in the same direction.

Measured in degrees or radians.

Wave fronts: A wavefront is an imaginary surface that connects all points on a wave that are in the same phase of motion. For example, in a water wave, wavefronts might represent the crests.

Wave Behavior: Waves do not just travel in a straight line; they interact with the environment and each other in predictable ways. These behaviors include reflection, refraction, diffraction, and interference.

Reflection: Reflection occurs when a wave bounces off a surface or boundary. The angle of incidence (the angle between the incoming wave and the normal to the surface) is equal to the angle of reflection. Example: The echo of sound, when a wave hits a surface or boundary, it can bounce back, a phenomenon known as **reflection**. The energy of the wave is partially transferred back into the medium from which it came. **Example**: An echo is the reflection of sound waves from a surface. Light reflecting off a mirror is another example. Bouncing off a wall, or light reflecting off a mirror.

Refraction: Refraction is the bending of a wave as it passes from one medium to another due to a change in its speed. The wave changes direction because the speed of the wave is different in the new medium. Example: A straw appears bent when placed in water due to the refraction of light. **Refraction** occurs when a wave changes direction as it passes from one medium into another with a different density. This change in direction occurs due to a change in wave speed, but the energy continues to be transmitted. **Example**: When light passes from air into water, it bends and slows down, but the energy carried by the light wave continues to propagate.

Diffraction: Diffraction occurs when a wave encounters an obstacle or passes through a narrow opening. The wave bends around the obstacle or spreads out as it passes through the gap. Example: Hearing sound from around a corner or seeing light spread after passing through a small aperture. When waves encounter obstacles or pass through small openings, they spread out, a process known as **diffraction**. The energy is still transmitted, but it spreads over a larger area. **Example**: Sound waves bending around a corner. Even if you cannot see the source of the sound, you can still hear it due to diffraction.

Interference: Interference happens when two or more waves meet. The resulting wave is a combination of the original waves.

When two or more waves overlap, they combine in a process known as **interference**. Depending on the type of interference (constructive or destructive), the energy can either increase (constructive interference) or decrease (destructive interference).

Constructive Interference: When waves align in phase (peaks with peaks, troughs with troughs), their energies add together, creating a wave with greater amplitude and more energy. **Constructive Interference:** When the crests of two waves overlap, they combine to form a wave with larger amplitude.

Destructive Interference: When waves are out of phase (peak with trough), their energies can cancel out, reducing the amplitude and the amount of energy. When the crest of one wave overlaps with the trough of another, they cancel each other out, reducing the wave's amplitude. Example: In sound, constructive interference can make a louder sound, and destructive interference can make it quieter.

Types of Waves Based on Propagation

Mechanical Waves: Mechanical waves require a medium (like air, water, or solid material) to travel through. These waves can be transverse or longitudinal. Examples: Sound waves, water waves, seismic waves.

Electromagnetic Waves: Electromagnetic waves do not require a medium and can travel through a vacuum. These waves include visible light, radio waves, microwaves, X-rays, and gamma rays. Examples: Light waves, radio waves, ultraviolet (UV) rays.

Standing Waves: A standing wave occurs when two waves of the same frequency and amplitude travel in opposite directions and interfere with each other. As a result, nodes (points of zero displacement) and antinodes (points of maximum displacement) are formed. Example: Vibrating strings on musical instruments form standing waves.

Energy Transfer in Waves

- In mechanical waves, energy is transferred through the vibration of particles in the medium.
- In electromagnetic waves, energy is carried by oscillating electric and magnetic fields.
- The amplitude of the wave is directly related to the amount of energy it carries. Higher amplitude means more energy.

Relationship between Wave Properties and Energy Transmission

Amplitude and Energy: The amplitude of a wave is directly related to the energy it carries. For mechanical waves, the greater the displacement of particles (amplitude), the more energy the wave is transmitting. For example, in sound waves, louder sounds have greater amplitude and carry more energy.

Frequency and Energy: For electromagnetic waves, the frequency is directly proportional to the energy. Higher-frequency waves (such as gamma rays or X-rays) carry more energy than lower-frequency waves (such as radio waves or microwaves).

Speed of Wave and Energy: The speed of a wave does not directly affect the energy it carries, but the medium through which it travels can influence the wave's energy transmission. Mechanical waves lose energy more quickly when traveling through denser or more viscous mediums due to friction or resistance.

Energy Loss in Waves: Not all the energy that a wave transmits reaches its final destination. Some energy is lost as the wave travels, particularly in mechanical waves. This loss is usually due to:

Damping: The energy of the wave is gradually dissipated as heat or other forms of energy due to friction or resistance in the medium.

Absorption: In some cases, energy from the wave is absorbed by the medium itself. For instance, as sound travels through air, some of the energy is absorbed by air molecules, which results in a decrease in sound intensity over distance.

Conclusion

Waves transmit energy by causing oscillations in a medium (for mechanical waves) or through oscillating electric and magnetic fields (for electromagnetic waves). The amount of energy transmitted depends on various factors like amplitude, frequency, and the medium of propagation. Understanding how waves transmit energy is crucial for applications ranging from sound and light technologies to medical imaging and communication systems.

Applications of Waves in Everyday Life

- **Sound Waves:** Sound waves are longitudinal mechanical waves that travel through air, water, or solids. They are essential in communication (speaking, music) and technology (microphones, loudspeakers).
- **Light Waves:** Electromagnetic waves such as light are crucial in vision, photography, communication (fiber optics), and solar energy.
- **Water Waves:** Water waves are mechanical waves that travel on the surface of water, useful in studying oceanography and marine navigation.
- **Radio Waves:** Electromagnetic radio waves are used for broadcasting and communication (TV, radio, mobile phones, and Wi-Fi).
- **Seismic Waves:** Seismic waves are mechanical waves generated by earthquakes. These waves help in understanding the Earth's interior and are crucial in earthquake detection and analysis.

Conclusion

The study of general wave properties is fundamental in understanding how energy is transmitted through different media. Whether through sound, light, or water waves, the principles of wavelength, frequency, speed, amplitude, and wave behavior govern a wide range of phenomena in the natural and technological world. Waves play an essential role in communication, medical imaging, entertainment, and scientific research, making them one of the most important concepts in physics.

LASER BEAM

The term "laser" stands for "**Light Amplification by Stimulated Emission of Radiation,**" which is, in a nutshell, how lasers work. Light particles (called photons) are excited with current causing them to emit energy in the form of light. This light forms the laser beam.

A laser beam is a focused, coherent stream of light produced by a device called a laser (Light Amplification by Stimulated Emission of Radiation).

Coherence: Unlike regular light, which consists of many different wavelengths, a laser beam is made up of light waves that are synchronized. This means all the light waves have the same wavelength (color) and move in step with each other, resulting in a highly focused and intense beam.

Monochromatic: Laser light is usually monochromatic, meaning it is made up of one single wavelength or color. This is different from white light, which is made up of many different wavelengths.

Directionality: Laser beams are highly directional. The light emitted from a laser does not spread out much, allowing it to travel long distances with minimal dispersion. This is why laser beams appear as a narrow, straight line.

High Intensity: Because the light is focused and not dispersed, a laser beam can carry a lot of energy in a small area, making it extremely intense and useful in applications requiring precision.

How Laser Beams are produced

Stimulated Emission: A material inside the laser (such as a gas, crystal, or semiconductor) is excited by an external energy source. When the atoms in the material return to a lower energy state, they emit photons. These photons stimulate other atoms to emit more photons of the same wavelength and phase, creating an amplified, coherent beam of light.

Optical Cavity: The light bounces between two mirrors inside the laser, further amplifying the beam. One of the mirrors is partially transparent, allowing the laser beam to escape and be used.

Applications:

- Medical: For precise surgeries and treatments like laser eye surgery.
- Industrial: Cutting and engraving materials.
- Communication: In fiber-optic cables for transmitting data over long distances.
- Entertainment: Light shows and visual effects.
- Lasers can range in power, from low-power lasers used in laser pointers to high-power lasers used in industrial and military applications.

Nature of White Light and Laser Light

Nature of White Light

White light is a mixture of all visible wavelengths of light. It appears colorless but can be separated into its constituent colors through refraction, diffraction, or dispersion.

Composition of White Light

Visible Spectrum: White light contains all the colors of the visible spectrum, which can be represented by the acronym ROYGBIV: Red, Orange, Yellow, Green, Blue, Indigo, and Violet. **Spectrum Range:** The visible spectrum ranges from approximately 380 nm (violet) to 750 nm (red).

Sources of White Light

- **Natural Sources:** The Sun is the primary natural source of white light, emitting a broad spectrum of wavelengths.
- **Artificial Sources:** Incandescent bulbs, fluorescent lamps, LED lights, and other artificial light sources also emit white light, although the spectral composition may vary.

Properties of White Light

- **Dispersion:** When white light passes through a prism, it bends at different angles, separating into its constituent colors due to differences in wavelength. Shorter wavelengths (violet) refract more than longer wavelengths (red).
- **Reflection and Absorption:** When white light strikes an object, it can be reflected, absorbed, or transmitted. The colors we perceive depend on which wavelengths are reflected or absorbed by the surface.

Nature of Laser Light

Laser light is characterized by its unique properties, differing significantly from ordinary light sources.

Characteristics of Laser Light

- **Monochromatic:** Laser light typically consists of a single wavelength or color. This property results in a very narrow bandwidth, unlike white light, which contains a wide range of wavelengths.
- **Coherent:** The light waves in a laser beam are in phase with one another. This coherence allows laser beams to maintain their shape over long distances and to focus to a small point.
- **Directional:** Laser light travels in a very narrow beam, with minimal divergence. This property allows lasers to focus energy precisely and deliver it over significant distances without losing intensity.
- **High Intensity:** Due to its coherent and focused nature, laser light can achieve high intensity levels, making it suitable for various applications.

Types of Lasers

- **Solid-State Lasers:** Use solid materials (like crystals or glass) as the gain medium. Examples include Ruby lasers and Nd lasers.
- **Gas Lasers:** Use a gas as the gain medium. Examples include Helium-Neon (He-Ne) lasers and CO_2 lasers.
- **Semiconductor Lasers:** Use semiconductor materials, commonly found in laser diodes. Examples include those used in CD players and laser pointers.
- **Fiber Lasers:** Use optical fibers as the gain medium and are widely used in telecommunications and medical applications.

Uses of White Light

- **Illumination:** White light is commonly used for general lighting in homes, offices, and public spaces, providing visibility and safety.
- **Photography and Imaging:** Cameras and other imaging devices utilize white light to capture images. The combination of colors helps produce realistic and vibrant photos.
- **Spectroscopy:** In scientific research, white light can be dispersed into its constituent colors to study the properties of materials through absorption and emission spectra.
- **Displays:** White light is used in various display technologies, such as LCDs and LEDs, to create vibrant and colorful images.

Uses of Laser Light

Medical Applications

- Surgery: Lasers are used in precision surgical procedures, such as LASIK eye surgery and skin resurfacing.
- Therapy: Laser therapy is employed to treat conditions like acne, scars, and tattoos, promoting skin healing and regeneration.

. Industrial Applications

- Cutting and Welding: Lasers are widely used in manufacturing for cutting and welding materials with high precision.
- Engraving: Laser engraving is utilized for marking and etching designs on various materials, including metals and plastics.

Communication

- Fiber Optic Communications: Lasers are used to transmit data through optical fibers, providing high-speed internet and telecommunication services.

Research and Development

- Lasers play a vital role in scientific research, including experiments in physics, chemistry, and materials science.

Entertainment

- Lasers are used in light shows, concerts, and theatrical performances to create stunning visual effects.

Security and Sensing

- Laser systems are employed in security applications, such as laser tripwires and scanning systems for motion detection.

Conclusion

White light is a blend of all visible wavelengths, serving essential roles in illumination, imaging, and spectroscopy. In contrast, laser light is defined by its monochromatic, coherent, and directional properties, enabling it to excel in a wide range of applications, from medical procedures to communication technologies. Understanding the nature and uses of both white light and laser light is crucial for harnessing their potential in various fields.

Effects of Over-Exposure to Ultraviolet (UV) and Other Forms of High-Frequency Electromagnetic Radiation

High-frequency electromagnetic radiation includes ultraviolet (UV) radiation, X-rays, and gamma rays. These forms of radiation have higher energy and shorter wavelengths compared to visible light, making them capable of penetrating biological tissues and causing various effects.

Types of High-Frequency Electromagnetic Radiation

- Ultraviolet (UV) Radiation: Wavelength: Ranges from about 10 nm to 400 nm, divided into three categories: UVA (320–400 nm): Longwave UV, can penetrate the skin more deeply. UVB (280–320 nm): Medium wave UV, primarily responsible for sunburn and skin damage. UVC (100–280 nm): Shortwave UV, mostly absorbed by the ozone layer and does not reach the Earth's surface.

- X-Rays: Wavelength: Ranges from about 0.01 nm to 10 nm. They are used in medical imaging and cancer treatment.
- Gamma Rays: Wavelength: Less than 0.01 nm, emitted by radioactive materials and certain types of cosmic events. High energy makes them useful in cancer treatment but also very harmful.

Biological Effects of UV Radiation

- Skin Damage: Sunburn: Caused primarily by UVB radiation, leading to red, painful skin, and peeling.
- Photo aging: UVA radiation penetrates deeply, contributing to premature aging, wrinkles, and loss of skin elasticity.
- Skin Cancer: Over-exposure increases the risk of various types of skin cancer, including:
- Basal Cell Carcinoma: The most common and least aggressive form.
- Squamous Cell Carcinoma: More aggressive than basal cell and can spread.
- Melanoma: The most dangerous type, arising from melanocytes.

Eye Damage

- Photo keratitis: Also known as "snow blindness," caused by UVB exposure leading to temporary corneal inflammation.
- Cataracts: Long-term UV exposure is linked to cataract formation, leading to cloudy vision and potential blindness.
- Macular Degeneration: Potential damage to the retina that can impair vision.

Immune System Suppression: Over-exposure to UV radiation can suppress the immune response, making individuals more susceptible to infections and diseases.

Biological Effects of X-Rays and Gamma Rays

- Cellular Damage: DNA Damage: High-energy radiation can ionize atoms, leading to direct damage to DNA molecules, which may result in mutations.
- Cell Death: High doses can lead to cell death, particularly in rapidly dividing cells such as those in bone marrow, skin, and the lining of the gastrointestinal tract.
- Cancer Risk: Both X-rays and gamma rays are classified as carcinogenic by the International Agency for Research on Cancer (IARC). Increased exposure can raise the risk of leukemia and solid tumors.

Acute Radiation Syndrome (ARS): Occurs after exposure to high doses of radiation in a short time. Symptoms include nausea, vomiting, hair loss, and skin burns, potentially leading to death if the dose is severe.

Other Potential Health Effects

- Hormonal Changes
- Exposure to UV radiation can affect the production of melatonin and other hormones, potentially disrupting circadian rhythms.
- Reproductive Effects
- Some studies suggest potential reproductive effects, including reduced fertility and developmental issues in embryos.

Environmental Effects of UV Radiation

- Ecosystem Impact: Increased UV radiation can affect phytoplankton, the foundation of aquatic food webs, leading to disruptions in marine ecosystems.
- Material Degradation: UV radiation can degrade materials such as plastics, wood, and rubber, reducing their lifespan and integrity.

Prevention and Protection

- Personal Protective Measures
- Sunscreen: Use broad-spectrum sunscreen with SPF 30 or higher, reapplying every two hours, especially after swimming or sweating.
- Protective Clothing: Wear hats, sunglasses with UV protection, and long-sleeved clothing.
- Shade: Seek shade, especially during peak sun hours (10 a.m. to 4 p.m.).

Limiting Exposure to X-Rays and Gamma Rays

- Medical Imaging: Ensure that X-rays are only performed when necessary and consider alternatives when possible. Pregnant women should inform healthcare providers about their condition.
- Occupational Safety: Use appropriate shielding and safety protocols for workers exposed to high-frequency radiation.

Over-exposure to ultraviolet and other forms of high-frequency electromagnetic radiation can lead to serious health risks, including skin damage, eye injuries, immune suppression, and increased cancer risk. Understanding these risks is crucial for effective prevention and protection measures to mitigate potential harm. By adopting protective practices and being aware of exposure sources, individuals can reduce the likelihood of adverse effects associated with high-frequency electromagnetic radiation.

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:

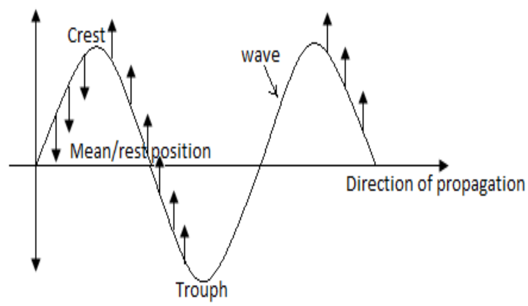
We can classify all waves into two categories:

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.

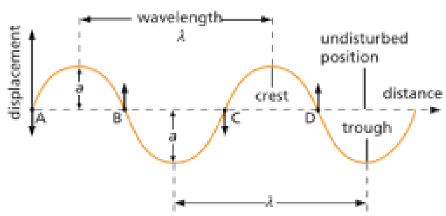
ii. LONGITUDINAL WAVES

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.

GENERAL REPRESENTATION OF A WAVE/ TERMS USED IN WAVES



Displacement–distance graph for a wave at a particular

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 disturbances.

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 = $f\lambda$ wave equation

Examples

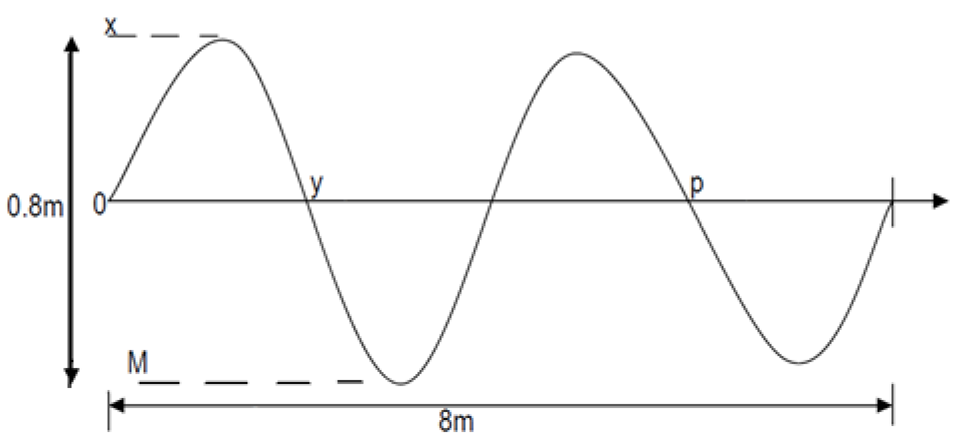
1. A radio station produces waves of wave length 10m. If the wave speed is 3×10^8m/s, calculate

(i) Frequency of radio wave.

(ii) Period T

(iii) Number of cycles completed in 10s

2. The distance between 10 consecutive crests is 36cm. Calculate the velocity of the wave if the frequency of the wave is 12Hz.
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.

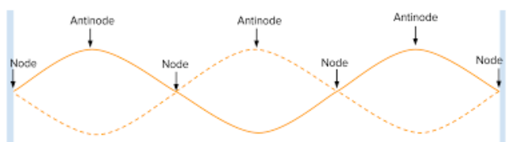
4.A vibrator produces waves which travel 35 m in 2 seconds. If the waves produced are 5cm from each other, calculate;

(i) the wave velocity

(ii) wave frequency

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.



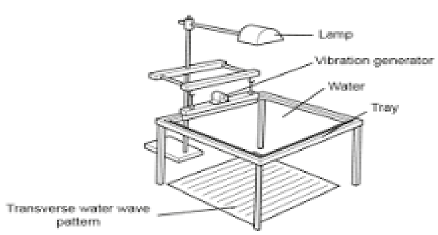
The distance between two neighboring nodes is

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.

During reflection of water waves, the frequency and velocity of the wave does not change.

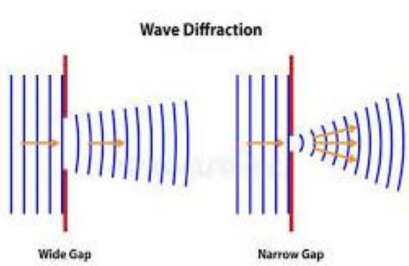
REFRACTION OF WAVE

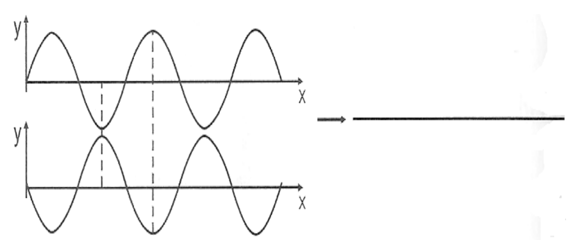
This is the change of in direction of wave travel as it moves from one medium to another of different depth. It causes change of wave length and velocity of the wave. However, the frequency and the period are not affected. In a ripple tank, the change in direction is brought about by the change in water depth.

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.

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.

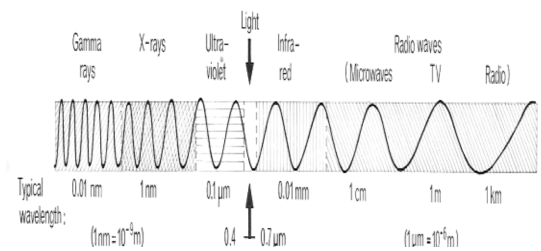
N.B - When waves undergo diffraction, wave length and velocity remain constant.

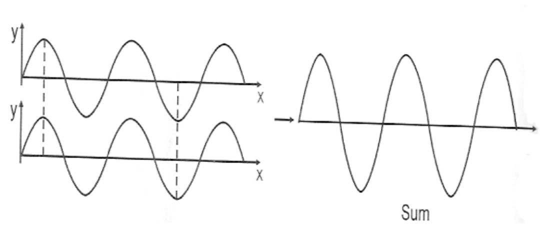
INTERFERENCE OF WAVES

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 (3.0×10^8m/s).
- They can be reflected, refracted, diffracted and undergo interference.
- They possess energy.

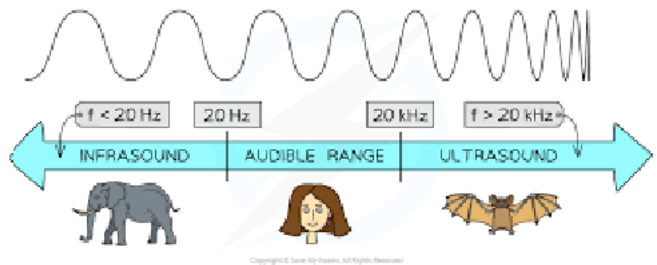
EFFECTS OF ELECTROMAGNETIC WAVES ON MATTER

(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.

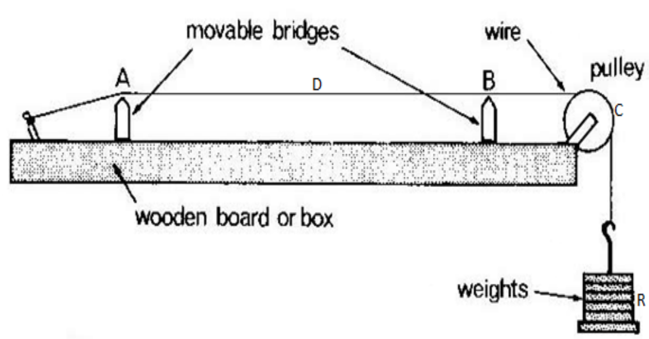
VIBRATION IN STRINGS

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)

3.5 Sound waves

Learning Outcomes

a) Understand that sound is an example of a wave form that requires a medium through which to travel, and determine its velocity in air by the echo method (k, s)

Sound waves are a type of mechanical wave that propagate through a medium (such as air, water, or solids) due to the vibration of particles within the medium. They are longitudinal in nature, meaning that the oscillations of the particles occur parallel to the direction of the wave's propagation. Sound waves play a crucial role in human communication, music, and technology and are vital for understanding phenomena related to hearing and acoustics.

How Sound is produced as a Form of Energy

Sound is a form of mechanical energy that travels through a medium (such as air, water, or solids) in the form of waves. It is produced by the vibration of objects, which create pressure changes in the surrounding medium, leading to the propagation of sound waves.

Production of Sound

Vibration of Objects

Basic Mechanism: Sound is generated when an object vibrates. This vibration causes surrounding particles in the medium to move, creating waves of compressed and rarefied air (or other mediums). Examples: Vocal Cords: When air passes through the vocal cords, they vibrate, producing sound.

Musical Instruments: String instruments produce sound through vibrating strings, while percussion instruments create sound by striking surfaces.

Sound Waves

- Nature of Waves: Sound travels as longitudinal waves, where particles of the medium oscillate parallel to the direction of the wave's travel.
- Compression and Rarefaction: In a sound wave, compressions are regions where particles are close together, while rarefactions are regions where particles are spread apart.

Properties of Sound

- Loudness: Loudness is a subjective perception of the intensity of a sound. It depends on the amplitude of the sound wave.
- Amplitude: Greater amplitudes produce louder sounds because more energy is transferred to the medium, causing more significant particle displacement.
- Measurement: Loudness is measured in decibels (dB). For example, normal conversation is around 60 dB, while a rock concert can exceed 100 dB.
- Pitch: Pitch is the perceived frequency of a sound, determining how high or low it sounds.
- Frequency: Higher frequencies correspond to higher pitches, while lower frequencies correspond to lower pitches. Frequency is measured in hertz (Hz). Example: A whistle produces high-frequency sounds, resulting in a high pitch, while a bass guitar produces lower frequencies, resulting in a lower pitch.

Relationship between Vibrations, Loudness, and Pitch

Vibrations and Loudness

- **Direct Correlation:** The louder a sound is, the more intense the vibrations are. For example, a drum produces louder sounds with stronger strikes, resulting in larger amplitude vibrations.
- **Energy Transfer:** Increased vibration intensity transfers more energy to the surrounding medium, creating more significant pressure changes and resulting in higher loudness.

Vibrations and Pitch

Frequency of Vibration: The frequency at which an object vibrates directly influences the pitch of the sound produced. Faster vibrations produce higher frequencies and thus higher pitches. Example: A shorter guitar string vibrates faster than a longer one, producing a higher pitch. This is why instruments with shorter strings (like violins) produce higher notes than those with longer strings (like cellos).

Loudness and Pitch

Perception: Loudness and pitch can interact in perception. For example, a high-pitched sound may seem louder than a low-pitched sound at the same amplitude due to the sensitivity of human hearing.

Equal Loudness Contours: Studies show that the ear's sensitivity varies with frequency, influencing how we perceive loudness at different pitches.

Sound is produced through the vibration of objects, creating waves that propagate through a medium. The properties of sound—*loudness* and *pitch*—are closely related to the amplitude and frequency of the sound waves, respectively. Sound plays a crucial role in communication, music, and numerous applications across various fields.

Transmission of Sound in Air

Characteristics of Air

Medium Type: Air is a gas composed of molecules that are relatively far apart compared to solids and liquids.

Density: The density of air is lower than that of water and solids, which affects how sound travels.

Mechanism of Sound Transmission

Particle Motion: When an object vibrates, it creates compressions and rarefactions in the air. Molecules in the air collide with adjacent molecules, transferring energy.

Wave Propagation: The compressions (areas of high pressure) move outward as sound waves, while the rarefactions (areas of low pressure) follow. This process continues as molecules pass kinetic energy from one to another.

Speed of Sound in Air

Speed: Sound travels at approximately 343 meters per second (m/s) in air at room temperature (20°C).

Influencing Factors: The speed of sound in air increases with temperature because warmer air has more energetic molecules, leading to faster collisions.

Transmission of Sound in Water

Characteristics of Water

Medium Type: Water is a liquid with molecules that are closer together than in gases but still allow some movement.

Density: Water is denser than air, which affects sound speed and transmission.

Mechanism of Sound Transmission

Particle Arrangement: In water, molecules are arranged more closely than in air, leading to more efficient energy transfer during sound wave propagation.

Pressure Changes: When a sound wave travels through water, it causes localized increases and decreases in pressure, allowing the wave to travel effectively through the liquid.

Speed of Sound in Water

Speed: Sound travels faster in water, at approximately 1,480 m/s at room temperature.

Reason for Speed: The increased density and closer molecular arrangement allow sound waves to transmit more energy per unit of distance traveled.

Transmission of Sound in Solids

Characteristics of Solids

Medium Type: Solids have tightly packed molecules, with strong intermolecular bonds and limited movement.

Density: Solids are generally denser than both air and water, facilitating the transmission of sound.

Mechanism of Sound Transmission

Particle Vibration: In solids, sound waves cause the molecules to vibrate in place, transferring energy through the material by means of both longitudinal and transverse waves.

Efficient Energy Transfer: The close packing of molecules means that energy is transferred more effectively compared to gases or liquids, resulting in faster sound propagation.

Speed of Sound in Solids

Speed: Sound travels much faster in solids, typically ranging from 2,000 m/s (for softer materials like rubber) to over 6,000 m/s (for hard materials like steel).

Influencing Factors: The speed is influenced by the material's density and its elasticity (the ability to return to original shape after deformation).

Summary of Factors Affecting Sound Transmission

Density

General Principle: Higher density materials typically transmit sound faster than lower density materials because of more efficient energy transfer.

Sound Speed: The speed of sound increases with density in solids and liquids but has more complex relationships in gases.

Particle Theory

Energy Transfer: Sound is transmitted through the collision of particles. In solids, the close arrangement of particles allows for quick energy transfer; in liquids, it is also efficient, while in gases, the energy transfer is slower due to greater distances between particles.

Medium Comparison

- Air: Low density, slow speed (~343 m/s).
- Water: Higher density, moderate speed (~1,480 m/s).
- Solids: Highest density, fastest speed (up to ~6,000 m/s or more).

The transmission of sound through air, water, and solids varies significantly due to differences in density and molecular structure. In gases, sound travels slowly due to lower density and molecular spacing. In liquids, the closer arrangement of molecules increases speed, while in solids, the compactness and strong bonds facilitate the fastest transmission.

Nature of Sound Waves

Mechanical Wave: Sound waves require a medium (such as air, water, or solids) to propagate. Unlike electromagnetic waves, they cannot travel through a vacuum.

Longitudinal Wave: In a sound wave, the particles of the medium oscillate back and forth in the same direction as the wave is traveling. This results in alternating regions of compression and rarefaction.

Compression: A region where particles are pushed together, creating a high-pressure area.

Rarefaction: A region where particles are spread apart, creating a low-pressure area.

Properties of Sound Waves

Wavelength (λ): The wavelength of a sound wave is the distance between two consecutive compressions or rarefactions. It is typically measured in meters (m). Formula: Wavelength is related to the speed of sound (v) and frequency (f) by the equation: $v=f\lambda$

Frequency (f): The frequency of a sound wave refers to the number of compressions or rarefactions that pass a particular point in one second. It determines the pitch of the sound. Unit: Hertz (Hz) Human Hearing Range: Typically between 20 Hz and 20,000 Hz. Sounds below 20 Hz are called *infrasonic*. Sounds above 20,000 Hz are called *ultrasonic*.

Speed of Sound (v): The speed of sound is the rate at which sound waves propagate through a medium. It depends on the properties of the medium, such as its density and elasticity.

Formula: Speed is related to frequency and wavelength: $v=f\lambda$

Factors affecting the speed of sound:

Medium: Sound travels fastest in solids, slower in liquids, and slowest in gases. In air (at 20°C), the speed of sound is approximately 343 m/s. In water, sound travels at about 1,480 m/s. In steel, sound travels at about 5,960 m/s.

Temperature: As temperature increases, the speed of sound increases because the particles move faster.

Amplitude (A): The amplitude of a sound wave is the maximum displacement of particles from their equilibrium position. It is directly related to the loudness or intensity of the sound. Unit: Meters (m) or, for sound, it can be measured in *decibels (dB).*

Relationship with energy: The greater the amplitude, the louder the sound and the more energy the wave carries.

Period (T): The period is the time it takes for one complete cycle (one compression and one rarefaction) of the sound wave.

Wave Behavior of Sound: Sound waves, like other types of waves, exhibit certain behaviors when they encounter obstacles or when they travel through different media.

Reflection of Sound (Echo): Reflection occurs when a sound wave bounces off a surface and returns to the original source. The time delay between the original sound and its reflection creates an echo. Example: Hearing an echo when shouting in a canyon or empty hall.

Refraction of Sound: Refraction is the bending of sound waves as they pass from one medium to another or when there is a change in the conditions of the medium (e.g., temperature, density). Example: Sound waves travel faster in warmer air than in cooler air, so on a cold night, and sound from a distant source may be heard more clearly.

Diffraction of Sound: Diffraction is the bending of sound waves around obstacles or through openings. Low-frequency sound waves (with longer wavelengths) diffract more easily than high-frequency waves. Example: Being able to hear someone speaking even when they are behind a wall or corner.

Interference of Sound: Interference occurs when two or more sound waves meet, resulting in a new wave pattern.

Constructive interference: When two waves combine to make a louder sound (larger amplitude).

Destructive interference: When two waves combine to cancel each other out, resulting in a quieter sound or silence. Example: Noise-canceling headphones use destructive interference to reduce unwanted ambient sound.

Intensity and Loudness of Sound

Intensity (I): The intensity of a sound wave refers to the amount of energy the wave transmits per unit area per second. Unit: *Watts per square meter* (W/m^2).

Loudness: The loudness of a sound is a subjective measure of the sound's intensity as perceived by the human ear. Loudness depends on both the amplitude of the wave and the sensitivity of the ear to different frequencies.

Unit: Measured in *decibels (dB*). The decibel scale is logarithmic, meaning that an increase of 10 dB corresponds to a sound that is 10 times more intense.

Threshold of hearing: 0 dB (the quietest sound the human ear can detect).

Threshold of pain: 120 dB (sound levels above this can cause pain and hearing damage).

Doppler Effect

The Doppler Effect is a change in the frequency (and thus pitch) of a sound wave as the source of the sound moves relative to the observer.

If the source is moving towards the observer, the sound waves are compressed, resulting in a higher frequency and a higher-pitched sound.

If the source is moving away from the observer, the sound waves are stretched out, resulting in a lower frequency and a lower-pitched sound. Example: The change in pitch of a siren as an ambulance passes by.

Sound in Different Media

Sound in Air: The most common medium for sound propagation. Speed of sound in air at room temperature (20°C) is about 343 m/s.

Sound in Water: Sound travels much faster in water (about 1,480 m/s) than in air because water molecules are closer together and can transmit vibrations more efficiently.

Sound in Solids: Sound travels fastest in solids, such as metals or wood, because the particles in solids are tightly packed. Example: Placing your ear on a railway track lets you hear an oncoming train earlier than hearing through the air.

Resonance: Resonance occurs when an object is made to vibrate at its natural frequency by absorbing energy from a sound wave of the same frequency. This results in a dramatic increase in amplitude. Example: A singer breaking a glass by singing a note that matches the natural frequency of the glass.

Applications of Sound Waves

Sonar (Sound Navigation and Ranging). Sonar uses sound waves to detect objects underwater by emitting sound pulses and detecting their echoes. It is used in:

Submarine navigation.

Fisheries: To locate schools of fish.

Oceanography: Mapping the ocean floor.

Ultrasound: Ultrasound involves sound waves with frequencies above 20,000 Hz. It is used in:

Medical imaging: Ultrasound machines create images of internal organs or developing fetuses.

Industrial cleaning: High-frequency sound waves clean delicate instruments or machinery.

Non-destructive testing: Detecting cracks or flaws in materials like metal or concrete.

Music: In music, sound waves are produced by vibrating strings (in guitars, violins), air columns (in wind instruments), or membranes (in drums). The quality of sound (timbre) is influenced by the wave's frequency, amplitude, and waveform.

Communication: Speech and hearing are based on the propagation of sound waves through air. Microphones and loudspeakers work by converting sound waves into electrical signals and vice versa.

Human Perception of Sound. Hearing Mechanism. Sound waves enter the ear, causing the eardrum to vibrate. The vibrations are transmitted to the cochlea, where they are converted into electrical signals sent to the brain. Frequency Range. Humans can typically hear frequencies between 20 Hz and 20,000 Hz. The ear is most sensitive to frequencies between 2,000 Hz and 5,000 Hz.

Conclusion

Sound waves are essential in various aspects of life, from communication and entertainment to technology and medical applications. Their properties, including frequency, amplitude, and speed, govern how we perceive and interact with sound. By understanding the behavior of sound waves, we can harness them for a wide range of uses, from sonar and ultrasound to music and hearing.

Investigating the Velocity of Sound in Air Using the Echo Method

The echo method is a practical way to measure the velocity of sound in air. It involves producing a sound, allowing it to travel a known distance (d), and measuring the time (t) it takes for the sound to return as an echo.

Principles of the Echo Method

Understanding Echoes

An echo is the reflection of sound waves off surfaces, returning to the listener after a delay.

Speed of Sound: The velocity of sound (v) can be calculated using the formula:$v = \frac{2d}{t}$, where: d = distance traveled by sound, t= time taken for the echo to return

Assumptions

The sound travels at a constant speed in the medium (air) under controlled conditions (e.g., similar temperature, humidity).

The distance measured is the one-way distance to the reflecting surface; thus, the total distance for the echo is twice the one-way distance.

Procedure for Measuring the Velocity of Sound Using the Echo Method

Equipment Needed

A sound source (like a clap of hands, whistle, or electronic sound generator)

A measuring tape or distance measuring tool

A stopwatch or timer for measuring the time interval

Procedure

Choose an open area where a hard surface (like a wall or a large rock) can reflect sound waves.

Measure the distance (d) from the sound source to the reflecting surface.

Generate a loud sound (such as clapping hands or using a whistle) at the chosen distance.

Start the stopwatch at the moment the sound is made and stop it when the echo is heard. Record the time (ttt) taken for the echo to return.

Use the formula $v = \frac{2d}{t}$ to calculate the speed of sound in air. Since the time measured is for the sound to travel to the wall and back, divide the time by 2 before using it in the formula.

Factors Influencing the Velocity of Sound

Temperature: The speed of sound increases with temperature due to increased kinetic energy of air molecules. A typical value at 20°C is around 343 m/s.

Humidity: Higher humidity increases the speed of sound because moist air is less dense than dry air, facilitating faster particle movement.

Altitude: At higher altitudes, lower air pressure can decrease the speed of sound due to lower density.

Accuracy of Results

Precision in Timing: Human reaction time can affect the accuracy of measuring time. Using electronic timers can improve precision.

Distance Measurement: Ensuring the distance is measured accurately is crucial for reliable results.

Environmental Conditions: Wind, temperature variations, and obstacles can affect sound propagation and should be minimized during the experiment.

The echo method provides a straightforward way to investigate the velocity of sound in air by measuring the time it takes for sound to travel to a reflecting surface and back. This method not only demonstrates the principles of sound but also reinforces concepts related to wave propagation and energy transfer in different media.

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 of Sound Waves

The spectrum of sound waves refers to the range of frequencies that sound waves can have**, from the lowest to the highest audible and inaudible frequencies.** The term "spectrum" in sound is analogous to the spectrum of light, where different wavelengths of light correspond to different colours.
In sound, different frequencies correspond to different pitches or tones.

Concepts in Sound Waves:

Sound Waves: Sound waves are longitudinal waves that travel through a medium (such as air, water, or solids) by compressing and rarefying the particles in the medium.
They have properties such as frequency, wavelength, amplitude, and velocity.
Frequency: Frequency, measured in Hertz (Hz), refers to the number of sound wave cycles per second.
It is the key factor in determining the pitch of a sound: higher frequencies correspond to higher-pitched sounds, and lower frequencies correspond to lower-pitched sounds.
Amplitude: Amplitude refers to the height of the wave and is related to the loudness of the sound. Larger amplitudes produce louder sounds, while smaller amplitudes produce softer sounds.
Wavelength: Wavelength is the distance between successive compressions (or rarefactions) in a sound wave. It is inversely related to the frequency: higher frequencies have shorter wavelengths, and lower frequencies have longer wavelengths.

Types of Sound Waves Based on the Spectrum:
Infrasonic Waves (Below 20 Hz):
These are sound waves with frequencies below the human hearing range (less than 20 Hz).
Infrasonic waves are often produced by natural phenomena like earthquakes, volcanic eruptions, and ocean waves.
While humans cannot hear infrasonic waves, they can sometimes feel them as vibrations.
Audible Sound Waves (20 Hz to 20,000 Hz):
This is the range of frequencies that can be heard by the human ear.
Low-frequency sounds (20 Hz to 500 Hz) include bass sounds, such as deep musical notes or the rumble of thunder. Mid-frequency sounds (500 Hz to 2,000 Hz) correspond to everyday speech and musical notes. High-frequency sounds (2,000 Hz to 20,000 Hz) include higher-pitched musical instruments, bird calls, and some high-pitched speech sounds. The human ear is most

sensitive to frequencies between 2,000 Hz and 5,000 Hz, which is where much of human speech resides.

Ultrasonic Waves (Above 20,000 Hz):
Ultrasonic waves have frequencies above the human hearing range, typically greater than 20,000 Hz. Ultrasound is used in various technological and medical applications, such as imaging (ultrasound scans) and cleaning.
Animals like bats and dolphins use ultrasonic frequencies for echolocation.

Representation of the Sound Spectrum: The sound spectrum is a graphical representation of the different frequencies present in a sound signal. The x-axis represents the frequency (measured in Hz), and the y-axis represents the amplitude or intensity of the sound at each frequency.

Pure Tones: A pure tone has only one frequency. In the sound spectrum, it appears as a single spike at a specific frequency, with no other frequencies present.
Complex Sounds: Most real-world sounds are complex and consist of multiple frequencies. The sound spectrum of a complex sound shows multiple spikes or continuous regions, each corresponding to a different frequency component of the sound. Musical instruments, human voices, and other sounds all have unique spectrums that reflect their harmonic structure.

Noise: Noise contains many frequencies without any specific order or harmony. In the spectrum, noise appears as a broad range of frequencies with no distinct peaks.
Examples of noise include the sound of a waterfall, wind, or static on a radio.

Applications of Sound Spectrum:
Music: In music, the spectrum is used to analyze the different harmonic components of musical notes and instruments. The richness of a musical sound comes from the combination of multiple harmonics, each contributing a unique frequency to the sound.
Speech: The sound spectrum is crucial in speech analysis. Different vowels and consonants have characteristic frequency patterns, and the study of these patterns helps in fields like speech recognition and phonetics.

Sonar and Echolocation:
Sonar systems use sound waves to detect objects underwater by emitting sound pulses and analyzing the reflected waves. The frequency spectrum helps

determine the size, distance, and composition of objects. Animals such as bats and dolphins use echolocation by emitting ultrasonic sound waves and interpreting the echoes to navigate and find prey.

Medical Imaging: In ultrasound imaging, high-frequency sound waves (above 20,000 Hz) are used to create images of structures inside the body, such as a fetus during pregnancy or internal organs.

Sound Engineering: In audio engineering, the sound spectrum is analyzed and adjusted to enhance or reduce certain frequencies (e.g., equalization) to improve sound quality for music, radio, or film.

Conclusion:

The sound spectrum is a fundamental concept that describes the range of frequencies present in a sound signal, from the very low infrasonic waves to the very high ultrasonic waves. The spectrum helps us understand how different sound waves behave, how they are perceived, and how they can be applied in technology, medicine, and everyday life.

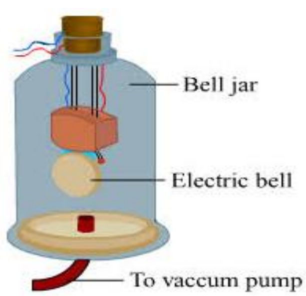
PROPERTIES OF SOUND WAVES

• 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 Sound Cannot Pass Through a Vacuum



Objective:

To demonstrate that sound waves require a medium (air, water, or solids) to travel and cannot propagate through a vacuum.

Apparatus:

Bell jar (glass jar with a vacuum pump), Electric bell or buzzer (small, battery-operated), Vacuum pump (used to remove air from the jar), Power supply or batteries for the bell, and Glass plate (to seal the bell jar)

Procedure:

- Place the electric bell or buzzer inside the bell jar and connect it to the power supply (batteries) so that the bell can ring when powered.
- Ensure the bell jar is connected to a vacuum pump that will be used to evacuate the air from the jar.
- Seal the bell jar with the glass plate to ensure an airtight environment.
- Turn on the power supply to the electric bell. Initially, before starting the vacuum pump, the bell should be clearly heard ringing because sound waves are travelling through the air inside the bell jar to reach your ears.
- Slowly start the vacuum pump to remove the air from the bell jar. As the air is evacuated, listen carefully to the sound of the bell.
- **Observe the Change:**
- As the vacuum pump continues to remove air, you will notice that the sound from the bell becomes fainter and eventually cannot be heard at all. Even though the bell is still ringing (you can visually confirm the vibration), the sound will not reach your ears.
- **Turn off the Vacuum Pump:**
- After evacuating as much air as possible and observing that the bell can no longer be heard, turn off the vacuum pump.
- Gradually allow air back into the bell jar. As the air re-enters, the sound of the bell will become audible again.
- **Explanation:**
- Before removing the air: Sound waves travel through the air in the bell jar. These waves are longitudinal waves that require a medium (air in this case) to propagate. Hence, the sound of the bell can be heard.
- After removing the air: As the air is removed from the bell jar by the vacuum pump, the medium through which the sound waves travel is reduced. In a complete vacuum, there are no air particles to transmit the sound vibrations, so the sound cannot travel, and the bell becomes inaudible.
- When air is reintroduced: Once the air is let back into the jar, the medium for sound transmission is restored, and the sound waves can once again travel to your ears, making the bell audible.

Conclusion:

- This experiment demonstrates that sound cannot travel through a vacuum because there is no medium (such as air) for the sound waves to propagate through. Sound requires a medium like air, water, or solids to travel, unlike light, which can travel through a vacuum.

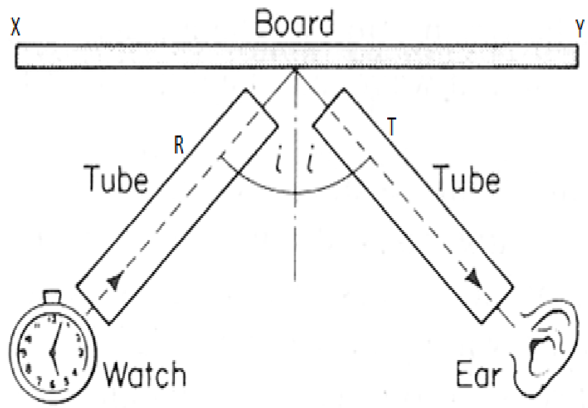
The speed of sound depends on;

Temperature: Increase in temperature increases the speed of sound i.e. sound travels faster in hot air than in cold air.

Wind: Speed of sound is increased if sound travels in the same direction as wind.

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.

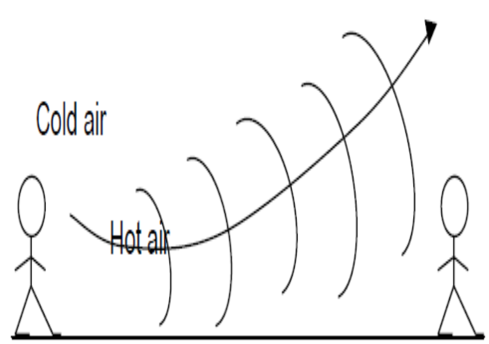
From the experiment, sound is heard distinctly due to reflection.

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.



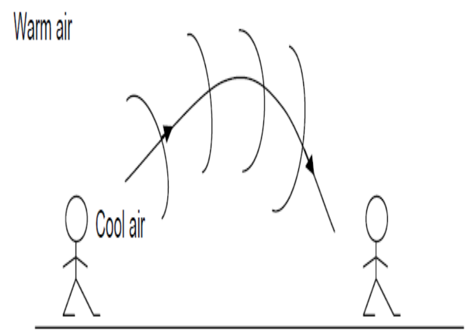
REFRACTION OF SOUND DURING DAY

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.



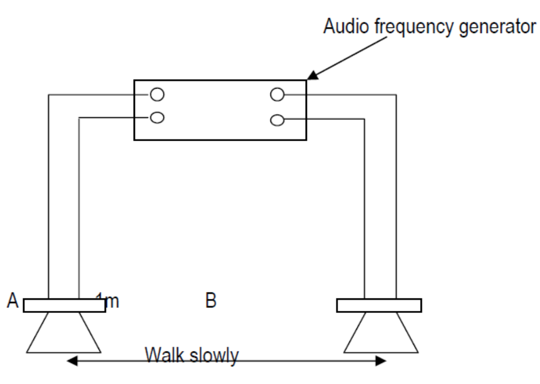
DIFRACTION OF SOUND

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.

For an echo; velocity of sound, $v = \frac{2d}{t}$

Activity

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.
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.
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?
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.
   (**Distance between the walls = 1155m)**
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).
   (**d = 990m)**

MEASUREMENT OF VELOCITY OF SOUND USING AN ECHO 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. T
Velocity of sound, $v = \frac{2d}{t}$

Activity

A student made 50 claps in one minute. If the velocity of sound is 330s, find the distance between the student and the wall(d=198m)

Reverberation:

Reverberation is the persistence of sound after its source has stopped, caused by multiple reflections of the sound waves off surfaces in an enclosed space. Unlike an echo, which is a distinct repetition of a sound, reverberation involves a continuous blending of the sound as it reflects and gradually diminishes in intensity.

Key Concepts:

Sound Reflection:

When sound waves hit a surface (such as walls, ceilings, or floors), they are reflected back into the space. In an enclosed room, these reflected sound waves combine with the direct sound from the source.

Reverberation Time: Reverberation time refers to the time it takes for the sound to decay after the source has stopped. Technically, it's the time required for the sound intensity to decrease by 60 decibels (dB). The longer the reverberation time, the more echoes and prolonged the sound appears.

Rooms with hard surfaces like concrete or tile floors tend to have long reverberation times because these materials reflect sound more efficiently.

Conversely, soft materials like carpets, curtains, or acoustic panels absorb sound, reducing reverberation time and making the room sound “drier.”

Difference between Reverberation and Echo:

Reverberation is the overlapping and continuation of sound caused by reflection in a confined space. It creates a sense of fullness or richness in the sound but doesn't produce a distinct repetition of the sound.

Echo, on the other hand, is a distinct repetition of the original sound. For an echo to occur, the reflected sound must travel a longer distance (typically more than 17 meters) so that it is heard separately from the original sound.

Causes of Reverberation:

Size and Shape of the Room: Large rooms or spaces with high ceilings tend to have longer reverberation times because sound waves travel longer distances before being absorbed or dissipated.

Irregularly shaped rooms can also contribute to reverberation by creating complex patterns of reflected sound.

Material of Surfaces: Hard, reflective surfaces like glass, concrete, or marble reflect sound more effectively, leading to more reverberation.

Soft, absorbent surfaces like carpets, curtains, and foam panels absorb sound energy, reducing reverberation by preventing multiple reflections.

Distance between Surfaces: The larger the distance between surfaces (walls or ceiling), the longer it takes for sound waves to bounce back and reach the listener, which can lead to a more noticeable reverberation effect.

Examples of Reverberation:

Concert Halls and Theaters: Reverberation in concert halls gives music a rich, full quality by allowing sound to linger slightly after it is produced. However, the reverberation time must be carefully controlled to avoid creating a muddled or indistinct sound.

Cathedrals and Churches: Due to their large size and hard stone surfaces, cathedrals typically have long reverberation times. This is why spoken words or music in such spaces often sound echoed and prolonged.

Recording Studios: Recording studios are often designed to have minimal reverberation. This allows for cleaner recordings of sound without the unintended effects of reflections from walls or other surfaces. Acoustic treatments like foam panels and baffles are used to absorb sound and reduce reverberation time.

Effects of Reverberation on Sound Quality:

Enhanced Sound:

Many cases, reverberation can enhance the quality of sound, especially in music. The reflection of sound waves can create a sense of spaciousness and depth, giving the sound a more natural and immersive quality.

Distortion: Too much reverberation can distort sound. When reverberation time is excessively long, individual sounds (such as spoken words) can overlap and become difficult to distinguish, leading to a loss of clarity and intelligibility.

Echoes Speech: In environments with excessive reverberation, speech may sound garbled or echoes because the reflections of earlier sounds interfere with new ones, making it harder to understand what's being said.

Controlling Reverberation:

Acoustic Panels: Soft materials, like foam or fabric-covered panels, can be installed on walls or ceilings to absorb sound waves and reduce reverberation. These panels are commonly used in recording studios, theaters, and auditoriums to control the acoustics of the room.

Carpets and Curtains: Adding carpets or curtains can also absorb sound, helping to reduce the amount of reflection and thus minimizing reverberation in smaller spaces like homes or offices.

Room Design: Designing rooms with irregular shapes or adding furniture can break up sound waves and prevent them from reflecting as strongly. This is useful in reducing reverberation in spaces where clear, crisp sound is important, such as conference rooms or classrooms.

Reverberation is an important acoustic phenomenon that affects how we perceive sound in enclosed spaces. While a moderate amount of reverberation can enrich music or speech, excessive reverberation can lead to distortion and a loss of clarity.

Music:
Music is an organized sequence of sounds that are structured and pleasing to the ear. It typically follows patterns of rhythm, melody, and harmony and is created through deliberate arrangement of musical notes.

Characteristics:
Melody: A sequence of notes that are perceived as a single, coherent entity.
Harmony: The combination of different musical notes played or sung simultaneously to produce a pleasing effect.
Rhythm: The timing of musical sounds, which creates the beat and tempo of a piece.
Noise: Noise is an irregular, disorganized sound that generally lacks a musical pattern and is considered unpleasant or jarring to the ear.

Characteristics:
Irregular waveforms: Unlike music, noise consists of random sound waves that do not form a harmonious structure.
Unpredictable frequencies: Noise often consists of a wide range of frequencies without any discernible pattern.
Examples: Traffic sounds, machinery, and loud disturbances such as a thunderstorm.
Musical Note: A musical note represents a specific sound with a definite pitch and duration. In Western music, notes are represented by letters (A, B, C, D, E, F, G) and can include sharps (#) and flats (♭).
Pitch: The highness or lowness of a sound, which is determined by the frequency of the vibration of sound waves.
Duration: How long a note is held, which can range from whole notes (long) to sixteenth notes (short).

Characteristics of Musical Notes:
Pitch: The frequency of the note, which determines how high or low it sounds. Higher frequencies produce higher pitches.
Duration: How long the note is held. Notation in sheet music indicates the duration, such as whole notes, half notes, quarter notes, etc.
Intensity: The loudness or softness of a note, which is controlled by the dynamics in music.
Timbre (Tone quality): The quality of the sound that distinguishes one instrument or voice from another, even when they play the same note.

Overtone: Overtones are the higher-frequency sound waves that accompany a fundamental note when it is played. They add richness and complexity to the sound.
Harmonics: Overtones are also known as harmonics. The fundamental frequency is the main note you hear, while overtones are higher frequencies that naturally occur at integer multiples of the fundamental frequency.
Effect on Timbre: The presence of overtones gives each instrument or voices its unique timbre. For example, a violin and a piano playing the same note will sound different because of their unique overtone patterns.

Beat: A beat is the basic unit of time in music, which provides the rhythm and pace. It is the regular pulse that you feel in a piece of music.
In Physics: In sound waves, a beat can also refer to the interference pattern between two sound waves of slightly different frequencies. This creates a pulsing effect as the waves alternately reinforce and cancel each other out.
Musical Beats: In music, beats create the tempo, or speed, of a composition, measured in beats per minute (BPM).

Loudness: Loudness is the perceptual measure of the intensity or amplitude of a sound. It refers to how strong or powerful the sound seems to our ears.
Relation to Amplitude: The loudness of a sound is directly related to its amplitude, which is the height of the sound wave. Larger amplitudes produce louder sounds, while smaller amplitudes produce softer sounds.
Measurement: Loudness is measured in decibels (dB). An increase in decibels corresponds to an exponential increase in loudness. Prolonged exposure to sounds over 85 dB can damage hearing.

Amplitude: Amplitude is the height of a sound wave and is directly related to the energy or intensity of the sound.
Relation to Loudness: Amplitude controls the volume of the sound. A higher amplitude means a louder sound, while a lower amplitude produces a quieter sound.
Waveform Representation: In a sound wave, the amplitude is the distance from the equilibrium point (the baseline) to the peak of the wave.
Sensitivity of the Ear: The sensitivity of the ear refers to its ability to detect sounds at various frequencies and intensities.
Frequency Range: The human ear can typically hear sounds between 20 Hz and 20,000 Hz (20 kHz), with the highest sensitivity between 1,000 Hz and 5,000 Hz, where speech sounds are located.

Loudness Range: The ear can detect sounds as quiet as 0 dB (the threshold of hearing) and can tolerate sounds up to about 120 dB (the threshold of pain), but exposure to very loud sounds can lead to hearing damage.

Pure and Impure Musical Notes:
Pure Musical Note: A pure musical note is one that consists of a single frequency or tone with no overtones. It has a smooth, sinusoidal wave form.
Sound Quality: Pure tones are rare in nature and are usually produced by scientific instruments, tuning forks, or synthesizers.
Example: A tuning fork produces a nearly pure note when struck.
Impure Musical Note: An impure musical note, also known as a complex tone, contains multiple frequencies, including the fundamental frequency and various overtones.
Sound Quality: Most musical sounds are impure because they consist of a mix of the fundamental pitch and its harmonics (overtones). This gives richness and complexity to the sound.
Example: A note played on a piano or a violin, which includes the fundamental pitch plus harmonics, creating a fuller, more textured sound.

3.6 Heat quantities and vapours

Learning Outcomes

a) *Understand and use the concepts of heat capacity and latent heat (k, u,s)*
b) *Know and explain the implications of the high values of the specific latent heat and the specific heat capacity of water (k,u)*
c) *Carry out calculations and investigations on specific heat capacity and specific latent heat (u,s)*
d) *Understand the concept of latent heat and change of state, and use them to explain melting and boiling point (u,s)*
e) *Understand the meaning of saturated and unsaturated vapours, saturated vapour pressure, and how these terms relate to boiling and evaporation(u)*
f) *Appreciate the cooling effect of evaporation and how this contributes to maintaining constant body temperature (k, u, s,v/a)*

Concepts of Heat Capacity

Heat energy is the measure of the total internal energy of a system. This includes the total kinetic energy of the system and the potential energy of the molecules.

It has been seen that the internal energy of a system can be changed by either supplying heat energy to it, or doing work on it.

The internal energy of a system is found to increase with the increase in temperature. This increase in internal energy depends on the temperature difference, the amount of matter, etc.

Heat capacity is defined as the amount of heat energy required to raise the temperature of a given quantity of matter by one degree Celsius.

Heat capacity for a given matter depends on its size or quantity and hence it is an extensive property. The unit of heat capacity is joule per Kelvin or joule per degree Celsius.

Mathematically**, $Q=C\Delta T$**. Where Q is the heat energy required to bring about a temperature change of ΔT and C is the heat capacity of the system under study. Where: C = heat capacity (measured in joules per degree Celsius, J/°C), Q = heat energy absorbed or released (measured in joules, J), ΔT = change in temperature (measured in degrees Celsius, °C).

Types of Heat Capacity

Constant Pressure Heat Capacity (C_p): The heat capacity when the pressure is held constant during the temperature change.

Constant Volume Heat Capacity (C_v): The heat capacity when the volume is kept constant during the temperature change.

Factors Affecting Heat Capacity

Different substances have different heat capacities due to variations in molecular structure and bonding.

Solids, liquids, and gases have different heat capacities, with gases generally having higher heat capacities than solids.

Heat capacity can change with temperature; as substances heat up, their ability to store thermal energy may vary.

Effect of Heat Energy on the Temperature of different Materials of the Same Mass

When heat energy is added to a material, it generally causes the temperature of that material to increase. However, the extent of this temperature change varies significantly between different materials, even when they have the same mass. This difference is primarily due to the material's specific heat capacity.

Temperature Change and Specific Heat Capacity

Specific Heat Capacity (c) is the amount of heat energy required to raise the temperature of one kilogram of a substance by one degree Celsius (or one Kelvin). The formula for calculating the temperature change (ΔT) when heat energy (Q) is added is given by: $Q = mc\Delta T$, Where: Q = heat energy added (in joules, J), m = mass of the substance (in kilograms, kg), c = specific heat capacity (in J/(kg·°C)), and ΔT = change in temperature (in °C)

Comparison of Different Materials

When the same amount of heat energy is added to equal masses of different materials, the temperature change experienced by each material will differ based on their specific heat capacities.

Materials with High Specific Heat Capacity:

Example: Water (c≈4,200J/(kg

Effect: It requires a large amount of heat energy to achieve a small temperature increase. For instance, if you add 1,000 J of heat to 1 kg of water, the temperature will rise by approximately 0.24 °C.

Materials with Low Specific Heat Capacity: Example: Iron (c≈450 J/(kg)

Effect: It requires less heat energy to produce the same temperature change. If you add 1,000 J of heat to 1 kg of iron, the temperature will rise by about 2.22 °C.

Explanation of Heat Capacity

Heat Capacity (C) is an extensive property that refers to the amount of heat required to change the temperature of an entire object, not just a unit mass. It is defined as: $C = \frac{Q}{\Delta T}$, where: C= heat capacity (in J/°C or J/K), Q = heat energy added (in joules, J) and ΔT = change in temperature (in °C)

Relationship between Heat Capacity and Specific Heat Capacity

The heat capacity of an object can be expressed in terms of its specific heat capacity and its mass: C=mc , where: m = mass of the substance (in kg), c = specific heat capacity of the substance (in J/(kg·°C))

This shows that larger masses of a substance will have greater heat capacities. For example, a pot of water (larger mass) has a higher heat capacity than a small cup of water, even though both contain water (same specific heat).

The effect of heat energy on temperature varies significantly among different materials of the same mass due to their differing specific heat capacities. Materials with high specific heat capacities require more energy for a given temperature change, while those with low specific heat capacities heat up more quickly.

Specific Heat Capacity

Specific Heat Capacity (c) is a more refined version of heat capacity that expresses the heat capacity per unit mass of a material. It is an intensive property, meaning it does not depend on the amount of material.

Mathematical Expression: Specific heat capacity is defined as:$C = \frac{Q}{m\Delta T}$

Where: c = specific heat capacity (measured in joules per kilogram per degree Celsius, J/(kg·°C)), m = mass of the substance (measured in kilograms, kg), Q and ΔT are the same as defined earlier.

Characteristics

Different substances have distinct specific heat capacities. For example:

Water: =4,200 J/(kg·°C) (high specific heat, which is why it moderates temperatures)

Iron: =450 J/(kg·°C) (lower specific heat compared to water)

Importance of Specific Heat Capacity

Thermal Regulation: Specific heat capacity plays a crucial role in climate and weather patterns, influencing how different surfaces heat and cool.

Engineering Applications: Understanding specific heat is vital for thermal management in engineering, including HVAC systems, engines, and materials science.

Practical Implications of Heat Capacity and Specific Heat Capacity

Heating and Cooling

Heating: When heat is added to a substance, its temperature increases proportionally to its heat capacity. Substances with high specific heat capacities require more energy to increase their temperature.

Cooling: Conversely, substances lose heat and cool down. Materials with high specific heat capacities retain heat longer, which can be important for energy efficiency.

Applications in Daily Life

Cooking: Specific heat capacity explains why water is effective for cooking (it absorbs a lot of heat without a significant temperature change).

Thermal Insulation: Materials with low specific heat capacity are used in insulation to minimize heat loss.

Climate Change: The specific heat capacity of oceans plays a significant role in regulating Earth's climate, absorbing heat from the sun and stabilizing temperatures.

Heat capacity and specific heat capacity are fundamental concepts in thermodynamics, essential for understanding how substances respond to heat. While heat capacity measures the total heat energy required to change a substance's temperature, specific heat capacity provides insight on a per-mass basis. Both concepts are crucial in a variety of applications, from engineering to environmental science, and influence many aspects of daily life.

Applications and Implications of the High Specific Latent Heat and Heat Capacity of Water

Water's unique thermal properties, particularly its high specific latent heat and high specific heat capacity, have significant implications across various fields, including environmental science, engineering, climate control, and everyday life.

High Specific Heat Capacity of Water

Specific Heat Capacity: The amount of heat energy required to raise the temperature of 1 kg of water by 1 °C. Water has a specific heat capacity of approximately 4,200 J/(kg·°C), making it one of the highest among common substances.

Applications

Climate Regulation:

Large bodies of water absorb and store heat from the sun, moderating coastal temperatures and creating a more stable climate. This helps prevent extreme temperature fluctuations in coastal regions.

The ocean acts as a heat reservoir, absorbing heat during the summer and releasing it during the winter, influencing weather patterns and climate stability.

Heating and Cooling Systems:

Water is used in heating, ventilation, and air conditioning (HVAC) systems due to its high specific heat capacity, which allows it to transfer and store thermal energy efficiently.

In buildings, water-based radiant heating systems use hot water to warm floors and walls, providing consistent and efficient heating.

Industrial Processes:

Temperature Control: Industries that require precise temperature control (e.g., chemical manufacturing) utilize water for cooling and heating, leveraging its high heat capacity for effective thermal management.

Biological Systems:

Thermoregulation: Water's high specific heat capacity helps organisms regulate their internal temperatures. For example, large bodies of water help maintain stable temperatures in ecosystems, benefiting aquatic life.

Implications

Energy Efficiency: The high specific heat capacity of water means that less energy is needed to achieve a desired temperature change in large volumes, leading to more energy-efficient systems.

Environmental Impact: The ability of water to moderate temperatures contributes to the stability of ecosystems, making it vital for biodiversity and the health of natural habitats.

SPECIFIC LATENT HEAT

Specific latent heat is the amount of heat energy required to change the state of a unit mass (1kg) of a substance without changing its temperature. It is an important concept in thermodynamics and is typically expressed in joules per kilogram (J/kg).

There are two main types of specific latent heat:

Specific Latent Heat of Fusion: This is the heat energy required to change a solid into a liquid at its melting point (e.g., ice to water). For water, this is about 334,000 J/kg.

Specific Latent Heat of Vaporization: This is the heat energy required to change a liquid into a gas at its boiling point (e.g., water to steam). For water, this is approximately 2,260,000 J/kg.

During these phase changes, the temperature of the substance remains constant even though heat is being added or removed. This is because the energy is used to overcome the intermolecular forces holding the particles in their respective states rather than increasing their kinetic energy.

In practical applications, understanding specific latent heat is crucial in fields like meteorology, engineering, and environmental science, as it helps explain processes such as weather patterns, refrigeration, and energy transfer in various systems.

High Specific Latent Heat of Water

Specific Latent Heat: The amount of heat energy required to change the state of 1 kg of a substance without changing its temperature. Water has a high latent heat of vaporization (about 2,260 kJ/kg) and a high latent heat of fusion (about 334 kJ/kg).

Applications High Specific Latent Heat of Water

Weather and Climate:

Evaporation and Precipitation: The high latent heat of vaporization is crucial in the water cycle. When water evaporates from oceans and lakes, it absorbs large amounts of heat, which is released during condensation, forming clouds and precipitation.

Storm Formation: The release of latent heat during condensation powers storms and weather systems, influencing local and global weather patterns.

Cooling Systems:

Evaporative Cooling: Systems that use the cooling effect of water evaporation (like swamp coolers) take advantage of water's high latent heat to provide efficient cooling in dry climates.

Industrial Cooling: Many industrial processes use water to absorb heat, leveraging its latent heat properties for effective temperature control.

Cooking:

Boiling and Steaming: Cooking methods that rely on boiling or steaming utilize the high latent heat of water, allowing food to cook evenly without exceeding 100 °C (at sea level).

Implications High Specific Latent Heat of Water

Energy Transfer: The high latent heat of water facilitates the transfer of energy within the environment, impacting weather systems and climate.

Thermal Regulation: In ecosystems, water's ability to absorb and release heat during phase changes helps maintain temperature stability, benefiting both aquatic and terrestrial life.

Summary of Implications

Climate Stability: The thermal properties of water play a critical role in climate regulation and stability, making it essential for sustaining life on Earth.

Energy Efficiency in Systems: Water's high specific heat and latent heat properties enable the design of efficient heating, cooling, and energy transfer systems in various applications.

Ecological Importance: The unique thermal properties of water support diverse ecosystems, influencing plant and animal life through temperature regulation and moisture availability.

Water's high specific heat capacity and high latent heat are not only fundamental physical properties but also essential characteristics that have profound implications in multiple fields. These properties enable water to moderate climate, support industrial processes, and play a vital role in biological systems, emphasizing its importance in both environmental and practical contexts.

Oceans role in regulating global temperatures through several mechanisms:

Heat Absorption and Storage: Oceans absorb a significant amount of solar energy, storing heat in their vast bodies of water. This heat is distributed throughout the ocean currents, helping to moderate temperatures across the globe.

Ocean Currents: Ocean currents act like conveyor belts, transporting warm water from the equator to the poles and bringing cold water from the poles back to the equator. This circulation helps balance temperature differences and influences climate patterns, such as the Gulf Stream, which warms parts of North America and Europe.

Evaporation and Humidity: The oceans produce water vapor through evaporation, which plays a key role in regulating temperature and weather patterns. Water vapor is a greenhouse gas, trapping heat in the atmosphere and contributing to the Earth's energy balance.

Heat Redistribution: Oceanic currents help redistribute heat around the planet. For example, warm surface currents transfer heat to the atmosphere, while colder, denser water sinks and moves along the ocean floor, affecting global climate systems.

Carbon Dioxide Absorption: Oceans absorb a large portion of atmospheric carbon dioxide, which helps mitigate climate change. However, increased CO2 levels can lead to ocean acidification, impacting marine ecosystems.

Seasonal and Long-term Climate Influence: Oceans can influence seasonal weather patterns, such as monsoons, and long-term climate phenomena like El Niño and La Niña, which affect global temperatures and weather systems.

Overall, the oceans act as a critical component of the Earth's climate system, influencing temperature, weather patterns, and the overall health of the planet.

Particle theory of matter

The particle theory of matter helps explain the loss or gain of heat during a change of state by focusing on the behavior and arrangement of particles in a substance. Here's how it works for different phase changes:

Solid to Liquid (Melting)

When a solid absorbs heat, the energy increases the kinetic energy of its particles. As the particles gain energy, they vibrate more vigorously, eventually breaking the rigid structure of the solid. The particles become less tightly packed and start to move past each other, transitioning into the liquid state.

Liquid to Gas (Vaporization)

In this phase change, heat is absorbed, providing the energy needed for the particles in a liquid to overcome intermolecular forces. The liquid particles gain enough kinetic energy to break free from the attractions of neighboring particles, allowing them to escape into the air as gas.

Gas to Liquid (Condensation)

When a gas cools down, it loses heat energy. As the gas particles lose energy, they slow down and move closer together. The intermolecular forces become strong enough to bring the particles together, forming a liquid.

Liquid to Solid (Freezing)

During freezing, a liquid loses heat energy. As the liquid cools, its particles lose kinetic energy, leading to a decrease in movement. The particles arrange themselves into a fixed, orderly structure, resulting in a solid.

Solid to Gas (Sublimation)

In sublimation, a solid directly turns into a gas without becoming a liquid first, requiring the absorption of heat. The solid particles gain enough energy to overcome the intermolecular forces holding them in place, allowing them to disperse into the gaseous state.

Gas to Solid (Deposition)

This process involves a gas turning directly into a solid, releasing heat in the process. The gas particles lose energy and come together to form a solid structure without passing through the liquid state.

In summary, the particle theory illustrates that heat changes during phase transitions involve the movement and arrangement of particles, with heat gain leading to increased energy and movement, and heat loss resulting in decreased energy and more ordered structures.

Origins of the energy in a storm

The energy in a storm primarily originates from several interconnected sources and processes:

Solar Energy: The Sun is the primary source of energy for the Earth's atmosphere. Solar radiation heats the Earth's surface unevenly, causing variations in temperature. This heating is crucial for driving weather systems, including storms.

Evaporation of Water: As solar energy heats bodies of water, water evaporates, turning into water vapor. This process absorbs latent heat, which is stored in the water vapor. When the water vapor condenses back into liquid water (during cloud formation), this latent heat is released, contributing significantly to the energy of the storm.

Convection: Warm, moist air is less dense than cooler air, causing it to rise. As the warm air rises, it cools and expands. This upward movement creates areas of low pressure, leading to the formation of clouds and storms. The process of convection is a key mechanism for energy transfer in storm systems.

Temperature Differences: Storms often occur at the boundaries of different air masses (such as cold fronts and warm fronts). The interaction between these air masses can create significant temperature differences, leading to instability in the atmosphere. This instability is a driving force behind storm development.

Pressure Systems: High and low-pressure systems play a crucial role in storm formation. Low-pressure areas draw in surrounding air, leading to rising currents that can generate storms. The contrast between high and low pressure can enhance wind speeds and contribute to storm intensity.

Coriolis Effect: The rotation of the Earth affects the movement of air and can influence storm systems. The Coriolis Effect causes winds to curve, which helps organize storm systems and contributes to the rotation of cyclones and hurricanes.

Topography: Mountains and other geographical features can affect local weather patterns. When moist air encounters mountains, it is forced to rise, leading to cooling and precipitation, which can intensify storms.

In summary, the energy in a storm arises from solar heating, evaporation, convection, temperature and pressure differences, the Coriolis Effect, and geographical factors. Together, these elements create the dynamic conditions necessary for storm development and intensity.

The different rates at which land and sea heat up and cool down are primarily due to their physical properties and specific heat capacities.

Specific Heat Capacity:

Land: The specific heat capacity of land is generally lower than that of water. This means that land requires less energy to increase its temperature compared to water.

Sea: Water has a high specific heat capacity, allowing it to absorb and store more heat without a significant increase in temperature.

Heat Absorption and Retention:

Land: When exposed to sunlight, land surfaces absorb heat quickly and reach higher temperatures. However, they also lose that heat rapidly when the sun sets or when temperatures drop.

Sea: Water bodies can absorb heat throughout their depth. The heat is distributed through the water column, leading to slower warming. At night, water retains heat longer, cooling down more slowly.

Thermal Inertia:

Land: The thermal inertia of land is low, meaning it reacts quickly to changes in temperature.

Sea: Water's thermal inertia is high, resulting in more gradual changes in temperature. This makes water more stable in temperature compared to land.

Implications for Sea Breezes:

Daytime:

As the sun rises and heats the land quickly, the air above the land warms up and becomes less dense, causing it to rise. The cooler, denser air over the sea moves in to replace the rising warm air, creating a sea breeze. This breeze typically blows from the sea to the land, bringing cooler, moist air.

Nighttime:
At night, the land cools down quickly, while the sea retains heat longer. The air over the land becomes cooler and denser, causing it to sink. Conversely, the air over the sea remains relatively warmer and less dense. As a result, the wind may shift, and sometimes a land breeze can occur, blowing from the land to the sea.

Broader Climatic Impacts:
The difference in heating rates contributes to local climate variations, affecting weather patterns and precipitation. In coastal areas, the regular occurrence of sea and land breezes can influence temperature regulation, humidity levels, and local ecosystems.

Summary:
The differential heating and cooling of land and sea are driven by their specific heat capacities, thermal properties, and absorption characteristics. These differences lead to the formation of sea breezes during the day and land breezes at night, impacting local weather patterns and climatic conditions.

To investigate how stearic acid changes with temperature, you can follow a systematic experimental approach.

Investigation Steps

Materials Needed: *Stearic acid (solid), Heating apparatus (water bath or hot plate), Thermometer, Beaker, Ice bath (optional, for cooling), Stirring rod, and Scale (for measuring mass)*

Procedure

Place a known mass of stearic acid in a beaker.

Set up the heating apparatus to gradually heat the beaker while monitoring the temperature with a thermometer.

Gradually heat the stearic acid while stirring gently to ensure uniform temperature distribution.

Record the temperature at regular intervals (e.g., every 1-2 minutes).

Observe the state of the stearic acid (solid, liquid) at each temperature.

Continue heating until you notice a change in state from solid to liquid.

Carefully note the temperature at which the stearic acid begins to melt (melting point).

Once the stearic acid is fully melted, remove it from the heat and allow it to cool naturally or place it in an ice bath.

Record the temperature at regular intervals as it cools and observe the state change back to solid.

Note the temperature at which the stearic acid begins to solidify (freezing point).

Findings and Explanation

Melting Phase: As the temperature increases and reaches the melting point, stearic acid absorbs heat (latent heat of fusion) without a temperature increase. During this phase change, the energy is used to break the intermolecular forces holding the solid structure, allowing particles to move more freely in the liquid state.

Liquid Phase: Once completely melted, the stearic acid exists as a liquid, and further heating raises its temperature until reaching its boiling point (if applicable). Heat is absorbed by the liquid, increasing the kinetic energy of the particles.

Cooling Phase: When cooling, stearic acid loses heat (latent heat of solidification) as it transitions from liquid to solid. During this phase change, the energy released allows the particles to arrange themselves into a solid structure, which involves the formation of intermolecular bonds.

Freezing Phase: The temperature remains constant during the phase change from liquid to solid, as the energy is released rather than resulting in a temperature decrease.

The investigation demonstrates that stearic acid undergoes phase changes (melting and freezing) at specific temperatures, during which it absorbs or releases heat without a change in temperature. This behavior illustrates the concepts of latent heat and the energy dynamics involved in phase transitions.

Specific Heat Capacity (c)

Specific heat capacity is the amount of heat required to raise the temperature of 1 kg of a substance by 1℃ (or 1 K).

The formula to calculate the specific heat capacity is: $Q=mc\Delta T$, where:

- Q = heat energy absorbed or released (in joules, J)
- m = mass of the substance (in kilograms, kg)
- c = specific heat capacity of the substance (in J/kg°C)
- ΔT = change in temperature (in °C or K)

Calculation: Let's assume you are heating 2 kg of water, and its temperature increases by 30°C. The specific heat capacity of water is approximately 4200 J/kg°C. $Q=mc\Delta T=2\ kg\times 4200\ Jkg°C\times 30\ °C$, $Q=252{,}000J$

This means 252,000 joules of heat are required to raise the temperature of 2 kg of water by 30°C.2.

Specific Latent Heat (L)

Specific latent heat is the amount of heat energy required to change the state of 1 kg of a substance without changing its temperature.

Latent Heat of Fusion (L_f) – for changing from solid to liquid (melting)
Latent Heat of Vaporization (L_v) – for changing from liquid to gas (evaporation/boiling)
The formula to calculate latent heat is: Q=mL, Where:

- Q = heat energy absorbed or released (in joules, J)
- m = mass of the substance (in kilograms, kg)
- L = specific latent heat of the substance (in J/kg)

Calculation (Latent Heat of Fusion): Let's assume you are melting 0.5 kg of ice at 0°C. The latent heat of fusion for ice is approximately 334,000 J/kg.
$Q=mL_f=0.5kg×334,000kgJ$ $Q=167,000J$. This means 167,000 joules of heat are required to melt 0.5 kg of ice without raising its temperature.
Experimental investigation of Specific Heat Capacity of a metal block
Apparatus:

- Metal block of known mass (e.g., copper or aluminum)
- Heating element
- Thermometer
- Joulemeter (to measure energy supplied) or known power supply and stopwatch
- Insulation (to reduce heat loss)

Method:
Measure the mass of the metal block.
Attach the heating element to the block and insulate it to prevent heat loss.
Record the initial temperature of the block.
Turn on the power supply and heat the block for a specific amount of time, measuring the energy supplied (Q) using a joulemeter or power rating and time.
If using a power supply, calculate Q=power×time
Measure the final temperature of the block.
Use the formula $Q=mc\Delta TQ$ to calculate the specific heat capacity.

Experimental investigation of specific latent heat (latent heat of fusion) of fusion for ice
Apparatus:

- Ice
- Calorimeter (or insulated container)
- Water at room temperature
- Thermometer
- Balance (for mass)
- Joulemeter or heating element

Method:
Measure the mass of the calorimeter and some warm water in it.
Record the initial temperature of the water.

Add ice into the water and allow it to melt completely while stirring to ensure even distribution of temperature.

Record the final temperature of the water after all the ice has melted.

Measure the mass of the remaining water to determine the mass of the melted ice.

Use the formula $Q=mc\Delta T$, to find the energy lost by the water as it cools.

Use $Q=mL_f$ to calculate the specific latent heat of fusion for ice, where Q is the energy absorbed by the ice to melt.

Latent Heat and Change of State

Latent heat is the amount of energy absorbed or released by a substance during a change of state (phase change) without a change in temperature. This energy is used to overcome the intermolecular forces between particles, rather than increasing the kinetic energy of the particles (which would raise the temperature).

There are two main types of latent heat:

Latent Heat of Fusion (L_f): The heat energy required to change a substance from solid to liquid (melting) or liquid to solid (freezing) at constant temperature.

Latent Heat of Vaporization (L_v): The heat energy required to change a substance from liquid to gas (boiling or evaporation) or gas to liquid (condensation) at constant temperature.

Change of State

During phase changes, such as melting or boiling, the temperature of the substance remains constant because the energy supplied is used to break the bonds between the particles rather than to increase their motion. The energy associated with these processes is referred to as latent heat.

Melting Point

Melting is the change of state from solid to liquid. When a solid is heated, its particles gain energy and vibrate more vigorously. As the temperature reaches the melting point, the particles have enough energy to overcome the attractive forces holding them in a rigid structure.

At this point, additional heat supplied to the system goes into breaking these intermolecular bonds rather than raising the temperature, so the temperature remains constant until all the solid has melted. This energy required to convert the solid to a liquid without changing the temperature is called the latent heat of fusion.

Example: For ice, the latent heat of fusion is about 334,000 J/kg. When ice melts, this energy is absorbed to break the hydrogen bonds between the water molecules, but the temperature of the ice-water mixture stays at 0°C until all the ice has melted.

Boiling Point

Boiling is the change of state from liquid to gas. As a liquid is heated, its particles move more rapidly and the temperature increases. At the boiling point, the particles have enough kinetic energy to overcome the intermolecular forces holding them together in the liquid state.

During boiling, the temperature remains constant, even though heat continues to be added. The energy supplied at the boiling point is used to separate the particles as they transition from liquid to gas, and this is called the latent heat of vaporization.

Example: For water, the latent heat of vaporization is about 2,260,000 J/kg. At 100°C, water requires this additional energy to turn into steam (water vapor), even though its temperature does not rise beyond the boiling point until all the liquid has evaporated.

Summary of Melting and Boiling Points in Terms of Latent Heat

Melting Point: When a solid reaches its melting point, the energy added (latent heat of fusion) is used to break the intermolecular forces and convert it to a liquid. The temperature remains constant during this process.

Boiling Point: At the boiling point, the energy added (latent heat of vaporization) is used to separate particles as they move from liquid to gas. The temperature also remains constant during boiling until all the liquid is converted to gas.

Both melting and boiling are examples of phase transitions where energy is involved but temperature stays steady, illustrating the concept of latent heat.

The concept of **latent heat** plays a crucial role in the functioning of refrigerators. A refrigerator works by removing heat from its interior, keeping the stored food and items cool. This process involves the **latent heat of vaporization** of a refrigerant (a fluid used in the cooling system) as it changes between its liquid and gas states.

Refrigeration Cycle

The refrigeration cycle relies on the principle of heat absorption during vaporization and heat release during condensation.

It involves four main components:

Evaporator: Absorbs heat from the refrigerator's interior.

Compressor: Compresses the refrigerant gas to increase its pressure and temperature.

Condenser: Releases heat to the surrounding environment.

Expansion valve: Lowers the refrigerant's pressure and temperature.

Role of Latent Heat in the Refrigeration Process

The refrigerant (often a gas such as R-134a or ammonia) circulates within the refrigerator's system, constantly changing from liquid to gas and back again. Latent heat in refrigeration can be understood in two phases: **evaporation and condensation.**

Phase 1: Evaporation (Absorption of Latent Heat)

In the evaporator, the refrigerant is in its liquid form at low pressure and temperature.

As the refrigerant absorbs heat from the refrigerator's interior, it undergoes a phase change from liquid to gas. This process requires energy, which comes from the surrounding environment (inside the fridge).

The energy absorbed during this phase change is the latent heat of vaporization, and it allows the refrigerant to evaporate and cool the air inside the fridge.

Cooling effect: Since the refrigerant absorbs heat, it cools down the contents of the refrigerator. This phase happens without a rise in temperature because the heat energy goes into changing the state of the refrigerant from liquid to gas (latent heat).

Phase 2: Compression and Condensation (Release of Latent Heat)

After the refrigerant has evaporated into a gas, it moves to the compressor, where its pressure is increased. This raises the temperature of the refrigerant gas.

The hot, high-pressure gas then moves to the condenser, typically located at the back or bottom of the refrigerator.

In the condenser, the refrigerant releases heat to the external environment and undergoes a phase change from gas to liquid. The heat released in this process is the latent heat of condensation.

Heat release: The refrigerant, now in liquid form, releases the latent heat that it absorbed during evaporation into the surrounding air, cooling down as it condenses.

Continuous Cycle

The liquid refrigerant then passes through the expansion valve, where its pressure and temperature are lowered, and the cycle repeats. This continuous cycle of absorbing latent heat (during vaporization) and releasing latent heat (during condensation) allows the refrigerator to maintain a low temperature inside.

Key Points:
Evaporation inside the refrigerator's evaporator absorbs heat from the contents, causing cooling.
Condensation in the condenser releases heat to the surrounding environment.
Latent heat allows the refrigerant to absorb and transfer heat efficiently without changing temperature during phase changes, which is essential for maintaining the cooling effect inside the fridge.

Summary:
In refrigerators, latent heat enables the refrigerant to absorb heat from the inside of the fridge (cooling it down) and then release this heat outside, maintaining a cold interior environment. The refrigerant's phase changes — from liquid to gas during evaporation (absorbing latent heat) and from gas to liquid during condensation (releasing latent heat) — are critical to the refrigeration process.

Saturated and Unsaturated Vapours
An Unsaturated vapour refers to a state where the vapour is not in equilibrium with its liquid. This means the vapour can still hold more molecules of the substance in its gaseous phase without condensing back into a liquid. In this state, evaporation can continue because the vapour pressure is below the **saturated vapour pressure**.
Saturated vapour is when the vapour is in equilibrium with its liquid at a given temperature. At this point, the rate of evaporation (liquid turning into vapour) equals the rate of condensation (vapour turning back into liquid). No more molecules can evaporate unless the temperature is increased, and any additional vapour introduced will condense back into the liquid.
Saturated Vapour Pressure (SVP)
Saturated vapour pressure (SVP) is the pressure exerted by a vapour when it is in equilibrium with its liquid at a specific temperature. At this point, the maximum amount of vapour that can exist above the liquid has been reached. SVP depends on temperature: as temperature increases, the kinetic energy of the liquid's molecules increases, leading to higher evaporation rates, and hence a higher saturated vapour pressure.

Relation to Boiling and Evaporation
Evaporation:
Evaporation is the process where molecules at the surface of a liquid gain enough energy to escape into the vapour phase. **Evaporation can occur at any temperature**, as long as the vapour above the liquid is unsaturated. It

only affects surface molecules, and it continues until the vapour becomes saturated, meaning the rate of condensation matches the rate of evaporation. Evaporation is a slower process and doesn't require the liquid to reach its boiling point.

Boiling: Boiling occurs when the **vapour pressure** of the liquid equals the **external (atmospheric) pressure**. At this point, bubbles of vapour can form within the liquid and rise to the surface. The **boiling point** is the temperature at which the **saturated vapour pressure** of the liquid equals the atmospheric pressure. Unlike evaporation, which only happens at the surface, boiling occurs throughout the entire liquid because bubbles of vapour can form inside the liquid once the saturated vapour pressure matches the external pressure.

Summary of the relationship:

Saturated vapour pressure is key in determining when a liquid will boil. A liquid boils when its saturated vapour pressure equals the surrounding atmospheric pressure.

Unsaturated vapour allows for continuous evaporation, while **saturated vapour** means the evaporation and condensation rates are in equilibrium.

Boiling is the rapid vaporization of a liquid and occurs when the saturated vapour pressure is high enough to equal the external pressure, while **evaporation** happens even below the boiling point and only from the surface of the liquid.

Boiling and Evaporation in Terms of Particle Theory of matter

Boiling:

Boiling is the rapid change of a liquid into a gas throughout the entire liquid.

According to particle theory, as a liquid is heated, its particles gain kinetic energy and move faster. At the boiling point, the particles have enough energy to overcome the intermolecular forces holding them together in the liquid.

At this temperature, the liquid's vapour pressure becomes equal to the external (atmospheric) pressure, and bubbles of vapour form within the liquid and rise to the surface to escape into the gas phase.

Boiling happens at a specific temperature (the boiling point), which depends on the external pressure.

Evaporation:

Evaporation is the slow change of a liquid into a gas at the surface of the liquid.

Unlike boiling, evaporation can occur at any temperature. The particles at the surface of the liquid with the highest kinetic energy are able to escape the liquid phase and enter the gas phase.

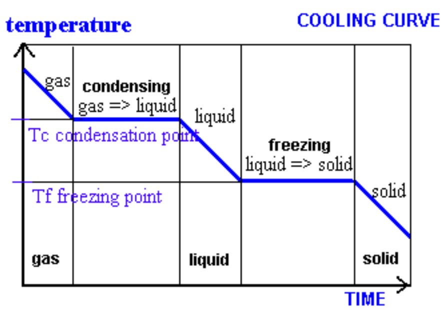
This process happens because some surface particles have enough energy to overcome the intermolecular forces binding them to the liquid, even at lower temperatures.
Evaporation only occurs from the surface and does not require the liquid to reach its boiling point.

How Perspiring Maintains Constant Body Temperature in Mammals
Mammals, including humans, use perspiration (sweating) to regulate their body temperature, especially in hot environments or during physical exertion.
When mammals sweat, their bodies release water onto the surface of the skin. The evaporation of this sweat cools the body.
The water molecules in sweat absorb latent heat from the skin as they transition from liquid to gas. This energy is used to break the bonds between the water molecules, allowing them to evaporate.
As a result, heat is removed from the body, leading to a cooling effect and helping to maintain a constant internal temperature.
This process is part of thermoregulation, ensuring that mammals stay within a safe temperature range despite environmental changes.

Why water boils at a temperature less than 100°c at the top of a mountain
The boiling point of water decreases at higher altitudes because of the reduction in atmospheric pressure.
At sea level, atmospheric pressure is higher, and water boils at 100°C because the vapour pressure of the water must match the atmospheric pressure to allow bubbles of vapour to form within the liquid.
At higher altitudes, the atmospheric pressure is lower, so water needs less energy (i.e., lower temperature) to reach the point where its vapour pressure equals the external pressure.
For example, on top of a mountain, where the atmospheric pressure is much lower than at sea level, water may boil at 90°C or even lower, depending on the height.

How a Pressure Cooker Works
A pressure cooker is a sealed cooking pot that increases the pressure inside by trapping steam. This elevated pressure allows the temperature of boiling water to rise above its normal boiling point of 100°C, speeding up the cooking process.
How it works:

When a liquid inside the pressure cooker is heated, it boils and turns into steam. Since the cooker is sealed, the steam cannot escape, and the pressure inside the cooker rises.
As the pressure increases, the boiling point of water increases. In a typical pressure cooker, the pressure might rise to 15 psi (pounds per square inch) above atmospheric pressure, which increases the boiling point of water to about 121°C (250°F).
At this higher temperature, food cooks faster because the increased kinetic energy of the water molecules speeds up the chemical reactions involved in cooking.
The higher pressure also forces moisture into the food, further accelerating the cooking process.
In summary, a pressure cooker works by increasing the boiling point of water, which allows the food to cook at a higher temperature and thus much faster than normal cooking at atmospheric pressure.



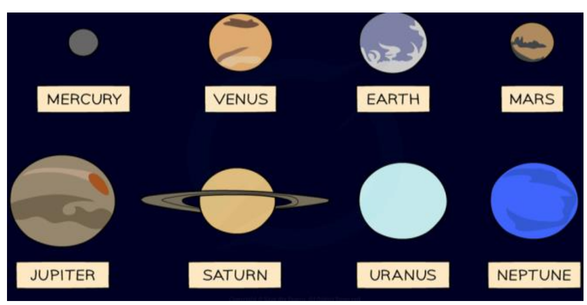
A cooling curve is a line graph that represents the change of phase of matter, typically from a gas to a solid or a liquid to a solid. The independent variable (X-axis) is time and the dependent variable (Y-axis) is temperature.

3.7 Stars and galaxies

Learning Outcomes

a) Know the source of energy in stars and appreciate the importance of the energy produced by the sun to the people on Earth (k,u)
b) Appreciate that stars vary in colour and brightness(u)
c) Know that stars have life cycles and that the fate of stars (white dwarfs, neutron stars and black holes) depends on their initial size (k,u)

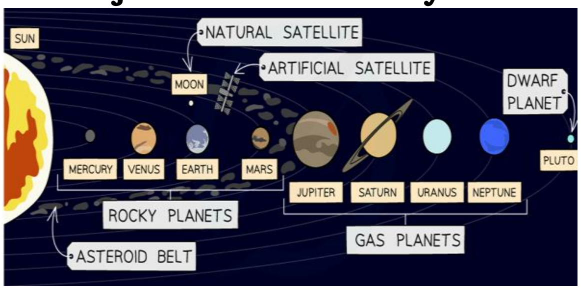
Asteroids & Comets



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



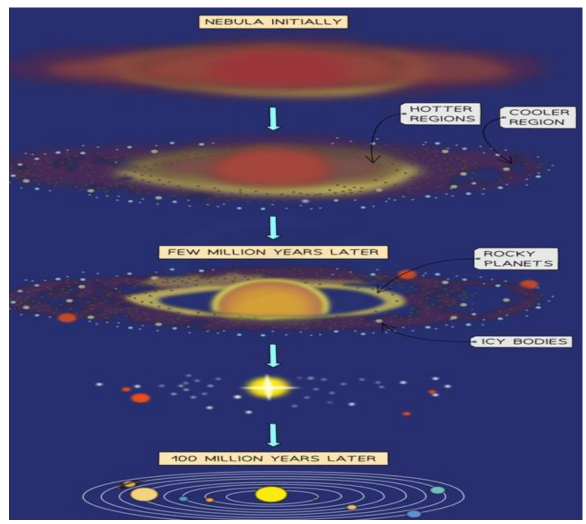
Assessment Tip

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:

<u>My Very Excellent Mother Just Served Us Noodles</u>

(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.***

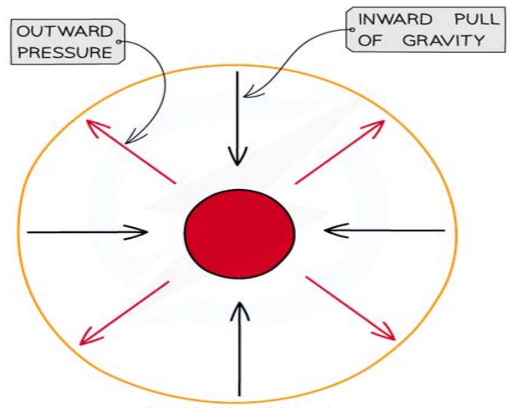
The speed of light is the *universal speed limit*; nothing can travel faster than the speed of light.

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

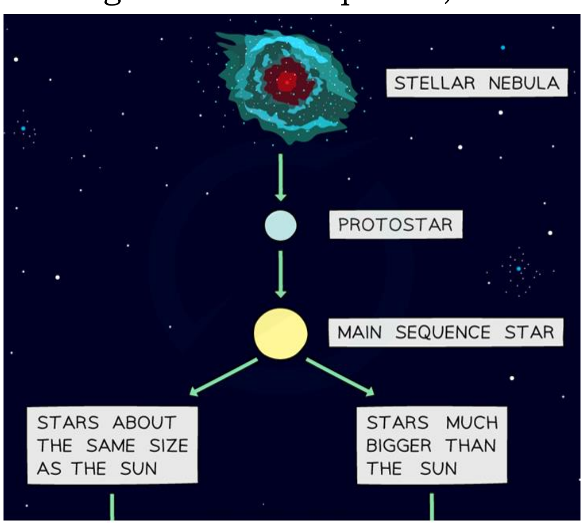


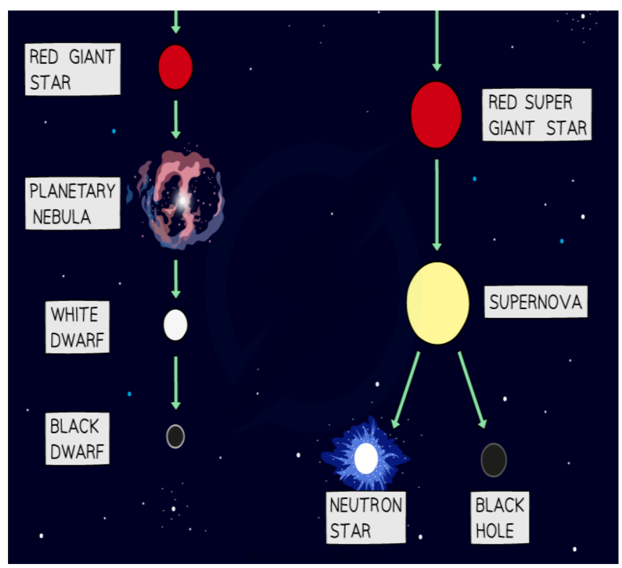
Star Formation

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





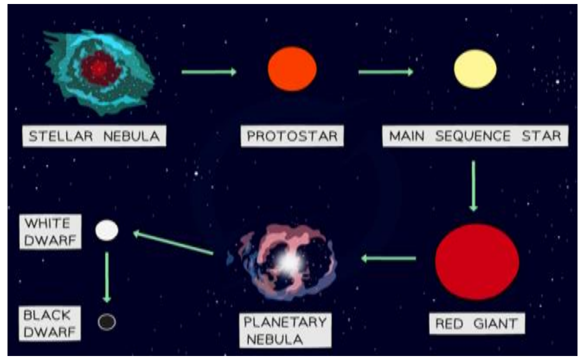
in equilibrium and said to be stable. The inward force due to gravity is equal to the outward pressure force from the fusion reactions.

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 stage

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.

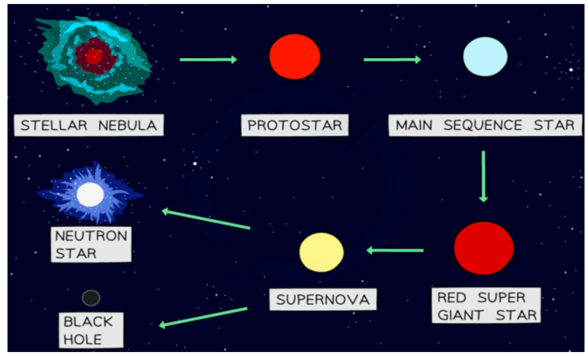
7. Black Dwarf

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.

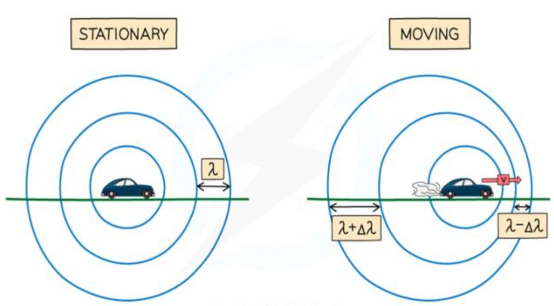
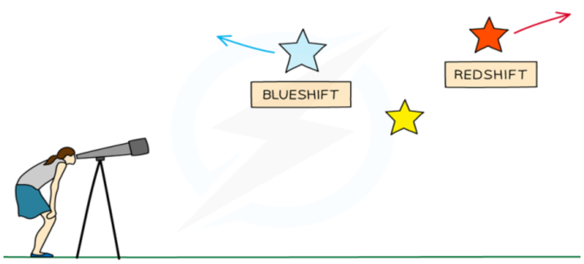


Diagram showing the wave fronts produced from a stationary object and a moving object.

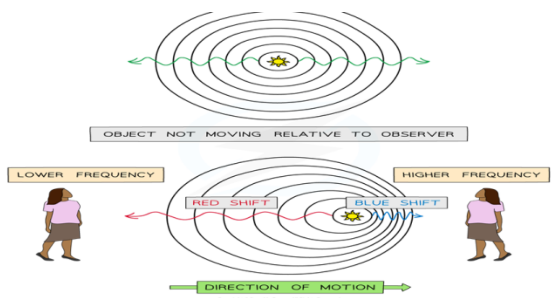
A moving object will cause the wavelength, λ, (and frequency) of the waves to change:

- ✓ *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*



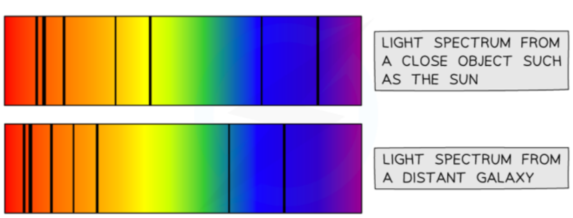
This effect is known as the *Doppler effect.* *Doppler effect: The apparent change in the frequency of the wave when there is relative motion between the observer and the source of the waves.*

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.

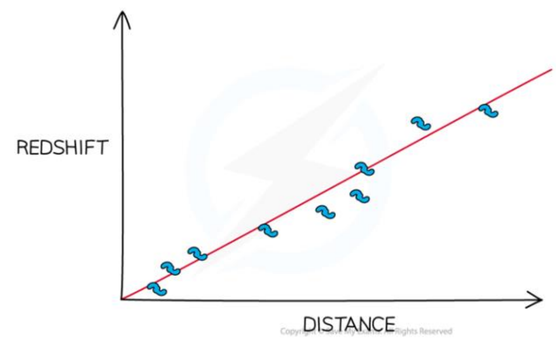
Light emitted from distant galaxies appears redshifted when compared with light emitted on Earth. The diagram below shows the light coming to us from a close object, such as the Sun, and the light coming to us from a distant galaxy



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.*



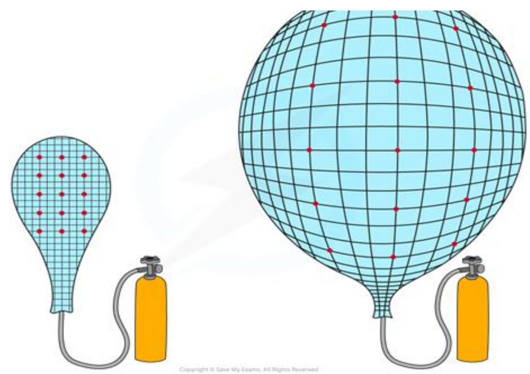
Graph showing the greater the distance to a galaxy, the greater the redshift

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.*

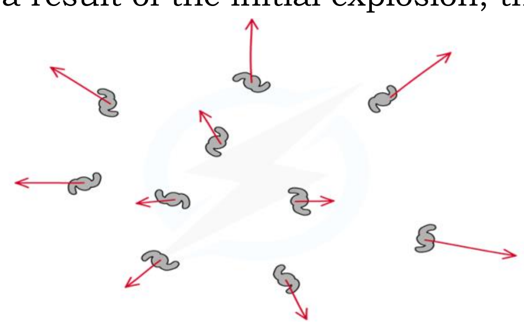
This caused the universe to expand from a single point, cooling as it does so, to form the universe today. Each point expands away from the others.



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.

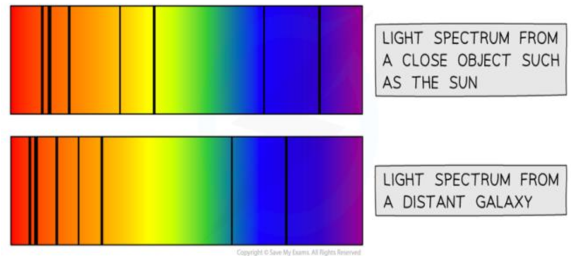
When the balloon is deflated, all the points are close together and an equal distance apart.

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

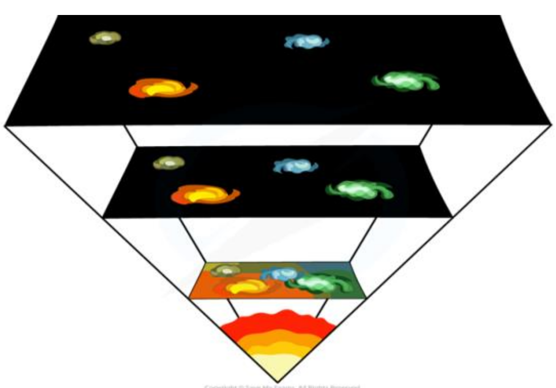
Red-shift provides evidence that the Universe is expanding because:

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.



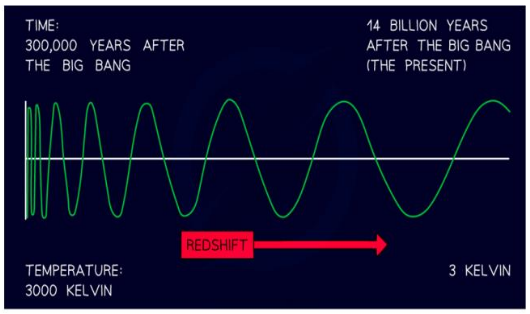
Tracing the expansion of the universe back to the beginning of time leads to the idea the universe began with a “big bang”

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.

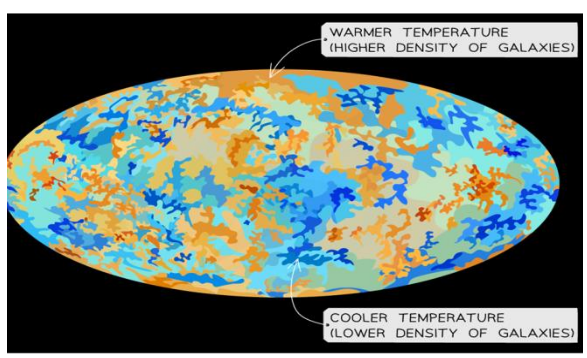
The CMB is a type of electromagnetic radiation which is a remnant from the early stages of the Universe.

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.

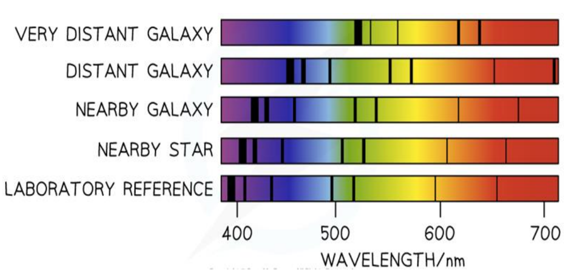
Measuring Galactic Speed & Distance

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 obtained; This equation will not be directly examined but the idea that the velocity of distant objects can be obtained 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.
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:

$$V = H_o d$$

Where:

H_O = 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, H_0 *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

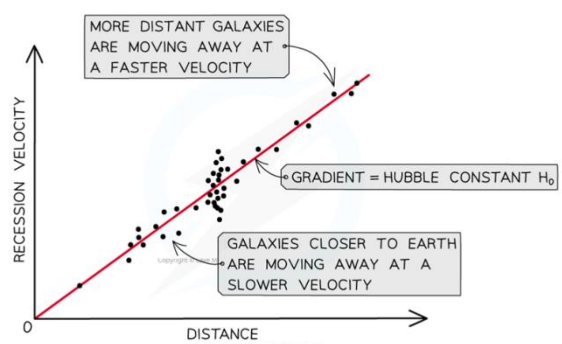
Assessment Tip: Make sure to learn the currently accepted value of the Hubble constant.

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

$V = H_0 d$. 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}

3.8 Satellites and communication

Learning Outcomes

a) Understand what artificial satellites are and how we make use of the min research and in everyday life (u,s)
b) Appreciate the importance of space exploration (u,v/a)

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.

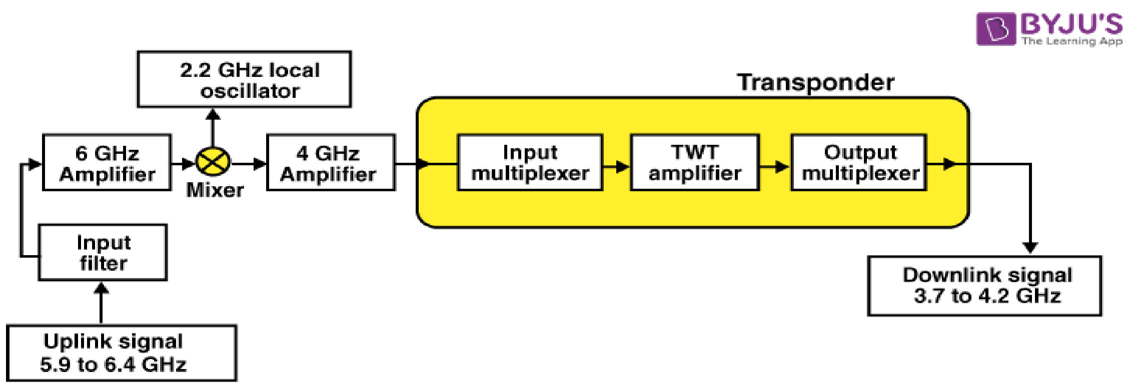
Satellite Communication

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



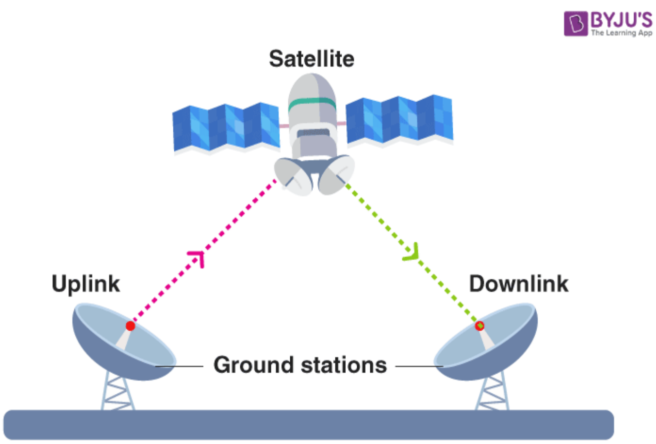
How Satellite Communications Work?

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

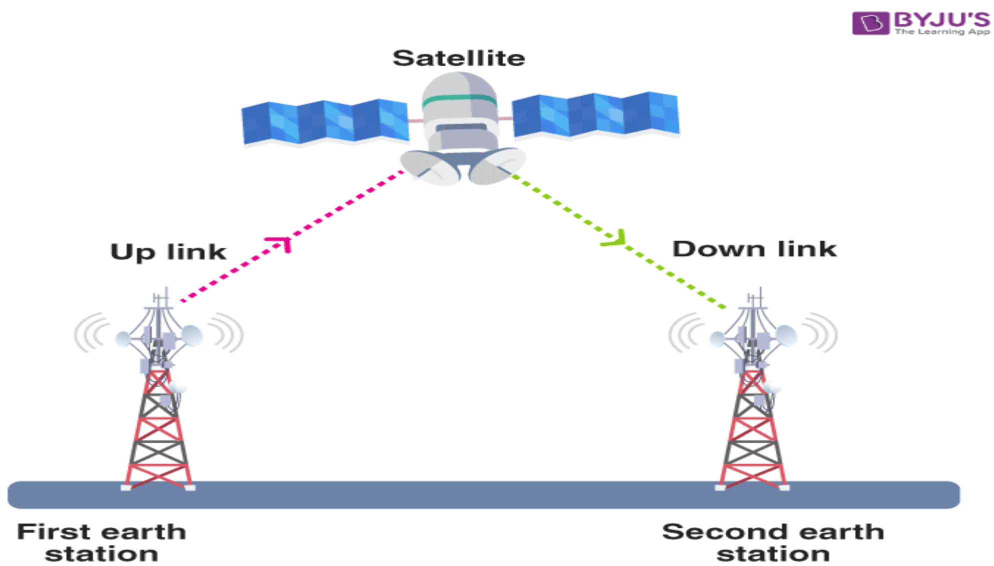
One-way Satellite Communication

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

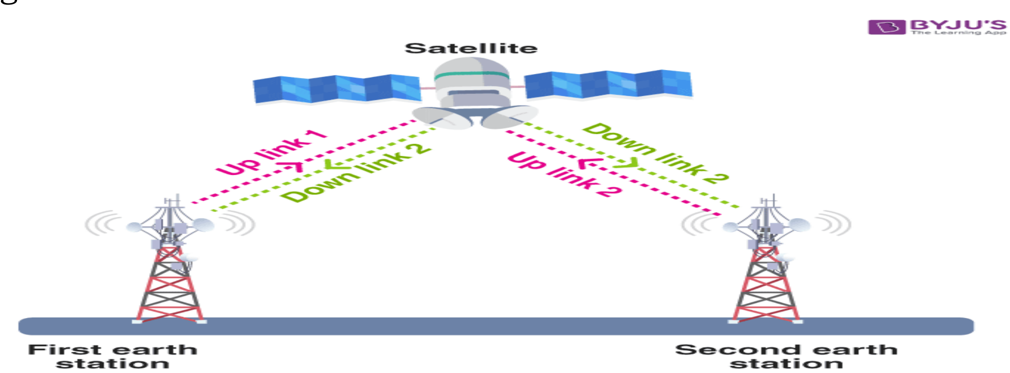
Following is the figure which explains the one-way satellite communication:



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.

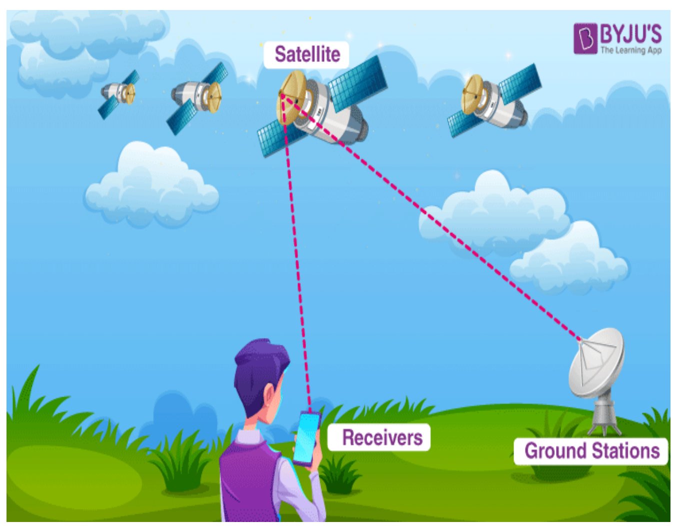
Disadvantages of Satellite Communication

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.

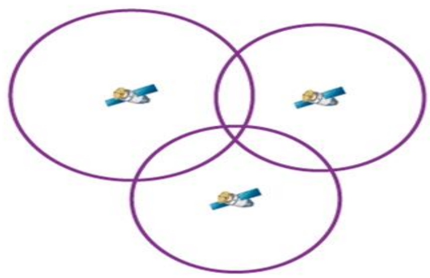
Following are the functionalities of each of these parts:

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 obtained 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.

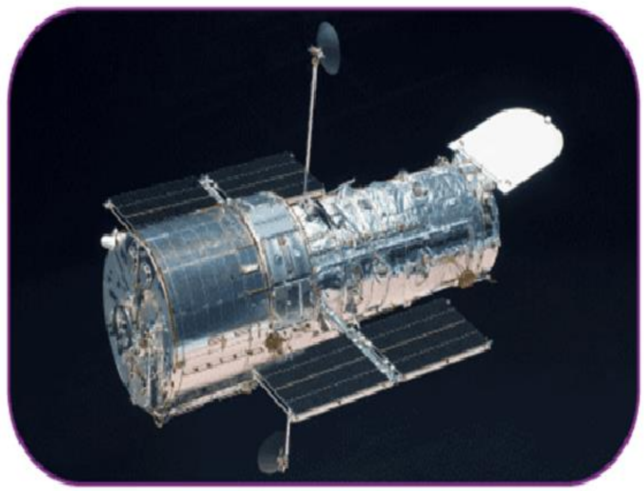
The Hubble Space Telescope

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.



Hubble Space Telescope

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.

Observations of Hubble Space Telescope

International Space Station

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 obtained 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 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

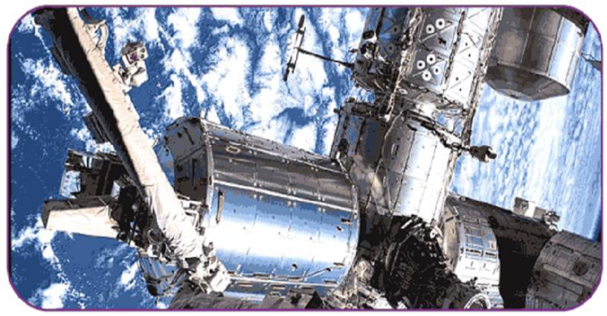
The ultimate goal of the International Space Station is to facilitate long-term space exploration and create useful inventions for the goodness of humanity.

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.

Senior Four

4.1 Introduction to current electricity

Learning Outcomes

a) Understand what e.m.f is (u)
b) Understand that cells convert chemical energy into electrical energy, producing current and also the force needed to create a flow of current in a circuit (u,s)
c) Understand that electric cells are very useful but have their limitations (u,v/a)
d) Understand the nature of electric current, its sources, what makes it flow around circuits and how and it is measured (u,s)
e) Know that some materials are electrical conductors and other are insulators(k)
f) Recognize, understand and apply knowledge of series and parallel circuits (k, u, s,v/a)
g) Appreciate that circuits may be represented as circuit diagrams consisting of an agreed set of symbols to represent components (k, u,s)

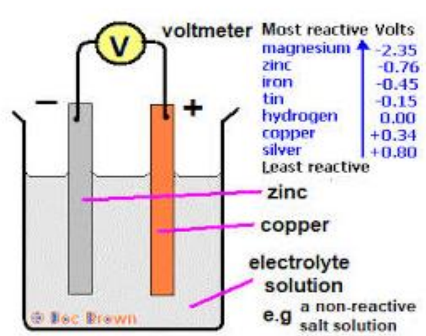
These are devices that can produce electricity by chemical action.

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. The zinc plate slowly dissolves and goes into the solution as zinc ions which displace hydrogen ions to form zinc sulphate.
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.
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 obtained 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.

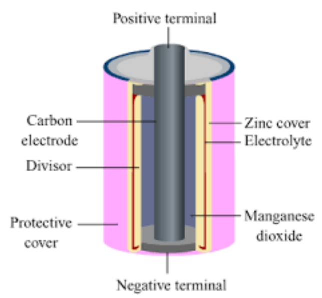
PRIMARY AND SECONDARY CELLS
Primary cell
This is one in which current is produced as a result of an irreversible reactions i.e. cannot be recharged when it runs down e.g. simple cells, dry cells and laclanche cells. Whenever the cell runs out, it implies that all ionized ions in the electrolyte have 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

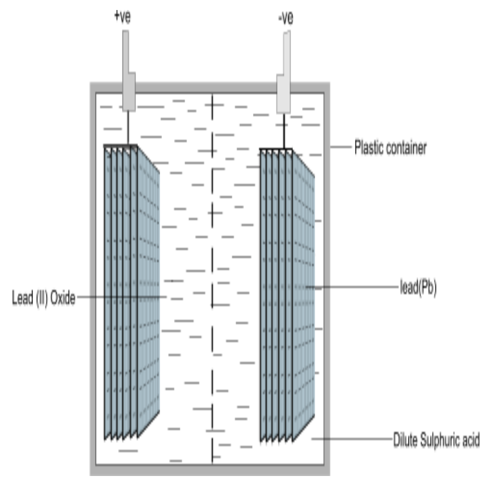
It is used in torches, radios and has an E.M.F of 1.5 volts.



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.

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.

4.2 Voltage, resistance and Ohm's law

Learning Outcomes

a) Understand electrical resistance, how it is measured, its relationship to current and voltage, and the factors that affect it (k, u, s)
b) Know the function and use of a diode, transistor, thermistor, LDR. Led and potentiometer (k,s)

CURRENT ELECTRICITY

Current electricity is the flow of charged particles from one point to another e.g. electrons. Electrical devices which use electricity are called electrical appliances.
Sources of electricity/emf include;
- Batteries
- Generators
- Solar panels/solar energy.
- Wind mills

TERMS USED IN ELECTRICITY;

CHARGE(Q):
This is the quantity of electricity which passes any point in a conductor. The SI unit of charge is a coulomb (C).

ELECTRIC CURRENT (I):
Charges move from one point to another in a given time. This rate of flow is called electric current.
Definition:
Electric current is the rate of flow of charge in a conductor. The SI unit of current is the ampere (A).
Note:
- The time should always be in seconds.
- Current is measured by an instrument called an ammeter.

Definition:
An ampere is the constant current when a charge of 1C flows in a conductor in one second.
OR
An ampere is current which when flowing in two straight parallel wires of infinite length placed one
meter apart in a vacuum produce a force of 2 × 10−7−1 on each of the wires.
But also = implying that = ×
Definition:
A coulomb is the quantity of charge which passes any point of a conductor in one second when a current of one ampere is flowing in the conductor.

Examples:

1. A current of 6A flows for 2 hours in a circuit. Calculate the quantity of electricity that flows in this time.
2. A charge of 2550C flows past a point in a circuit in 25minutes. Find the current flowing.
3. A current of 6mA flows for 2 hours in a circuit. Find the quantity of charge.
4. A charge of 20 kC crosses two sections of a conductor in 1minute. Find the current through the conductor.

POTENTIAL DIFFERENCE (p.d):

This is the work done in joules when one coulomb of charge moves from one point to another in a circuit.

If two points in a conductor are of different electric potentials, then a charge can move from one

point to another and work is said to be done. Potential difference is sometimes referred to as voltage. The instrument used to measure potential difference is a voltmeter.

The SI unit of potential difference is the Volt (V).

Definition:

A volt is the potential difference between two points in a circuit when one joule of work is done to move one coulomb of charge from one point to another.

ELECTROMOTIVE FORCE (emf):

This is the work done in joules when one coulomb of charge moves from one point to another in a circuit in a cell is connected.

The SI unit of emf is the Volt (V).

Sources of emf include; cells, generators, solar cells etc.

ELECTRICAL RESISTANCE (R):

This is the opposition to flow of current in a conductor. The SI unit of resistance is an ohm (Ω).

Definition:

An Ohm is the resistance of a conductor in which a current of 1A flows when a potential difference of one volt is applied across its ends.

INTERNAL RESISTANCE OF A CELL (r):

This is the opposition to flow of current within the cell.

FACTORS THAT AFFECT RESISTANCE OF A CONDUCTOR: (i) Length:

The resistance of a conductor is directly proportional to the length of a conductor (∝ 퐿).

Resistance of a conductor increases when its length increase. Therefore, the shorter the wire, the
lower the resistance and the longer the wire, the higher the resistance.

(ii) Cross-sectional area:
The resistance of a conductor is inversely proportional to its cross-sectional area. (∝ 1).
퐴
Thin wires have a high resistance while thicker wires have a low resistance.

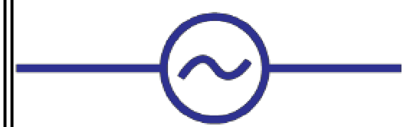
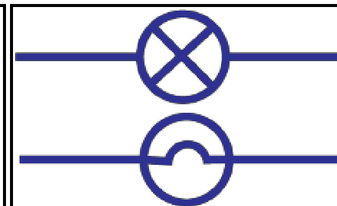
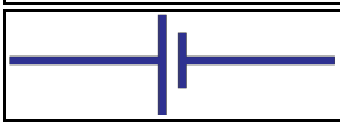
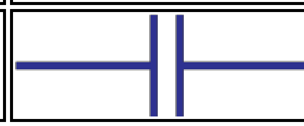
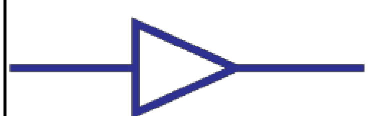
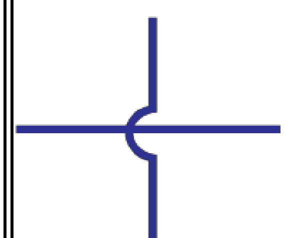
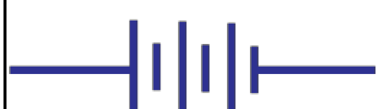
(iii)Temperature:
The resistance of a pure metals like copper increase when their temperatures increase.

(iv)Nature of conductor:
Good conductors like metals have a lower resistance compared to the bad conductors.

Note; The first two factors can be combined as
1. A conductor of length 20m has a cross sectional area of 2 × 10−42. Its resistance is 0.6Ω. Find
the resistivity of the conductor.
2. A wire of cross-sectional area of 0.0022 and length 2m has its resistivity as 1.0 10−7 Ω.
What is its resistance?
ELECTRIC CIRCUIT:
This is the path followed by current. Types of circuits include;
▪ Open circuit: This a circuit in which current is not flowing to the external circuit.
▪ Closed circuit: This is a circuit in which current is flowing to the external circuit.

Note:
A short circuit is a low resistance path for the flow of current.
It occurs when two points in a circuit are directly connected so that current flows through a shorter distance. This increases the flow of current hence damaging the circuit.

ELECTRICAL SYMBOLS IN ELECTRICAL CIRCUITS.

SYMBOL	NAME	SYMBOL
	Standard resistor	G
	Variable resistor (Rheostat)	
	Switch	
	Cell	
	Diode	
	Battery/accumulator	
A	Ammeter	V

OHM'S LAW

It states that current flowing through a metallic conductor is directly proportional to the potential difference across its ends provided temperature and other physical conditions are remain constant.

Examples:
Where R-resistance of conductor.
V-potential difference.
I-current.
1. Calculate the potential difference across a 10Ω resistor carrying a current of 2A.

퐕 = I퐑

2. The voltage across a 2Ω resistor is 4V. What is the current flowing?
3. Find the potential difference across a conductor of resistance 2Ω if the charge of 180C flows for
2 minutes.
4. What voltage is needed to make a current of 0.4A flow through when the appliance has resistance of 20Ω?
5. A current of 4A flows through an electric kettle when the p.d. across it is 8V. Find the resistance.

Experiment to verify ohm's law .
▪ The circuit is connected as shown above.
▪ Switch K is closed and the current flows through the circuit.
▪ Read and record the ammeter and voltmeter readings I and V respectively.
▪ The rheostat is adjusted to obtain several values of I and V and the results are tabulated.
▪ Plot a graph of V against I.
▪ A straight line is obtained showing that potential difference, V is directly proportional to current, I.

L imitation s of oh m's la w :
• The law only applies when the physical conditions of a conductor are constant e.g. temperature.
• The law doesn't apply to semiconductors e.g. diodes and electrolytes.

OHMIC AND NON OHMIC CONDUCTORS

Ohmic conductors:

These are conductors which obey ohm's law. They include; metals e.g. copper, iron. Zinc etc.
When a graph of I against V is plotted, a straight line is obtained.

Non-ohmic conductors:
These are conductors which do not obey ohm's law.
They include; filament lamps, diodes, neon gas etc.
When a graph of I against V is plotted, a non-straight line is obtained.

Graphs of current against voltage for different conductors (characteristic curves):

Ohmic conductor; e.g. copper wire, iron, zinc. I(A) V(V)	Filament lamp; I(A) V(V)
Semi-conductor diode; I(A) V(V)	Vacuum or Thermionic diode; I(A) V(V)
Thermistor or Carbon resistor;	Electrolyte;

<table>
<tr><td>I(A)

V(V)</td><td rowspan="2">e.g. dilute sulphuric acid

I(A)

V(V)</td></tr>
<tr><td>Neon gas;

I(A)

V(V)</td></tr>
</table>

CIRCUITS CONNECTION

Ammeter:
This is an electrical device used to measure current in a physics laboratory.
An ammeter has a very low resistance i.e. Ω
QN: Why is an ammeter constructed with a low resistance.
To allow all the current to be accurately measured without being affected by the resistance. The low resistance ensures that all the current to be measured passes through the ammeter without being opposed/resisted.

The ammeter is always connected in series i.e. it is placed in the path of current.

Ammeter:
This is an electrical device used to measure potential difference or voltage in a physics laboratory. A voltmeter has a very high resistance.

QN: Why is a voltmeter constructed with a very high resistance.
It has a very high resistance so as to draw a very low current from the source thus not affecting the total current in the circuit.

The voltmeter is always connected in parallel with the source of current.

RESISTORS

A resistor is a device which opposes the flow of current in a circuit. In a circuit, resistors are either arranged in series or in parallel.

Types of resistors:

(i) Standard resistors:

These are resistors whose resistances are known e.g. 2Ω, 5Ω, 10Ω etc.

(ii) Variable resistors/Rheostats:

These are resistors whose resistances can be varied by moving a slider.

The amount of current in the circuit can be varied by adjusting the rheostat.

Series arrangement of resistors:

Resistors are said to be in series if they are connected end to end so that the same current passes through them.

Note: In series;

▪ The same amount of current flows through each resistor.

▪ P.d or voltage across each resistor is different.

▪ Total voltage is equal to sum of individual voltages across each resistor.

Consider three resistors , connected in series across a potential difference, V.

Effective resistance

Note:

All electrical appliances e.g. lamps, bulbs etc. connected in series have the same amount of current flowing through them.

Parallel arrangement of resistors:

Resistors are said to be in parallel if they are connected side by side with their adjacent ends joined together at a common point.

Note: In parallel;

▪ P.d across each resistor is the same.

▪ Current flow in the circuit splits and therefore, current through each resistor is different.
▪ Total current is equal to sum of individual currents through each resistor.
Consider three resistors , connected in parallel across a potential difference, V.
Where R is Effective resistance
Note:
For two resistors connected in parallel;
Therefore, effective resistance,

CONNECTION OF CELLS:
Cells provide us with emfs and these emfs can be arranged in series or in parallel.

Series arrangement of cells:
Cells are said to be in series if the positive terminal of one cell is connected to negative terminal of another cell.
The total emf of the cells is equal to the sum of individual emfs.

Consider three cells each of emf, E and internal resistance, r connected in series as shown below.

Parallel arrangement of cells:
Cells are said to be in parallel if the positive terminals of the cells are connected to one point and the negative terminals of cells are connected to another point.
The total emf is equal to one of the emfs of the cell.

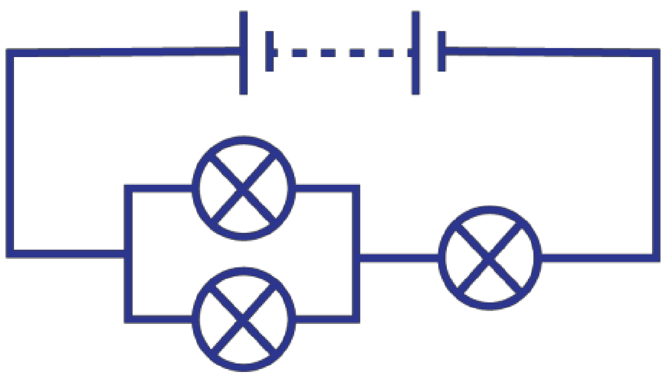
Consider three cells each of emf, E and internal resistance, r connected in series as shown below.
Consider a cell of emf, E and internal resistance, r connected in series to a standard resistor, R.
Terminal p.d lost p.d due to internal resistance

Terminal p.d is the voltage across the terminals of a cell when current is being delivered to an external circuit.
QN: Explain why terminal p.d is less than the actual emf of a cell.
Terminal p.d is always less than the emf because of the opposition to flow of current within a cell i.e. internal resistance.

EXAMPLES:

1. Find the total emf and total internal resistance in the following circuits if each cell has an emf of
1.5V and internal resistance of 1Ω
3. Eight identical cells each of emf 1.5V and internal resistance 0.1Ω are connected in a circuit as
shown below. Find the current flowing.

4. A battery of 4 cells each of emf 1.5V and negligible internal resistance are connected in the
circuit with 3 bulbs each of resistance 0.8Ω. Calculate the current flowing in the circuit.



EXPERIMENT TO DETERMINE INTERNAL RESISTANCE OF A CELL

Method 1: Using a voltmeter and standard resistor
- Measure the emf, E of the cell by connecting the terminals of the cell to the voltmeter.
- Connect a cell in series with a switch, K and a standard resistor, R.
- Connect a voltmeter across the standard resistor as shown below.
- Switch, K is then closed and the voltmeter reading V is noted and recorded.
- The internal resistance, r is got from

Method 2: Using a voltmeter, ammeter and standard resistor
- Measure the emf, E of the cell by connecting the terminals of the cell to the voltmeter.
- Connect a cell in series with a switch, K, an ammeter, A and a standard resistor, R.
- Connect a voltmeter across the standard resistor as shown below.
- Switch, K is then closed and the ammeter and voltmeter readings I and V are noted and recorded.
- The internal resistance, r is got from

ELECTRICAL ENERGY AND POWER

ELECTRICAL ENERGY:
Electrical energy is the work done in moving an electric charge by an electric force. The SI unit of electrical energy is the Joule (J)
This electrical energy is accompanied with a rise in temperature so this energy may be given out as heat energy.
This explains why wires become hot when electricity passes through them.

QN: Explain electrical wires (metals) heat up when electricity passes through them.
As current is switched on, electrons start moving through the wire. Due to resistance of the wire, the electrons are opposed from moving and they collide with the molecules of the wire. They lose some of their kinetic energy to the molecules of the wire which causes a rise in temperature (heat energy).

Simple derivations for work done
ELECTRICAL POWER:
This is the rate of doing work on a charged particle. Th SI unit of electrical power is the Watt (W).

2. How much energy is consumed by a 60W lamp in 10 hours?
CALCULATIONS IN ELECTRICAL CIRCUITS Steps and tips taken;
▪ Find the total or effective resistance in the circuit.
▪ When finding current through a resistor in parallel, first find the potential difference
(voltage) across the parallel connection.
▪ Power dissipated in any resistor is
▪ Power expended in the whole circuit is

EXAMPLES:
1. In the diagram below, a battery of emf 12V and internal resistance 0.6Ω is connected resistors.
Calculate;
(i) Current through the circuit.
(ii) Current through the 4Ω and 6Ω resistor.
(iii)Power dissipated in the 4Ω resistor.
(iv) Power expended in the circuit.

4. A dry cell of emf, E and internal resistance, r drives a current of 0.25A through a resistor of 5.5Ω and also drives a current of 0.3A through a resistor of 4.5Ω as shown in the figures.
Determine the emf, E and internal resistance, r.

COMMERCIAL ELECTRICITY
In Uganda, electricity is sold by electricity boards such as UMEME. They use our meters to estimate the electrical energy consumed
The energy consumed is measured in kilowatt hours (kWh).

Definition:
A kilowatt hour is the amount of electrical energy consumed by a device of power 1000W in one hour.
Calculations for cost of electricity:

NOTE:
All electrical appliances are marked (rated) showing the power rating in Watts and voltage in Volts. E.g.
An electrical appliance rated 240V, 60W means that the appliance supplies or consumes
60J every second when connected to a 240V mains supply.

EXAMPLES:
1. How much will it cost to run four bulbs rated at 40W each for 2 days, if the cost of each unit of electricity is shs. 30.?
2. Find the cost to run two bulbs rated at 60W each and an electric iron rated at 120W for 35 minutes, if the unit is 415 shs.

3. An electrical heater is rated at 3000W, 240V.
a) What is meant by the statement. b) Calculate;
(i). Current and resistance of the heater.
(ii). Total number of units it consumes in 1 1 hours.
2
(iii). The cost of electricity if each unit costs 9,000 shs after using the heater for
3
hours every day for 10 days.

(a) An electrical heater supplies or consumes 3000J every second when connected to a 240V mains supply.

4. Jane paid an electricity bill of 1800shs after using two identical bulbs for 2 hours every day for
10 days at a cost of 600shs per unit. Determine the power consumption by each of the bulbs.

EXERCISE:
1. Find the cost of running five 60W lamps and four 100W lamps for 8 hours if the electrical energy costs 5shs per unit.

2. Mr. Ssekwe uses 3 kettles of 800W each, a flat iron of 1000W, 3 bulbs of 60W each and 4 bulbs of 75W each. If they are used for 3hours every day for 30 days and one unit of electricity costs
200shs, find the total cost of running the appliances.

3. A television is rated 240V, 60W.
(a) What do you understand by the statement above. (b) Calculate the current flowing through the TV.
(c) Calculate the resistance of the television.
(d) Calculate the cost of running the television for 600 minutes if the unit cost is 60shs.

GENERATION AND TRANSMISSION OF ELECTRICITY (a) Generation of electricity:
Electricity is generated at power stations by using coal, nuclear reactions, wind, sun, running water etc.

(b) Transmission of electricity:
Electricity generated at power stations is stepped up to higher voltages before transmission using step transformers.
The power transmitted is usually alternating current and it is stepped down as it reaches factories, industries, towns and homes using step down transformers.
Transmission can either be overhead or underground.

How power losses are reduced during transmission of electricity:
▪ Electricity is transmitted at high voltages to reduce power loss due to the heating effect in the transmission cables.
▪ The transmission cables are made thick to reduce its resistance hence minimizing power loss.

(c) House wiring (domestic electrical installation):
Electricity is connected in a house by thick cables called the mains from the electricity poles to the meter box or fuse box and then to the main distribution box. From here electricity is supplied to the electrical appliances.
The electricity supply cables in a house consist of the following wires.

TYPE OF WIRE	COLOUR	USE
Live wire	Red or brown	It carries current to the appliance.
Neutral wire	Blue or black	It completes the circuit. Thus, it car source.
Earth wire	Yellow or green or yellow with green stripes	It is connected to the metal case of alternative path for stray current in live.

When wiring a house, the following should be included in the circuits.

DEVICE NAME	CONNECTION AND USE
(i) Switch	▪ It controls the flow of current in the circuit. ▪ It I connected to the live wire such that it whenever needed.
(ii) Fuse	▪ It contains a thin wire of a very low melting ▪ The thin wire melts whenever current excee ▪ It is connected to the live wire.
(iii) Sockets	▪ These are power points usually put on the w ▪ They have three holes leading to the live wi wire.

Precautions taken when wiring a house:
▪ The right colour codes must be followed i.e. red for live wire, black for neutral wire and yellow for earth wire.
▪ All switches should be connected to the live wire.
▪ Wires should be insulated.
▪ Keep hands dry when dealing with electricity.
▪ Earthing should always be done to prevent electrical shocks in case an appliance gets a fault.

LIGHT CIRCUITS
Electrical appliances e.g. bulbs and lamps are usually connected in parallel with the mains supply. The switches of these lamps are connected to the live wire. The neutral wire completes the circuit.
Advantages of connecting lamps in parallel:
➢ Lamps have the same voltage as the source.
➢ If one lamp gets a fault, the other lamps continue working.
➢ It enables switching on and off of the lamps independently (i.e. each lamp can have its own switch.)

Mode of operation of a filament lamp:
When switched on, the coiled tungsten filament is heated and it becomes white hot thus emitting light.
The higher the temperature of the filament, the greater the light given off.

Note:
• The filament is made of tungsten because tungsten has a high melting point. Therefore, it can't
melt easily when heated to very high temperatures.
• The filament is coiled to reduce the space it occupies in the glass bulb thus reducing heat through convection.
• The glass bulb contains inert gases (i.e. Argon/Nitrogen) at low pressure to reduce evaporation of the filament otherwise it would condense on the bulb and blacken it.

FLUORESCENT LAMPS (DISCHARGE LAMPS)
Fluorescent tube is a gas discharge lamp that uses electricity to energize or excite mercury vapour. It has electrodes at the ends and the inside wall is coated with fluorescent substance e.g. phosphor.

When switched on, mercury vapour is excited/energized and it emits ultra-violet radiations. The radiations strike the fluorescent substance causing it to produce visible light.

NB: Fluorescent substance is a substance that gives off light when radiations fall on it.
Advantages of fluorescent tubes/lamps over filament lamps:
• They are long lasting.
• They don't produce much heat.
• They consume less power.

Disadvantages of fluorescent lamps:
• They are expensive.
• They require high installation costs.
• They may not start when the supply voltage is low.

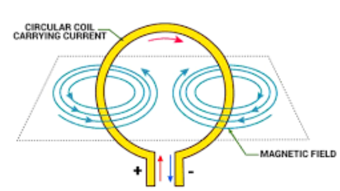
4.3 Electromagnetic effects

Learning Outcomes

a) Investigate the behaviour of magnets and magnetic fields(s)
b) Understand that a current carrying conductor produces a magnetic field that can be detected. (u,s)
c) Understand the application of electromagnets in devices such as motors, bells, and generators (u,s)
d) Understand the difference between a.c. and d.c (u)
e) Know how a.c. and d.c. can be inter-converted using rectifiers and inverters (k)
f) Understand the action and applications of transformers (u, s,v/a)

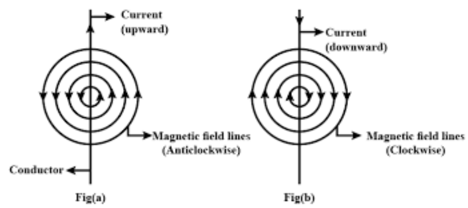
ELECTROMAGNETISM

Electromagnetism is a fundamental branch of physics that studies the interactions between electric charges and magnetic fields. It combines the principles of electricity and magnetism into a single theory, leading to the understanding of how electric currents



produce magnetic fields and how changing magnetic fields can generate electric currents.

Magnetic field due to a conductor (wire) carrying current



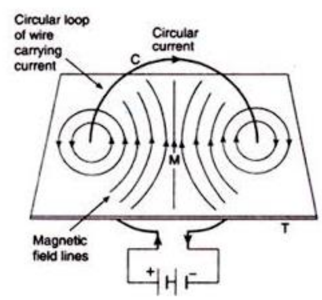
When current flows through a wire carrying current, a magnetic field is created around the wire.

(a)Field due to current moving out of the cardboard/paper

(b). Field due to a straight wire carrying current into a cardboard

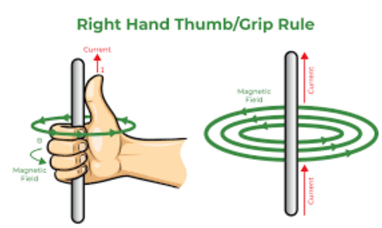
(c)Field due to a current carrying circular coil

The field lines at the centre of the coil are straight and at right angles to the plane of the coil.



Determination of the direction of the field due to a current carrying conductor

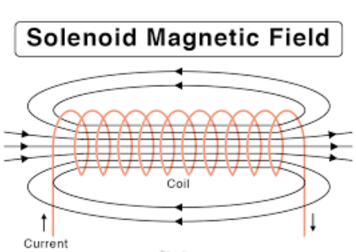
This can be done by the 'right hand grip rule'. *It states that imagine the wire as grasped in the right hand, with the thumb pointing along the wire in the direction of current, then the fingers point in the direction of the field due to the conductor.*



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*

Field due to a solenoid



How to increase the strength of the field in a solenoid

- Increasing the number of turns
- Increasing the current flowing through the solenoid
- Using low resistance copper wires in windings

Electromagnets

Electromagnets:
An electromagnet is a type of magnet in which the magnetic field is produced by an electric current. Unlike permanent magnets, electromagnets can be turned on and off and their strength can be varied by changing the current flowing through them.

How Electromagnets Work
The fundamental principle behind electromagnets is Ampère's Law, which states that an electric current flowing through a conductor produces a magnetic field around it.

Components:
Coil of Wire: Usually made of copper or aluminum, the wire is wound into a coil shape, which enhances the magnetic field when current flows through it.
Core Material: To amplify the magnetic field, the coil is often wrapped around a ferromagnetic core (commonly iron). The core becomes magnetized when current flows through the coil, creating a stronger magnetic field.
Power Source: An electric power source (like a battery or power supply) provides the current needed to generate the magnetic field.
Magnetic Field Creation:
When electric current flows through the coil, a magnetic field is generated around it. The direction of the magnetic field can be determined using the right-hand rule: if you wrap your right hand around the coil with your thumb pointing in the direction of the current, your fingers will curl in the direction of the magnetic field lines.

Characteristics of Electromagnets
Magnetic Field Strength:
The strength of an electromagnet's magnetic field can be influenced by several factors:
Number of Turns in the Coil: More turns increase the magnetic field strength.
Amount of Current: Higher current increases the magnetic field.

Core Material: Different materials have varying magnetic permeability. Ferromagnetic materials like iron greatly enhance the magnetic field compared to air or other non-magnetic materials.

Direction of the Magnetic Field:
The magnetic field direction can be reversed by reversing the direction of the current flow through the coil. This is particularly useful in applications like electric motors and solenoids.

Temporary Nature:
Electromagnets are temporary magnets. When the electric current is turned off, the magnetic field disappears, and the core returns to its non-magnetic state.

Types of Electromagnets

Solenoid: A coil of wire with a long length compared to its diameter. When current passes through it, it creates a uniform magnetic field inside the coil.

Relay: A type of electromagnet used as a switch. When the current flows through the coil, it activates a mechanical switch that opens or closes another circuit.

Electromagnetic Crane: Used in industrial applications to lift and move heavy metal objects. The electromagnet can be turned on and off to control the lifting and dropping of materials.

Magnetic Levitation Devices: Use electromagnets to create a magnetic field that allows objects to float, reducing friction and allowing for high-speed transportation (e.g., maglev trains).

Applications of Electromagnets

Industrial Applications:
Crane Systems: Used to lift and transport heavy ferromagnetic materials ***in*** warehouses and factories.

Magnetic Separation: Employed in recycling plants to separate ferromagnetic materials from non-magnetic waste.

Consumer Electronics:
Electric Motors: Electromagnets are crucial in converting electrical energy into mechanical energy.

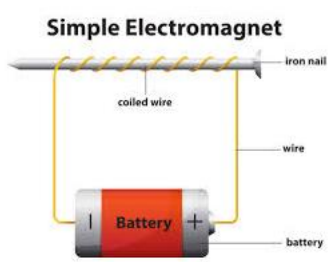
Speakers: Utilize electromagnets to convert electrical signals into sound by vibrating a diaphragm.

Medical Applications:
MRI Machines: Use powerful electromagnets to generate strong magnetic fields for imaging internal structures of the body.

Research Applications:
Particle Accelerators: Electromagnets are used to steer and focus particle beams in physics experiments.

Advantages and Disadvantages of Electromagnets
Advantages:
Control: The ability to easily turn the magnetic field on and off.
Adjustable Strength: The magnetic field strength can be varied by changing the current.
Compact Design: Can be made smaller than traditional permanent magnets while providing significant strength.

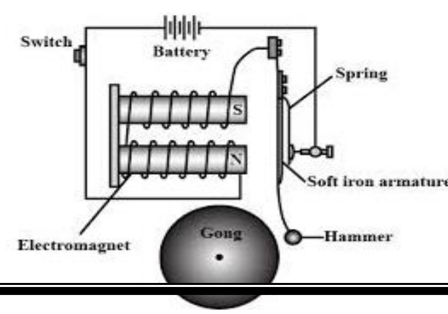
Disadvantages:
Power Dependence: Requires a continuous power supply to maintain the magnetic field.
Heat Generation: High current can lead to heating of the coil, which may require cooling mechanisms in high-power applications.



Construction of a Simple Electromagnet
Materials Needed:
- Insulated copper wire
- Iron nail (or any ferromagnetic core)
- Battery (DC source)
- Electrical tape (optional)

Procedure:
Wrap the Wire: Take the insulated copper wire and tightly wrap it around the iron nail, leaving some wire at both ends for connections. The more turns, the stronger the electromagnet.
Connect to Power Source: Strip the ends of the wire and connect them to the terminals of the battery. Ensure a secure connection.
Test the Electromagnet: Bring the electromagnet close to small metal objects (like paper clips) to see if they are attracted. Disconnect the battery to turn off the electromagnet.

Conclusion
Electromagnets are vital components in many modern technologies, providing controllable magnetic fields for various applications. Their ability to turn on and off, along with adjustable strength, makes



them invaluable in industries ranging from manufacturing to medicine.

The electric bell

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

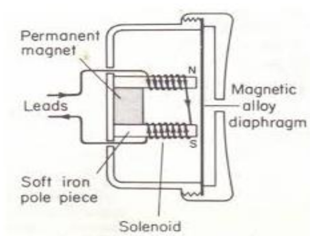


Fig. 36.14. Telephone receiver

The telephone receiver

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

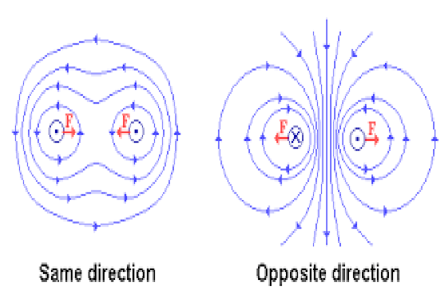
This magnetizes the electromagnet which pulls the diaphragm towards itself at varying distances depending on the strength of the current through the electromagnet from the microphone

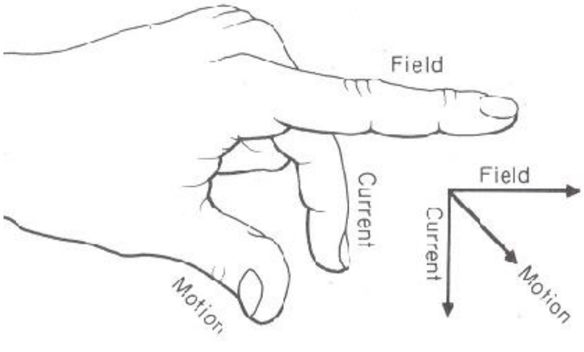
The diaphragm moves in and out and produces sound waves at the same frequency as those that entered the microphone

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)

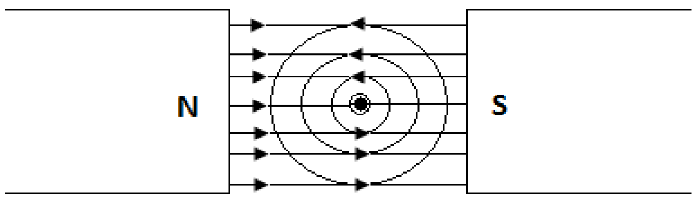




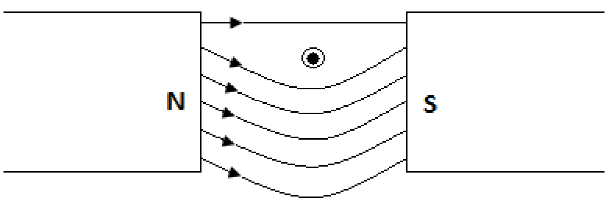
Fleming's left-hand rule (motor rule)

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

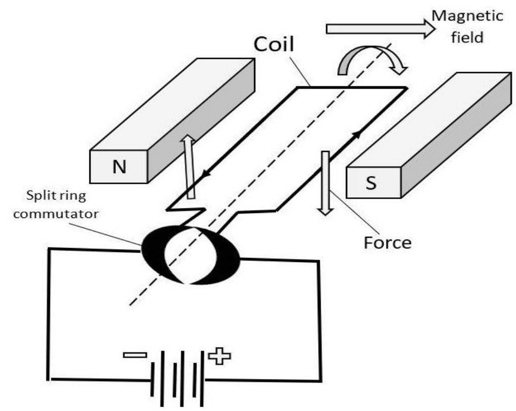
The effect of the magnetic field on a current carrying conductor is referred to as ***motor effect***

Application of the motor effect

- Simple d.c motor
- Moving coil galvanometer
- Moving coil loud speaker.

The simple D.C motor

A D.C. motor (Direct Current motor) is an electrical device that converts electrical energy from direct current into mechanical energy. It operates based on the principles of electromagnetism and is widely used in various applications, including toys, tools, and industrial machinery.



Basic Principles of Operation

The basic operation of a D.C. motor is founded on two main principles:

Electromagnetic Induction:

A current-carrying conductor placed in a magnetic field experiences a force. This principle is described by the Lorentz force law.

The Interaction of Magnetic Fields: The magnetic field produced by the current in the motor interacts with the external magnetic field (from permanent magnets or field windings), causing motion.

Components of a Simple D.C. Motor

A simple D.C. motor consists of several key components:

Stator: The stationary part of the motor that produces a magnetic field. This can be created using permanent magnets or field coils.

Rotor (Armature): The rotating part of the motor, typically a coil of wire wound around a core. When current flows through the coil, it generates a magnetic field.

Commutator: A switch mechanism that reverses the direction of current through the rotor windings as the motor turns. This ensures that the torque on the rotor remains in the same direction.

Brushes: Conductive materials (usually carbon) that maintain electrical contact with the commutator while allowing it to rotate.

Power Source: Provides the direct current needed for operation, such as a battery or DC power supply.

Working Principle

- When the D.C. motor is connected to a power source, current flows through the brushes into the commutator and then into the rotor windings.
- The current flowing through the rotor creates a magnetic field around the rotor. This field interacts with the magnetic field of the stator (from the permanent magnets or field coils).
- The interaction between the rotor's magnetic field and the stator's magnetic field produces a torque on the rotor, causing it to rotate.
- As the rotor turns, the commutator periodically reverses the direction of the current in the rotor windings. This reversal ensures that the magnetic forces continue to push the rotor in the same direction, allowing it to keep spinning.
- The rotor continues to spin as long as current is supplied. The speed of the motor can be controlled by varying the voltage or current supplied.

Characteristics of a Simple D.C. Motor

Direction of Rotation: The direction can be reversed by swapping the polarity of the power supply or by reversing the connections to the brushes.

Speed Control: The speed of the motor can be controlled by adjusting the voltage supplied. Higher voltage results in higher speed.

Torque: The motor produces torque that is proportional to the current. Higher current results in greater torque.

Applications of D.C. Motors

- D.C. motors are used in a wide range of applications due to their simplicity and ease of control:
- Small Appliances: Fans, pumps, and household devices.
- Robotics: For movement and actuation in robotic arms and mobile robots.
- Automotive: Powering windshield wipers, electric windows, and seat adjustments.
- Industrial Equipment: Used in conveyor belts, hoists, and machine tools.

Advantages and Disadvantages

Advantages:

- Simplicity: Easy to construct and control.

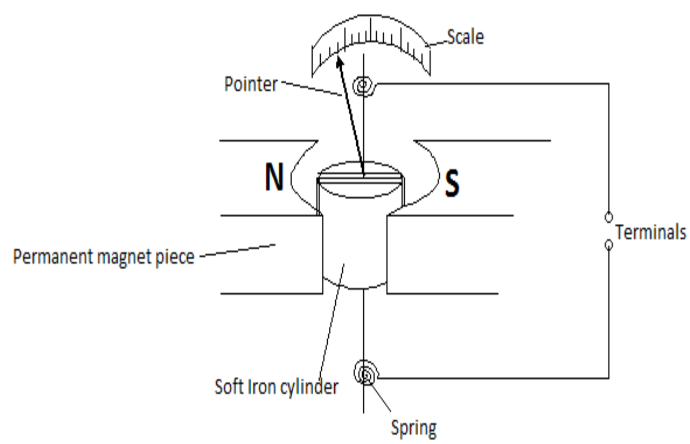
- Speed Control: Easily adjustable speed and direction.
- High Starting Torque: D.C. motors provide high torque from a standstill.

Disadvantages:

- Wear and Tear: Brushes and commutators can wear out over time, requiring maintenance.
- Limited Efficiency: Compared to some other motor types, D.C. motors can be less efficient due to losses in the brushes and commutator.

A simple D.C. motor is an essential device that converts electrical energy into mechanical energy using the principles of electromagnetism. Its straightforward design, ease of control, and versatility make it a crucial component in many everyday applications.

The moving coil Galvanometer



A moving coil galvanometer is an electromechanical instrument used to detect and measure small electric currents. It operates based on the principle of electromagnetism and provides a visual indication of current flow through a pointer and scale.

Basic Components of a Moving Coil Galvanometer

Coil: A loop or series of loops of wire (usually copper) wound around a soft iron core. The coil is free to rotate and is situated in a magnetic field.

Magnetic Field: Provided by permanent magnets, which create a uniform magnetic field in which the coil operates.

Pivot: The coil is mounted on a pivot or bearing that allows it to rotate freely.

Pointer: Attached to the coil, it moves over a graduated scale to indicate the current measurement.

Spring or Damping Mechanism: A spring or air damping system provides a restoring torque to bring the coil back to its original position when the current is removed.

Terminals: Points of connection for the electric circuit, allowing current to flow through the coil.

Principle of Operation

The operation of a moving coil galvanometer is based on Ampère's Law, which states that a current-carrying conductor in a magnetic field experiences a force.

When a current flows through the coil, it generates a magnetic field around it. The direction of this field is determined by the right-hand rule.
The magnetic field of the coil interacts with the magnetic field produced by the permanent magnets. This interaction exerts a torque on the coil.
The torque causes the coil to rotate. The angle of rotation is proportional to the current flowing through the coil. As the coil turns, the pointer attached to it moves across the scale.
As the coil moves, the spring (or damping mechanism) applies a restoring force that opposes the rotation. This force helps return the coil to its original position when the current is removed.
The angle of deflection of the pointer is calibrated to correspond to the magnitude of the current flowing through the coil. The greater the current, the larger the angle of deflection.

Scale Calibration
The scale of the galvanometer is calibrated to provide direct readings of current. The deflection can be linear or nonlinear, depending on the design and the range of currents being measured.
For precise measurements, the galvanometer may be calibrated using known current values.

Sensitivity and Range
Sensitivity: Moving coil galvanometers are sensitive devices, capable of detecting small currents due to their lightweight coils and strong magnetic fields.
Range: The range of current that can be measured can be expanded by using shunt resistors, which divert some of the current around the galvanometer. This allows the instrument to measure higher currents without damage.

Applications
Current Measurement: Used in laboratories for measuring small currents in circuits.
Detection of Electrical Faults: Helpful in identifying faulty connections or components.
Analog Meters: Employed in various analog measuring devices, such as ammeters and voltmeters.

Advantages and Disadvantages

Advantages:

High Sensitivity: Capable of detecting very small currents.

Analog Indication: Provides continuous readings, making it easy to observe changes in current.

Disadvantages:

Limited Range: Requires shunt resistors for measuring higher currents.

Mechanical Wear: The moving parts can wear out over time, leading to inaccuracies.

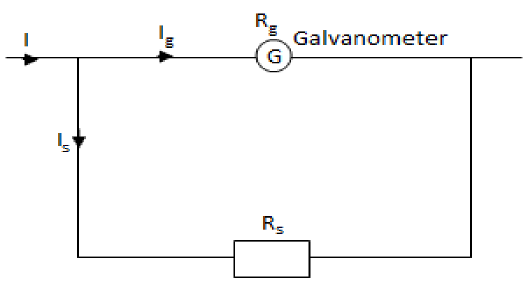
A moving coil galvanometer is a fundamental instrument used for measuring electric current through the interaction of a magnetic field and a current-carrying coil. Its design allows for high sensitivity and reliable measurements, making it a valuable tool in both laboratory and practical applications.

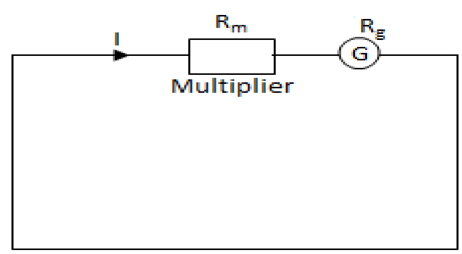
How to increase the sensitivity of the galvanometer

- 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

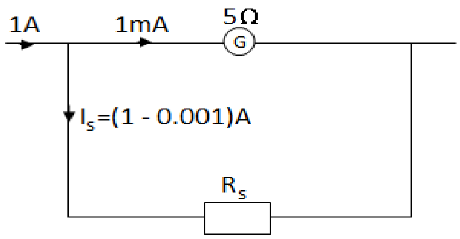
This is done by connecting a resistor of low value called a shunt in parallel with the galvanometer





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 the voltage across the galvanometer, is the voltage across the shunt

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

Activity. 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

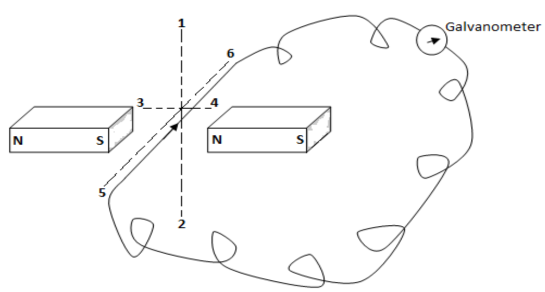
Activity

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

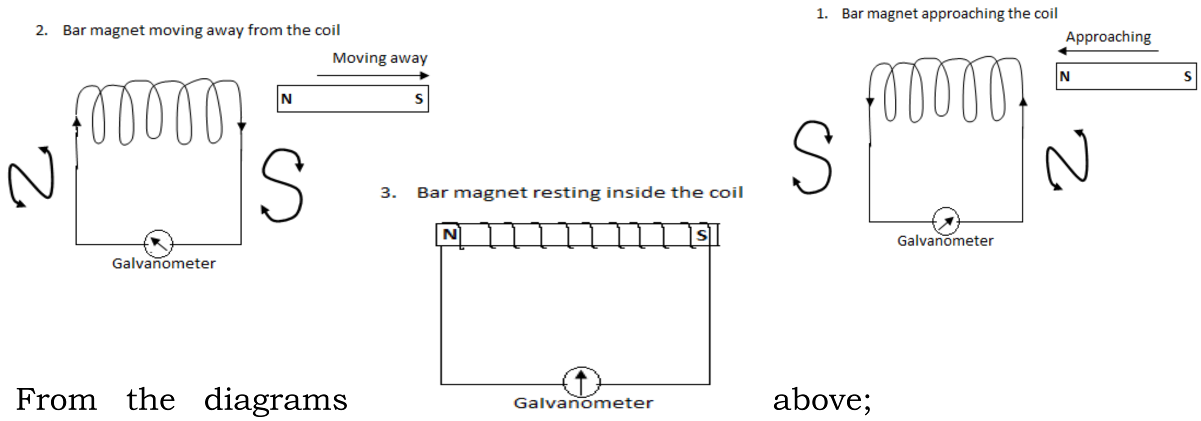
When the conductor is moved in other directions 3, 4, 5 and 6, there will be no deflection in the galvanometer since there will be no cutting in the magnetic field

Laws of electromagnetic induction

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

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



From the diagrams above;

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

1. 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
2. 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

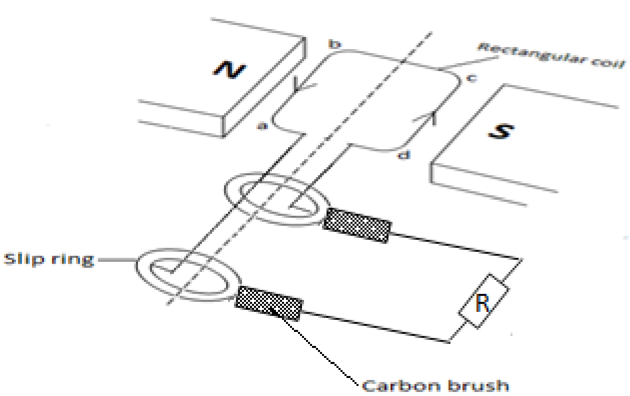
The simple A.C generator (Dynamo)

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

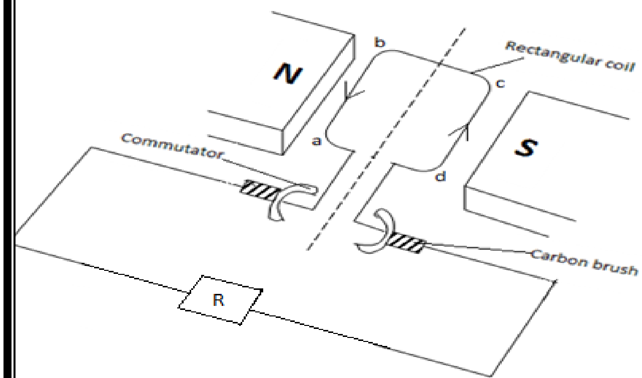


Mode of operation

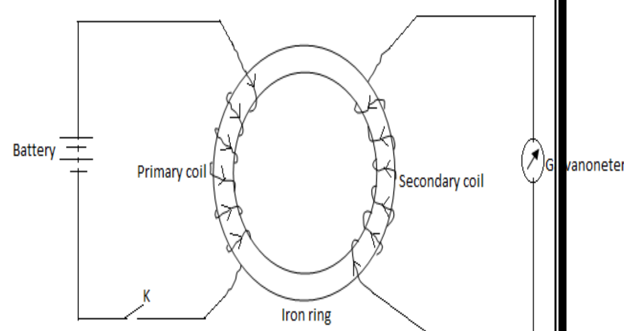
When the coil is rotates in the magnetic field, the field linking it changes

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.



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.

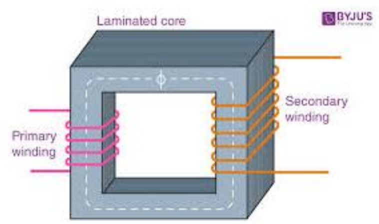
When switch K is closed, the galvanometer deflects momentarily and when it is opened, it deflects momentarily in the opposite direction

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

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

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.

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.

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

Activity

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

4.4 Electric energy distribution and consumption

Learning Outcomes

a) Understand the distribution of electricity from the source to consumer units(u)
b) Understand the energy transformations in common domestic electrical devices and how energy can be saved(u)
c) Understand how to use mains electricity safely and know the insulation colour codes used in domestic wiring (u, k,s)
d) Know the dangers of mains electricity and understand how these may be minimised by safety devices, and by sensible precautions (k, u,v/a)
e) Know how to read a domestic electricity meter and its significance (k, u,s)
f) Appreciate the importance of the use of energy saving appliances (u, s,v/a)

CURRENT ELECTRICITY

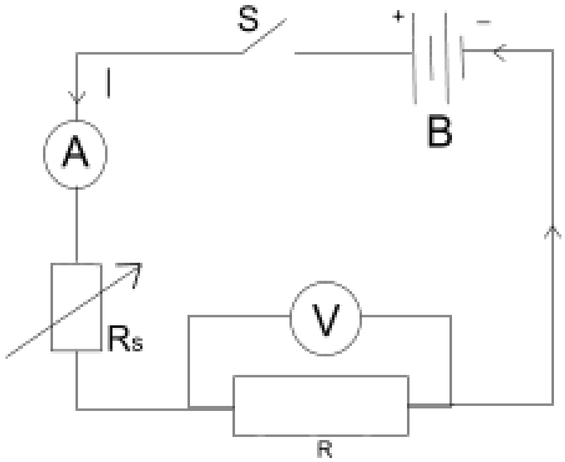
Current is the rate of flow of electric charge. i.e.
Charge flows in the direction opposite to the conventional flow of current.
SI unit of current is Amperes (A)
SI unit of charge is coulombs (C)

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

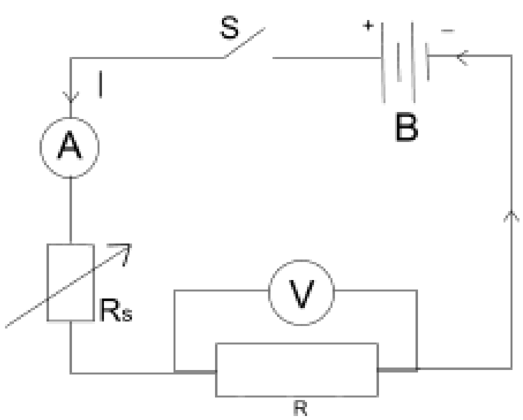
It is the sum of all p.ds across all various components of a circuit in which the cell is connected including the p.d required to drive current through the cell itself. S.I unit is **volts (v).**

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



Procedure

- Connect the resistor R in series with the ammeter and the DC power supply.
- Connect the voltmeter in parallel across the resistor to measure the voltage.
- Ensure that all connections are tight and accurate.
- Switch on the DC power supply and set it to a low voltage (e.g., 1V). Ensure that the power supply is capable of varying the voltage.
- Close the switch and allow the current to flow through the circuit.
- Use the ammeter to measure the current III flowing through the resistor.
- Use the voltmeter to measure the voltage V across the resistor.

- Record the voltage V and the corresponding current I in a table.
- Gradually increase the voltage in small steps (e.g., 1V, 2V, 3V, etc.), each time recording the corresponding current flowing through the resistor.
- For accuracy, repeat the measurements for each voltage step two or three times and calculate the average current for each voltage.
- For each voltage and current reading, calculate the resistance R using Ohm's law formula: $R = \frac{V}{I}$
- The calculated value of R should remain approximately constant if the conductor follows Ohm's law.
- The results in the table are then used to plot a graph of V against I.
- 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.

RESISTANCE AND RESISTORS

Resistance is the opposition to the flow of current. S.I unit is ohms (Ω).

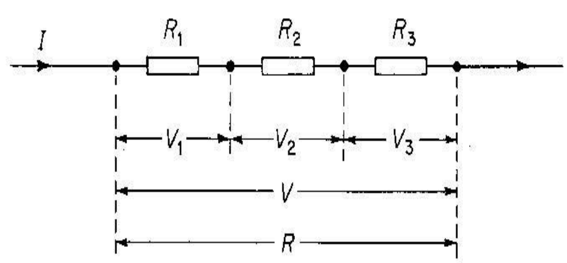
Definition of an ohm

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

Series and Parallel Circuits in Electricity



In electrical systems, components like resistors, capacitors, and inductors can be connected in various ways to control current and voltage. The two primary ways of connecting electrical components are series and parallel circuits. Each configuration affects the behavior of the circuit differently in terms of current, voltage, and resistance.

Series Circuits

In a series circuit, all components are connected end-to-end, forming a single path for the current to flow.

Characteristics of a Series Circuit

Current: The same current flows through all components because there is only one path for the current. $I_{total}=I_1=I_2=I_3=\cdots=I_n$. The current remains constant throughout the circuit.

Voltage: The total voltage across the circuit is the sum of the voltages across each individual component (resistor, capacitor, etc.). Each component experiences a voltage drop proportional to its resistance or impedance.

$V_{total}=V_{1+}V_2+V_3+\cdots+V_n$. This is known as voltage division.

Resistance: The total or equivalent resistance of a series circuit is the sum of the resistances of all individual components. $R_{total}=R_1+R_2+R_3+\cdots+R_n$

More resistors in series increase the overall resistance of the circuit, thus reducing the current (Ohm's Law: I=VR).

Example:

Suppose you have three resistors connected in series: $R_1=2\Omega,R_2=3\Omega,R_3 = 5\ \Omega$, with a battery providing 10V across the circuit.

Total resistance: $R_{total}=2\Omega+3\Omega+5\Omega=10\Omega$.

Current through the circuit: $I = \frac{V}{R_{total}} = \frac{10}{10}$=1A. The same 1A current flows through each resistor.

Voltage drop across each resistor: $V_1 = IR_1 = 1Ax2\Omega = 2V, V_2 = IR_2 = 1Ax3\Omega = 3V, V_3 = IR_3 = 1Ax5\Omega = 5V$. The sum of these voltage drops equals the total voltage of the battery (10V).

Parallel Circuits

In a parallel circuit, components are connected across the same two points, creating multiple paths for current to flow.

Characteristics of a Parallel Circuit

Current: The total current in the circuit is the sum of the currents flowing through each parallel branch. Each branch can carry a different current depending on its resistance. $I_{total}=I_1+I_2+I_3+\cdots+I_n$. This is known as **current division.**

Voltage: The voltage across each component in a parallel circuit is the same, regardless of the resistance in each branch. $V_{total}=V_1=V_2=V_3=\cdots=V_n$

Resistance: The total resistance of a parallel circuit is found using the reciprocal sum of the individual resistances. Adding more resistors in parallel decreases the overall resistance of the circuit. $\frac{1}{R_{total}}=\frac{1}{R_1}+\frac{1}{R_2}+\frac{1}{R_3}+\cdots+\frac{1}{R_n}$

Alternatively, for two resistors, the total resistance can be calculated as:

$$\boldsymbol{R=\frac{Product\ of\ two\ resistors}{sum\ of\ two\ resistors}=\frac{R_1R_2}{R_1+R_2}}$$

Applications of Series and Parallel Circuits

Series Circuits:

Commonly used in simple lighting circuits (like string lights), where the failure of one bulb breaks the circuit and causes all bulbs to go out.
Used in voltage dividers to reduce voltage levels in circuits,
A break in any component stops the entire circuit from functioning.

Parallel Circuits:

Common in household electrical wiring, ensuring that each appliance receives the same voltage and can operate independently,
Used in battery banks to increase current capacity while maintaining the same voltage.
A failure in one branch does not affect the operation of other branches, allowing the circuit to continue functioning.

Differences between Series and Parallel Circuits

Feature	Series Circuit	Parallel Circuit
Current	Same current flows through all components	Current divides among the branches
Voltage	Voltage divides among components	Same voltage across each component
Resistance	Total resistance is the sum of resistors	Total resistance is less than any individual resistor
Circuit Break	A break stops the entire circuit	A break in one branch doesn't affect others
Applications	Simple circuits, voltage dividers	Household wiring, independent loads

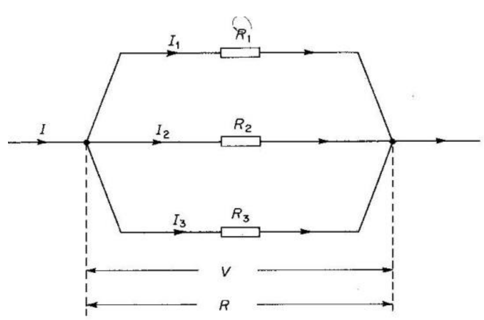
Practical Considerations

Combining Series and Parallel Circuits: Often in real-world applications, circuits are neither purely series nor purely parallel but a combination of both. Understanding how to calculate current, voltage, and resistance in these complex circuits is crucial for electrical engineers and technicians.

Troubleshooting: When diagnosing electrical circuits, knowing whether components are in series or parallel can help identify problems like open circuits or short circuits, and calculate missing values such as voltage drops or current.

In series connection

Consider three resistors of resistance R_1, R_2, R_3 connected end to end as shown.



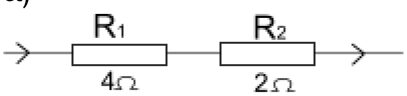
Applications but no Proving

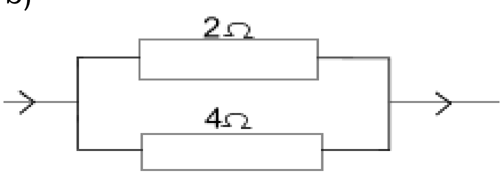
Effective resistance in series is the sum of resistances

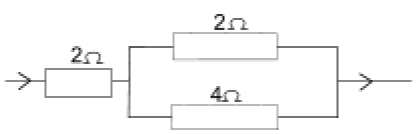
Effective resistance is greater than the greatest resistance

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,
Effective resistance is smaller than the smallest resistance in parallel
Note:
For two resistors in parallel
a)


b)


c)


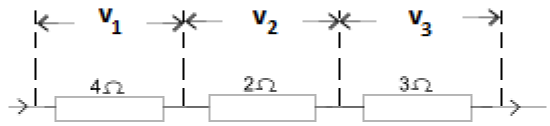
Effective resistance = R_P = = 0.8Ω

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

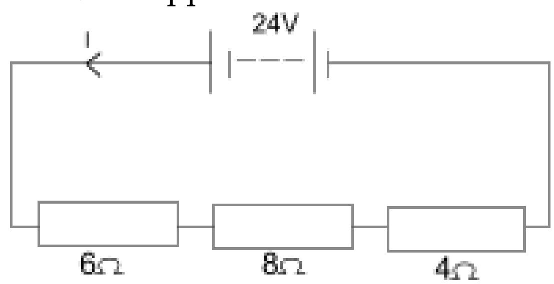


Calculate the potential difference across each resistor

TERMINAL p.d

It is the p.d across the terminals of the cell when the cell is producing current in a resistor. Also, 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



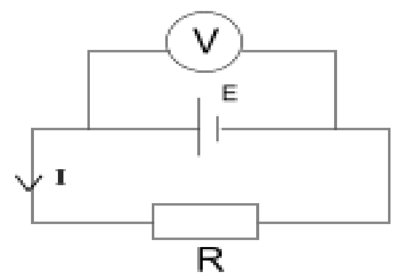
Calculate

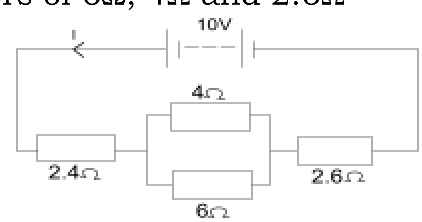
i) The effective resistance

ii) Total current through the circuit

iii) P.d across the 8Ω resistor

3. A battery of E.M.F 10 volts and negligible internal resistance is connected across resistors of 6Ω, 4Ω and 2.6Ω



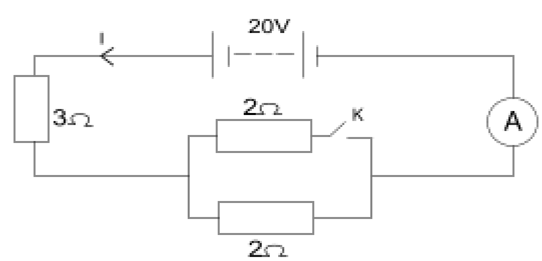


Calculate the effective resistance in the circuit.

ii) The p.d across the resistor in the parallel setting

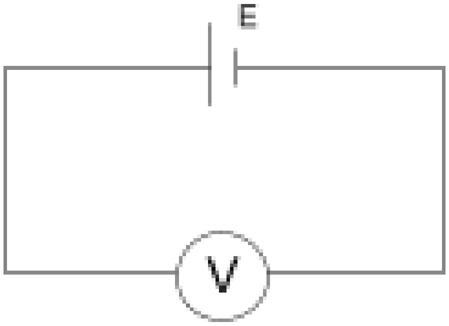
i) Current through R_1 and R_3

5. A source of EMF 20v and negligible internal is connected to resistors of 2Ω, 3Ω and 2Ω as shown in the figure. Find the ammeter reading when the switch is closed, and when K is open, current flows through the lower 2Ω resistor, the upper 2Ω will be out of circuit.



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 =

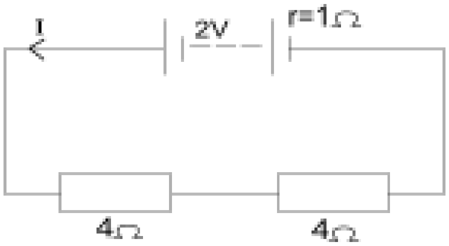
But v = IR,   I = E – IR

E = I + IR

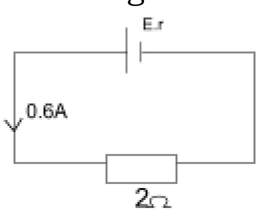
E = I (R+r)

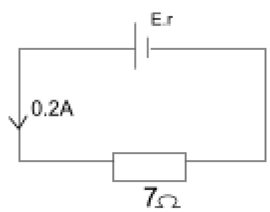
e.g 2 resistors each of 4Ω are connected to a 2v cell and an ammeter as shown below

a) Find the reading of the ammeter if the internal resistance of the cell is 1Ω



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.





Internal resistance, r = 0.5 and E= 1.50V

To determine the internal resistance of a cell using a voltmeter, ammeter, and variable resistor (rheostat)

Apparatus:

- A cell (battery)
- Voltmeter (0–5 V)

- Ammeter (0–5 A)
- Rheostat (variable resistor)
- Connecting wires
- Switch

Theory:

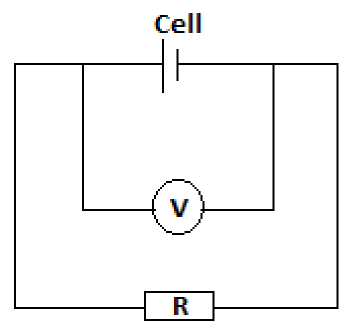
The internal resistance of a cell (r) affects its ability to provide current to an external circuit. When a current flows through a cell, some of the energy is lost due to the cell's internal resistance. The terminal voltage V across the cell can be related to the electromotive force (EMF) E and the internal resistance r by the formula:$V = E - Ir$, Where: V is the terminal voltage, E is the EMF of the cell, I is the current flowing through the circuit, r is the internal resistance of the cell.

Rearranging the equation gives: $E = V + Ir$

This relationship can be used to determine r by plotting a graph of V against I.

Procedure:

- Set up the circuit as shown in the diagram below:
- Connect the cell to the rheostat (variable resistor).
- Connect the ammeter in series with the cell and rheostat.
- Connect the voltmeter in parallel across the terminals of the cell.
- Close the switch and adjust the rheostat to obtain different values of current (from low to high).
- For each current setting, record the corresponding current III from the ammeter and the terminal voltage V from the voltmeter.
- Repeat the procedure for at least five different current readings.
- Observations:
- Record the values of current III and terminal voltage V in a table as shown below:



	Current I (A)	Voltage V(V)
1		
2		
3		
4		
5		

Data Analysis:

Plot a graph of V(vertical-axis) against I (horizontal-axis).

From the graph, determine the EMF E by extrapolating the line to the vertical-axis where I=0

The gradient of the line will give the negative value of the internal resistance r (since V=E−Ir)

Conclusion:

From the graph and the values obtained, the internal resistance r of the cell can be calculated.

Precautions:

Ensure proper connections to avoid short-circuiting the cell.

Take multiple readings for accuracy.

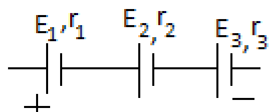
Avoid leaving the circuit closed for too long to prevent the cell from discharging rapidly.

This experiment will allow you to determine the internal resistance of the cell based on the measured relationship between the current and terminal voltage.

CONNECTING CELLS

Cells may be connected in series or in parallel

a) Series connection

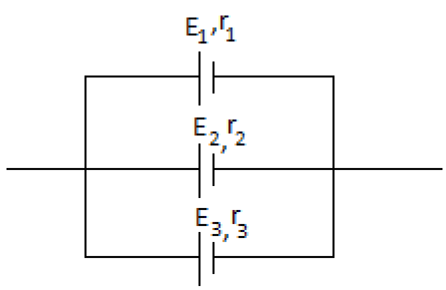


Cells in series

So effective E.M. F is the sum of the individual E.M.Fs

i.e $E = E_1 + E_2 + E_3$ and 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 int1ernal resistances

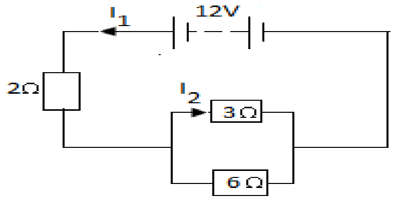
$$\frac{1}{r} = \frac{1}{r_1} + \frac{1}{r_2} + \frac{1}{r_3}$$

Activity.

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 the resistance of the lamp and p.d.V across the lamp

3.A battery of e.m.f 12V and negligible internal resistance is connected to resistances 2Ω, 3Ω, 6Ω as shown. 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, where Q = It . Electrical work done = VIt. But V = IR

Work done = I^2Rt 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**

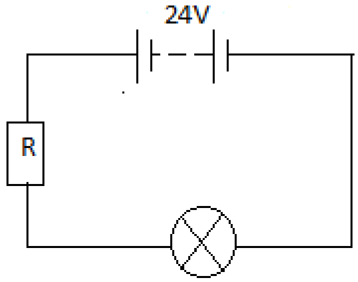
S.I unit of work is watts.1 watt = $1Js^{-1}$

A watt is the rate of working of 1J per second

Other units of power include; Kilowatt (kW), Megawatt (MW) (1KW = 1000w and 1 MW = 1000kW = 1,000,000W)

Activity

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

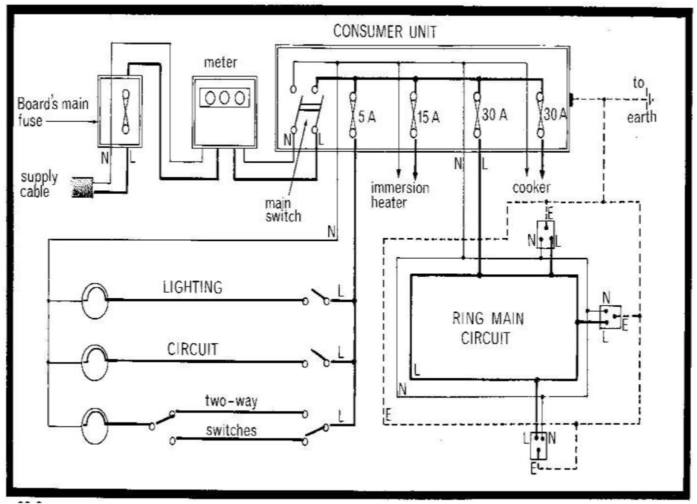
1. Find the cost of running five 60w and four 100w lamps for 8hours if electrical energy cost 5/= per unit
   Total power consumed = 5 x 60 + 4 x 100 = 700w = 0.70kW
   Electrical cost = 0.70 x 8 x 5 = 28/=
2. A house has one 100w bulb, two 75 watts bulbs and five 40w bulbs. Find the cost of having all 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/=
3. Calculate the cost of running an electric fire alarm for 2½ hours if it takes 13A on 100v supply and each unit cost 40/=
4. 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
5. 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?
6. 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 100ɨ and the month is assumed to have four weeks
7. 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^{o}c to 50^{o}c 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

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

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

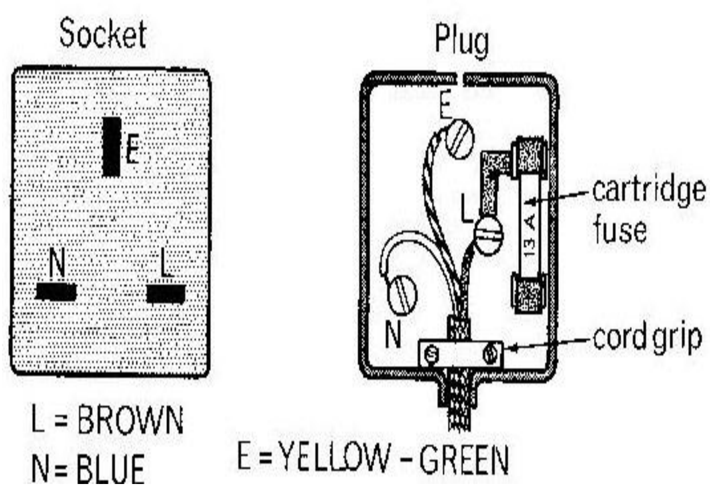
A short circuit in one appliance does not affect other appliances

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 Electric bulbs and tubes, electric flat iron, electric kettles, and 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 .

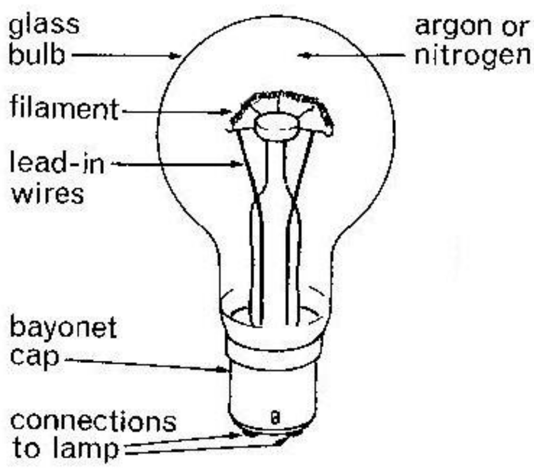
The gas prevents evaporation of tungsten and increases its operating temperature otherwise it condenses or blackens it. Efficiency of the bulb is improved by using a cold filament which reduces the space occupied by the filament and also reduces the rate of heat loss by convection

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

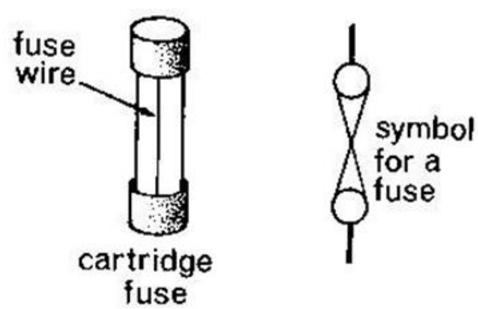


ADVANTAGES OF FLUORESCENT TUBES OVER FILAMENT LAMPS

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

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.

Function and Use of a Diode, Transistor, Thermistor, LDR, LED, and Potentiometer

Each of these components has specific functions and applications in electrical circuits and electronics, playing essential roles in the control, modification, or sensing of electrical signals.

1. Diode

Function: A *diode is a semiconductor device that allows current to flow in one direction only, blocking it in the opposite direction. It acts as a one-way valve for current.*

Uses:

Rectification: Diodes are commonly used in **rectifiers**, which convert AC (alternating current) to DC (direct current). This is crucial in power supplies.

Protection: Diodes protect circuits by blocking reverse polarity, preventing damage from incorrect voltage application.

Signal Demodulation: In radio receivers, diodes are used to extract audio signals from modulated RF signals.

Clamping and Voltage Regulation: **Zener diodes** are used for voltage regulation, allowing current to flow in reverse when a specific breakdown voltage is reached.

2. Transistor

Function: *A transistor is a semiconductor device used to amplify or switch electronic signals and electrical power. It can act as a switch or an amplifier depending on the circuit design.*

Types of Transistors:

Bipolar Junction Transistors (BJT): NPN and PNP types

Field-Effect Transistors (FET): MOSFET and JFET types

Uses:

Switching: Transistors are widely used in digital circuits to act as electronic switches. They are the building blocks of logic gates and microprocessors.

Amplification: In analog circuits, transistors amplify weak signals. For example, in audio systems, transistors amplify sound signals.

Oscillators: Transistors are used to create oscillating signals in radio transmitters and clock signals in microprocessors.

Signal Modulation: Transistors modulate the amplitude of a signal in communication systems.

3. Thermistor

Function: *A thermistor is a temperature-sensitive resistor whose resistance changes significantly with changes in temperature. There are two types:*

NTC (Negative Temperature Coefficient): Resistance decreases as temperature increases.

PTC (Positive Temperature Coefficient): Resistance increases as temperature increases.

Uses:

Temperature Sensing: Thermistors are used in thermometers, thermostats, and temperature sensors in devices like air conditioners, refrigerators, and engines.

Circuit Protection: PTC thermistors are used for over-current protection. As current increases and heats the thermistor, its resistance rises, reducing the current and preventing damage.

Temperature Compensation: NTC thermistors are used in circuits to compensate for temperature-induced changes in component characteristics, such as in LCD displays.

4. LDR (Light Dependent Resistor)

Function: *An LDR, or photoresistor, is a light-sensitive resistor whose resistance decreases as the intensity of light increases. It is made from semiconductor materials that change conductivity in response to light.*

Uses:

Automatic Lighting Systems: LDRs are used in streetlights, where they turn on the lights when it gets dark and off when it becomes light.

Light Meters: LDRs are used in devices to measure light intensity, such as in photography or environmental monitoring systems.

Security Systems: In burglar alarms, LDRs are used in light-detecting circuits to trigger alarms when light is interrupted.

Automatic Brightness Control: In televisions and smartphones, LDRs adjust the screen brightness based on ambient light levels.

5. LED (Light Emitting Diode)

Function: *An LED is a special type of diode that emits light when current flows through it in the forward direction. The color of the light emitted depends on the material used to make the LED.*

Uses:

Indicator Lights: LEDs are used in electronic devices to indicate power status, charging, or any other operational state.

Display Screens: LEDs are widely used in display technologies, such as in LED TVs, computer monitors, and billboards.
Lighting: LEDs are now used in home, automotive, and industrial lighting systems due to their energy efficiency and long lifespan.
Optoelectronics: LEDs are used in communication systems for transmitting signals via light in optical fibers.
Advantages of LEDs:
Low power consumption
Long operational life
High efficiency
Instant lighting with full brightness

6. Potentiometer
Function: *A potentiometer is a three-terminal resistor with an adjustable middle terminal (wiper), used to create a variable resistance in a circuit. It can be rotated or slid to change the resistance and, consequently, the voltage or current in a circuit.*

Uses:
Volume Control: Potentiometers are used in audio devices like radios, speakers, and amplifiers to control volume by adjusting the signal strength.
Adjustable Power Supplies: Potentiometers are used in circuits to adjust voltage or current, such as in dimmer switches for lights or controlling motor speed.
Sensing Position: Potentiometers are used in joysticks, throttle controls, and steering mechanisms to sense position by detecting the wiper's location on the resistive track.
Calibration: In electronic circuits, potentiometers are used to fine-tune or calibrate the output by adjusting the voltage or resistance to a desired level.

Component	**Function**	**Common Uses**
Diode	Allows current flow in one direction only	Rectification, protection, demodulation, voltage regulation
Transistor	Amplifies or switches electronic signals	Switching, amplification, oscillators, signal modulation
Thermistor	Resistance changes with temperature	Temperature sensing, circuit protection, temperature compensation

LDR	Resistance changes with light intensity	Automatic lighting, light meters, security systems, brightness control
LED	Emits light when current flows through it	Indicator lights, displays, lighting systems, optoelectronics
Potentiometer	Adjusts resistance by moving a wiper over a resistive element	Volume control, adjustable power supplies, sensing position, calibration

These components are essential building blocks in modern electronics, serving critical roles in controlling, detecting, and modifying electrical signals and energy. Understanding their functions and uses is crucial for designing and troubleshooting circuits.

4.5 Atomic models

Learning Outcomes

a) Understand the structure of an atom in terms of a positive nucleus and negative electrons(u)
b) Understand the terms: atomic number, mass number, and isotopes, and use them to represent different nuclides (k,u)
c) Understand the methods by which electrons are ejected from /matter atoms and how these electrons are useful (u, v/ a)

STRUCTURE OF AN ATOM

The structure of an atom can be described as consisting of two main regions: a positively charged nucleus at the center and negatively charged electrons surrounding the nucleus.

The Nucleus (Positive)

The nucleus is a small, dense core located at the center of the atom. It contains protons and neutrons: Protons are positively charged particles. Neutrons have no charge (they are neutral). The overall charge of the nucleus is positive due to the presence of protons. The number of protons in the nucleus is called the atomic number, which defines the element (e.g., hydrogen has 1 proton, carbon has 6 protons). The nucleus accounts for almost all of the atom's mass, but it occupies only a tiny fraction of the atom's volume.

Electrons (Negative): Surrounding the nucleus are electrons, which are negatively charged particles.
Electrons are much lighter than protons and neutrons (about 1/1836th of the mass of a proton). Electrons are arranged in regions of space called electron shells or energy levels. These shells orbit around the nucleus.
The number of electrons in a neutral atom equals the number of protons, which balances the atom's overall charge.
Electrostatic Forces: The negatively charged electrons are attracted to the positively charged nucleus by the electrostatic force (Coulomb force), which holds the atom together. Despite this attraction, electrons do not "fall" into the nucleus because they occupy specific energy levels or orbitals, which are governed by the principles of quantum mechanics.

Atomic Number (Z)
The atomic number is the number of protons in the nucleus of an atom.
It is represented by the symbol Z. The atomic number determines the identity of the element. For example: Hydrogen (H) has an atomic number of 1 because it has 1 proton. Carbon (C) has an atomic number of 6, meaning it has 6 protons. The atomic number also equals the number of electrons in a neutral atom, since protons and electrons balance each other’s charge.

Mass Number (A)
The mass number is the total number of protons and neutrons in an atom's nucleus. It is represented by the symbol A. Mass number = Protons (Z) + Neutrons (N). For example, carbon-12 (C-12) has a mass number of 12 because it has 6 protons and 6 neutrons. Unlike the atomic number, which is unique to each element, the mass number can vary among atoms of the same element, depending on the number of neutrons.

Isotopes
Isotopes are atoms of the same element (same number of protons) that have different numbers of neutrons. Isotopes have the same atomic number (Z) but different mass numbers (A). Because the number of neutrons varies, isotopes of an element may have different physical properties, such as different masses, but they behave chemically in the same way. For example, carbon has three naturally occurring isotopes:
Carbon-12 (C-12): 6 protons and 6 neutrons.
Carbon-13 (C-13): 6 protons and 7 neutrons.
Carbon-14 (C-14): 6 protons and 8 neutrons.

All three isotopes have 6 protons (atomic number = 6) but different mass numbers due to varying numbers of neutrons.

Representing Nuclides

Nuclides are represented using their atomic and mass numbers. The standard notation is: Where:

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

A is the mass number (protons + neutrons),
Z is the atomic number (number of protons),
X is the chemical symbol of the element.
Examples of Nuclide Representation:
Carbon-12: A = 12 (6 protons + 6 neutrons),
Z = 6 (6 protons). Carbon-14: A = 14 (6 protons + 8 neutrons),
Z = 6 (6 protons).
Uranium-238: A = 238 (92 protons + 146 neutrons),Z = 92 (92 protons).

Differences between Isotopes

Isotopes of the same element behave identically in chemical reactions because they have the same electron configuration. Isotopes have different masses, and this can affect their behavior in physical processes (e.g., heavier isotopes may diffuse more slowly).

Applications of Isotopes

Carbon-14 is used in radiocarbon dating to determine the age of ancient biological materials.
Isotopes like Iodine-131 are used in medical imaging and treatment, especially in cancer therapy.
Uranium-235 is used as fuel in nuclear reactors.

PRODUCTION OF ELECTRONS

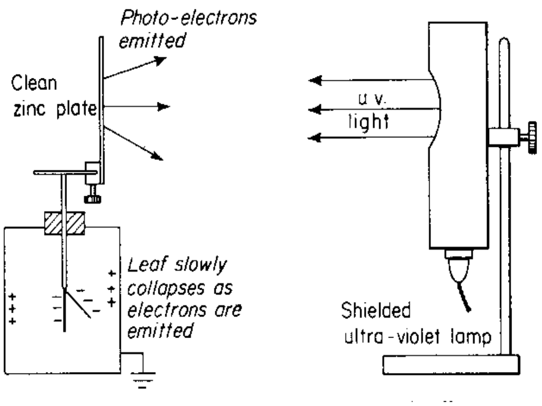
Electrons are ejected from a metal surface in two processes, namely;

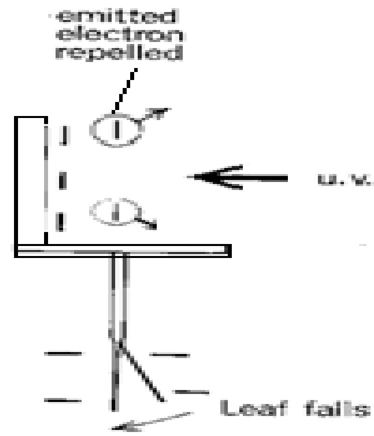
1. Thermionic emission
2. Photoelectric emission

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

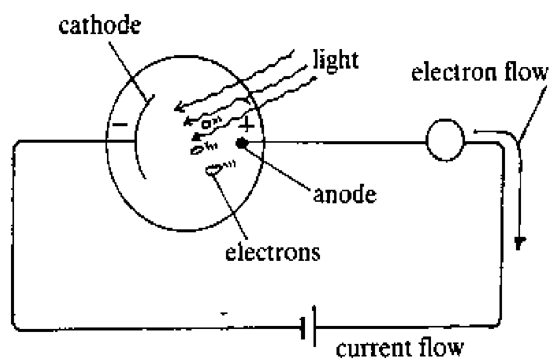
When an ultraviolet radiation is shone on a zinc plate placed on the cap of a negatively charged gold leaf electroscope, the divergence of the leaf reduces





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.

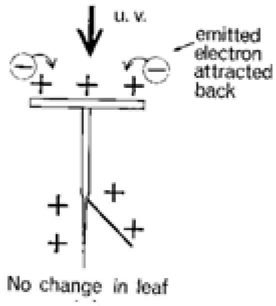
Light incident on the metal surface must have a certain minimum frequency known as threshold frequency.

Question

Ultraviolent radiation is incident on a clean zinc plate resting on the cap of a charged G.L.E. Explain what is observed?

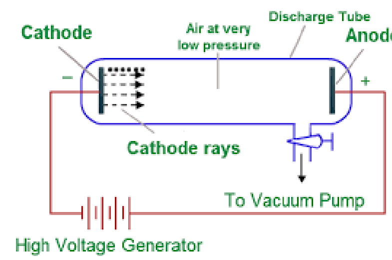
What is observed if radio wave is used instead of ultraviolent radiation?

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.



Radio waves have low energy thus are unable to eject electrons so there will be no effect on the leaf divergence of the electroscope.

CATHODE RAYS



These are streams of fast moving electrons.
They are negatively charged particles

PRODUCTION OF CATHODE RAYS

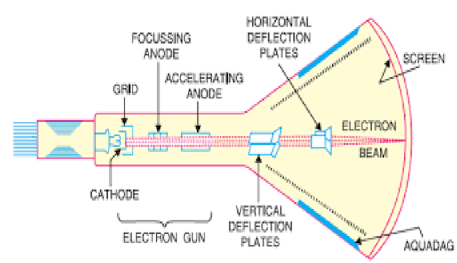
The filament is heated by an electric current through it.
The filament heats up the cathode
The cathode emits electrons by thermionic emission
The large p.d across the vacuum accelerates the electrons to move from cathode to the anode
The vacuum ensures that electrons move freely so that they do not 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

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.
The anode – the anode is used to accelerate the electrons and also focus the electrons into a fine beam.
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 coatings on the fluorescent screen converts kinetic energy in light and produce a bright spot when the electrons beam is focused on it.

.

USES OF A C.R O

Frequency measurements : This is achieved by comparing a wave form of known frequency with unknown frequency

Method

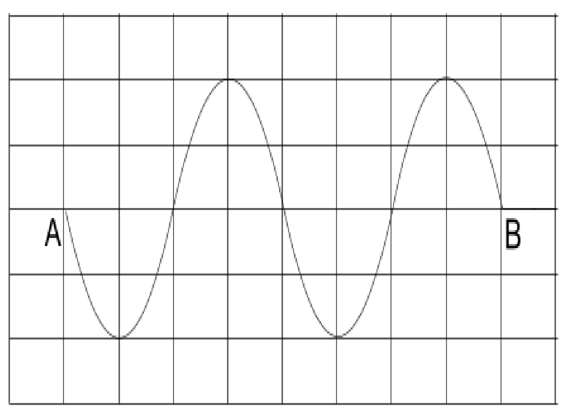
Adjust the time base of a C.R.O until one complete wave is obtained without altering the control grid of the C.R.O; apply a signal of known frequency.
Then compare the frequency by counting the number of complete waves.

1. **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.

Used to study wave forms of current and voltage

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

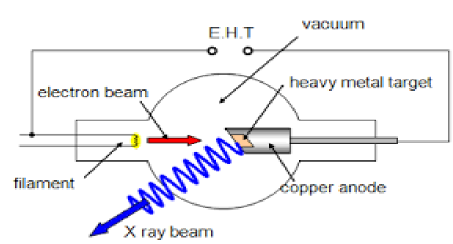
ii) find the amplitude of voltage generated if voltage gain is 5V per cm
Amplitude = 2cm, 1cm = 5V
2cm is equivalent to (5 x 2) V
= 10V

(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.

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.

Production of X-rays

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.

Types of X – rays
They include Hard X – rays and Soft X – rays

Hard X – rays: 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

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 in 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

In 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

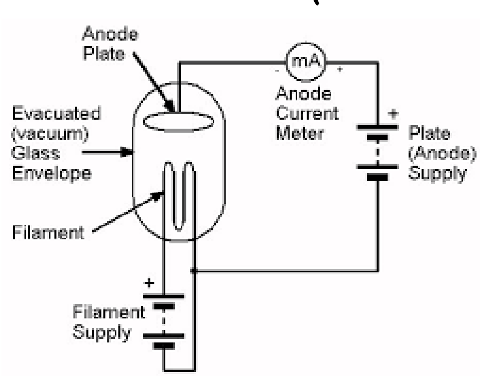
HOW AN X-RAY IS USED TO LOCATE BROKEN PARTS OF A BONE .

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

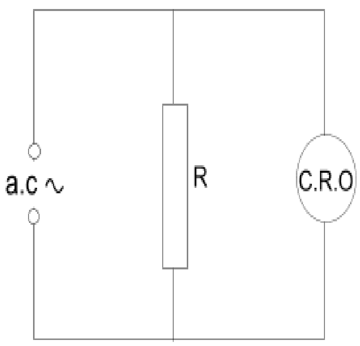
THERMIONIC DIODE (diode valve)

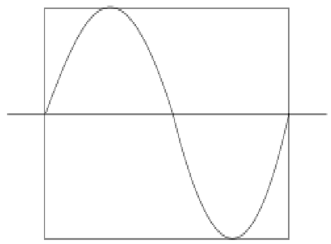


A diode is an evacuated glass containing anode and cathode and restricts current in one direction i.e. does not permit the reverse direction.

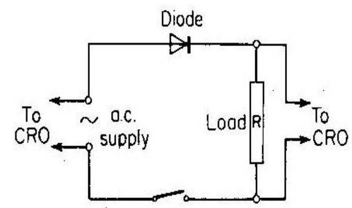
A cathode can be directly heated by passing current through it or can be indirectly heated by passing filament wire close to it.

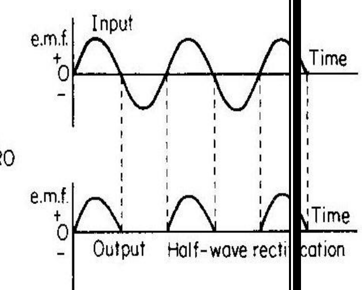
ACTION





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.



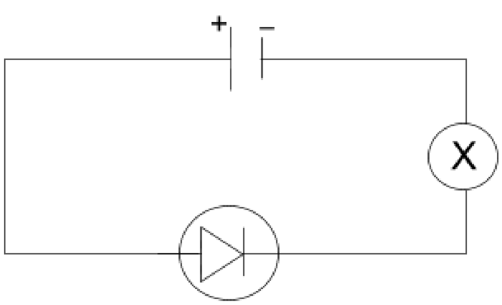


The electrons at the anode are detected by the milli ammeter connected to the anode

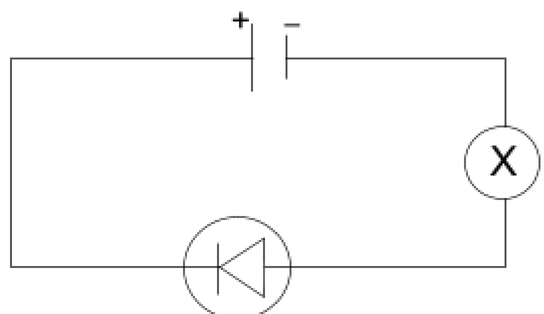
Diode as a rectifier

A rectifier allows current to flow in one direction

Rectification is the process of converting a.c to d.c.



a)



b)

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,

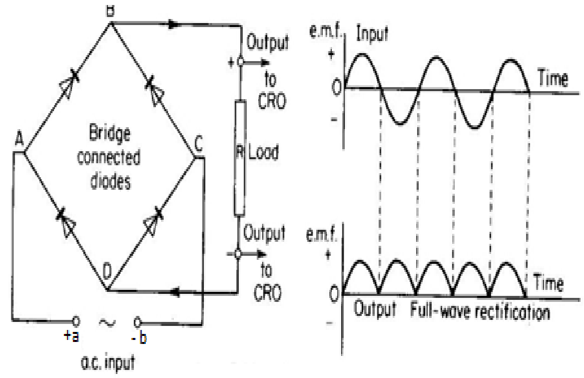
Alternating current input voltage = p.d across the resistor

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 **a**nd 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

4.6 Nuclear processes

Learning Outcomes

a) Understand the processes of nuclear fission and fusion and the associated energy changes(u)
b) Understand the spontaneous and random nature of nuclear decay and interpret decay data in terms of half-life (k, u,s)
c) Know the applications of radioactivity and the dangers associated with exposure to radioactive materials. (k,u)
d) Understand and appreciate that there are significant social, political, and environmental dimensions associated with use of nuclear power. (u,v/a)

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

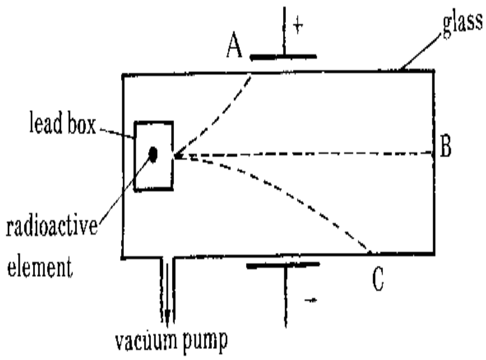
Alpha particles have a high ionizing power compared to beta particles

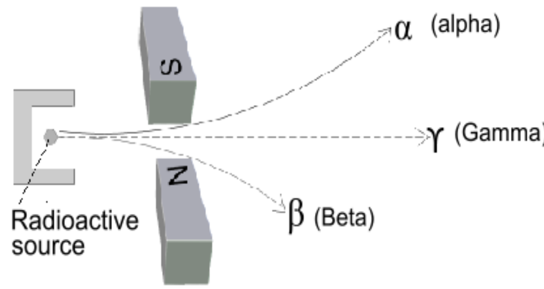
Deflection for beta particles in electric fields is towards the positive while that of the alpha particles is towards the negative plate

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.

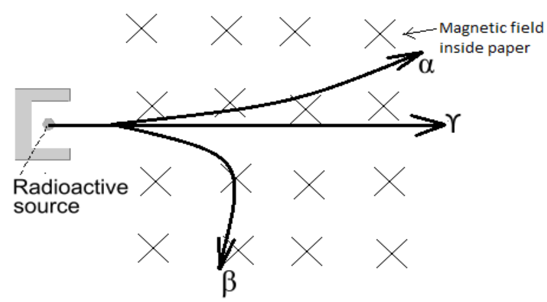
While gamma rays go through the field un deflected showing that the carry no charge.

DEFLECTION BY A MAGNETIC FIELD

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 equipment 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

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.

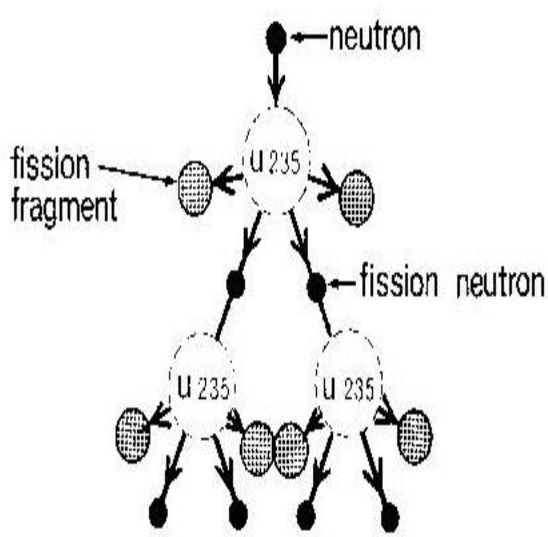
Count rate = 25 - 2 = 23c/min

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.

$$\underset{}{{}^{235}_{92}U} + \underset{\text{neutron}}{{}^{1}_{0}n} \rightarrow \underbrace{{}^{144}_{56}Ba + {}^{90}_{36}Kr}_{\text{fission fragments}} + \underset{\text{neutrons}}{2{}^{1}_{0}n}$$



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.

$$^{2}_{1}H + ^{2}_{1}H \longrightarrow ^{4}_{1}He + \text{energy} \qquad ^{2}_{1}H + ^{2}_{1}H \longrightarrow ^{4}_{1}He + ^{2}_{1}n + \text{energy}$$

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

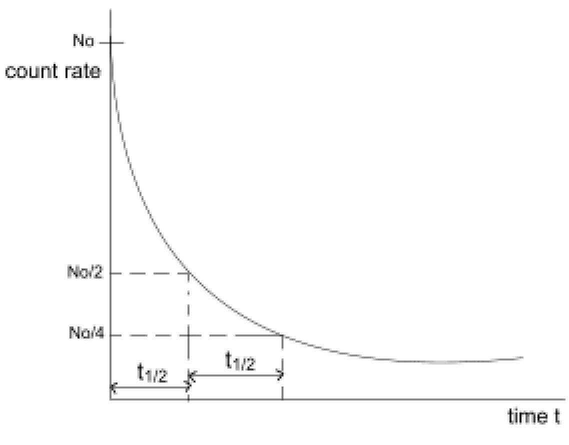
- Used to produce hydrogen.
- Used to produce electricity.
- Used to produce heat energy on large scale.

HALF LIFE

It is the time taken for radioactive substance to decay to half of its original mass e.g.

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.



Activity.

1) The following values obtained from the readings of a rate meter from a radioactive isotope of iodine. 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
   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?

4.7 Digital electronics

Learning Outcomes

a) Understand how resistors are used to make potential dividers in control and logic circuits (u,s)
b) Understand elementary logic and memory circuits that exploit devices such as bistable and a stable switches, logic gates and resistors as potential dividers (u,s)
c) Know that logic circuits are able to store and process binary information and that this can be exploited in an increasingly wide variety of digital instruments (k, u,s)

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

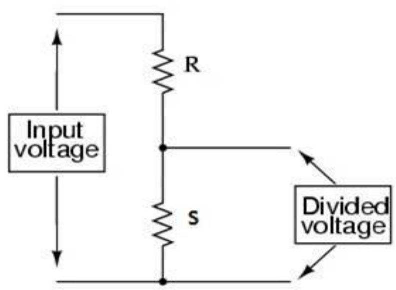
A potential divider consists of two resistors (R_1 and R_2=S) in series. The current I through both the resistors are the same. The potential across resistor R_1 is V_1 and R_2=S is V_2. The potential difference across the resistors can be mathematically written using Ohm's law.

$$V_1 = IR_1 \text{ and } V_2 = IR_2$$

Dividing V_1 by V_2,

$$\frac{V_1}{V_2} = \frac{R_1}{R_2}$$

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.

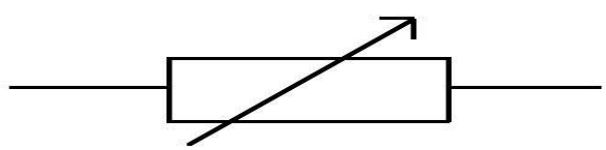
Resistance

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,

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.

Circuit Symbol of Variable Resistor

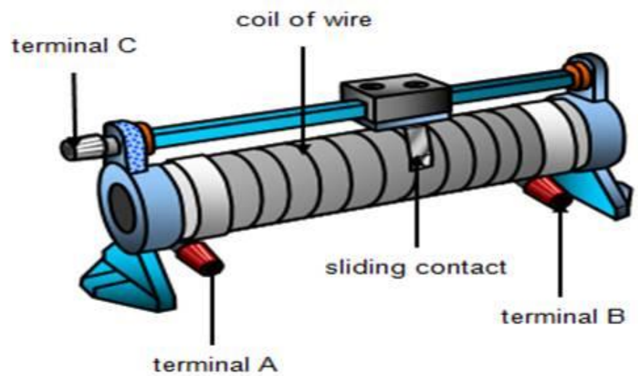
A rheostat is made using a resistance wire, which is wound around circular insulation. A sliding contact is placed in the wire to change the length of the resistor. An end of the wire and sliding contact is connected to the circuit. As the length of the resistance wire is changed, the resistance also 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.

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.

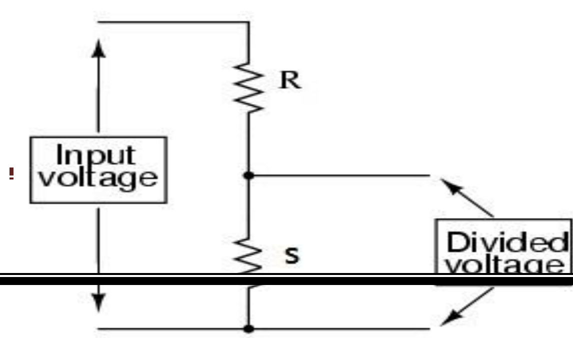


Application of Potential Dividers

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.

Potential Divider in Sensory Circuits



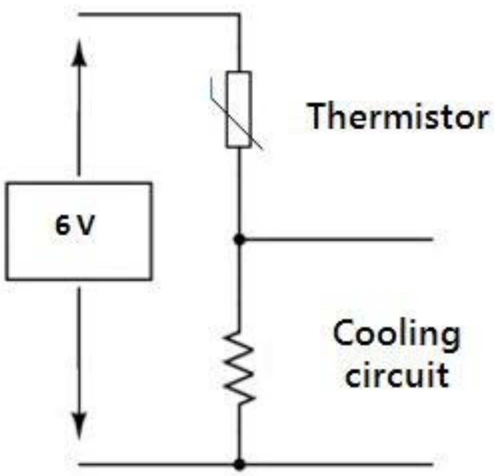
The voltage across sensory device (Vs) can be mathematically written as:

$V_s = \frac{S}{S+R} \times Input\ voltage$

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).



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.

$$Vcc = \frac{6 \times 5000}{5000+R_t}$$

Temperature	Resistance of Thermistor
2°C	1500 Ω
3°C	1000 Ω
4°C	500 Ω

$= 4.6\ V$

$$Vcc = \frac{6 \times 5000}{5000+1000} = 5.0\ V$$

The cooling circuit is on. This condition holds true when the temperature increases more than 3°C.

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.

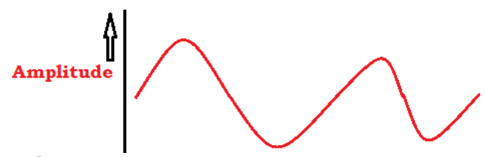
Digital electronics is a type of electronics that deals with the digital systems which processes the data/information in the form of binary (0s and 1s) numbers, whereas analog electronics deals with the analog system which processes the data/information in the form of continuous signals.

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.

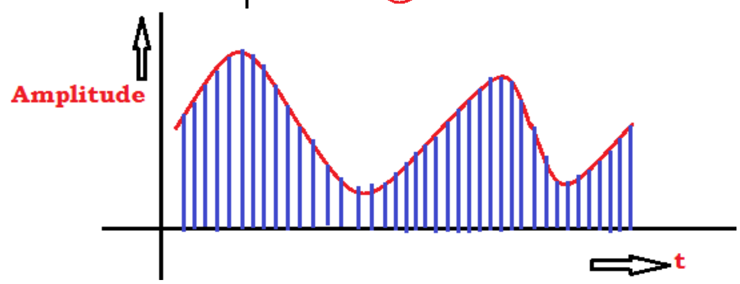


Figure 1.1(b1): *Discrete signal.*

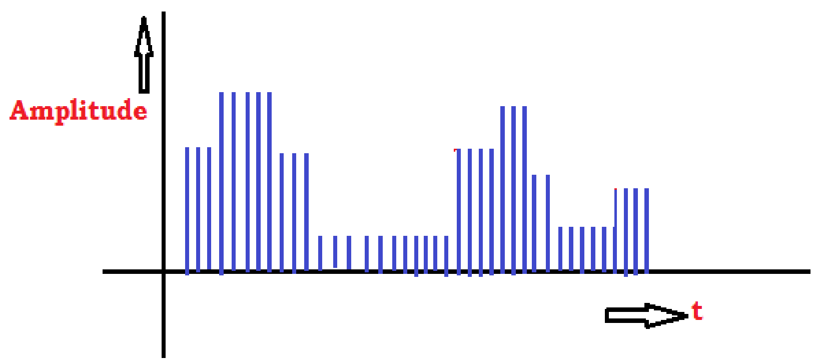


Figure 1.1(b2): Digital signal

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

Positive logic

Logic 0 = False, 0V, Open Switch, OFF

Logic 1= True, +5V, Closed Switch, ON

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

Boolean variables take only two values, logic 1 and logic 0, called binary numbers.

Basic operations of Boolean algebra are complement of a variable, ORing and ANDing of two or more variables.

Mathematical description of Boolean operations using variables is called ***Boolean expression.***

Complement of variable is represented by an over-bar (-), $Y = \bar{A}$

ORing of variables is represented by a plus symbol (+), A+B=Y (output)

ANDing of variables is represented by a dot symbol (.), A.B=Y (Output)

Boolean operations are different from binary operations.

Example: 1+1=10 in Binary Addition, 1+1=1 in Boolean algebra.

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.

A	$Y = \bar{A}$
0	1
1	0

Table 1.1:
Complement of variable A

A	B	Y=A+B
0	0	0
0	1	1
1	0	1
1	1	1

Table 1.2: OR operation on A and B

A	B	Y=A.B

Table 1.3: AND operation on A and 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 obtained 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:

Basic Logic Gates

There are three basic logic gates: **AND Gate, OR Gate, and** NOT **Gate**

Universal Logic Gates

In digital electronics, the following two logic gates are considered as universal logic gates: ***NOR Gate and NAND Gate***

Derived Logic Gates

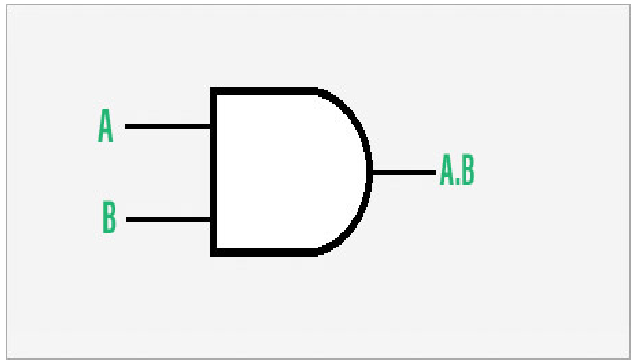
The following two are the derived logic gates used in digital systems:
XOR Gate, XNOR Gate, and AND Gate
In digital electronics, the **AND** gate is one of the basic logic gate that performs the logical multiplication of inputs applied to it. It generates a high or logic 1 output, only when all the inputs 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**, 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
0	0	0
0	1	0
1	0	0
1	1	1

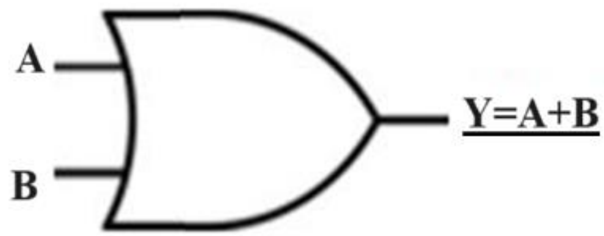


Symbol of AND Gate:
The logic symbol of a two input AND gate is shown in the following figure.
Symbol of Two-Input AND Gate
OR Gate
In digital electronics, there is a type of basic logic gate which produces a low or logic 0 output only when it's all inputs are low or logic 0.
For all other input combinations, 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
1	1	1

Symbol of OR Gate:
The logic symbol of a two-input OR gate is shown in the following figure.



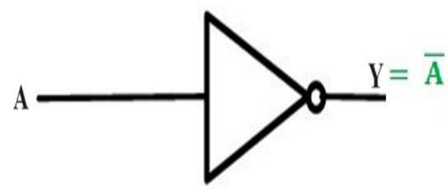
Symbol of Two-Input OR Gate

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:

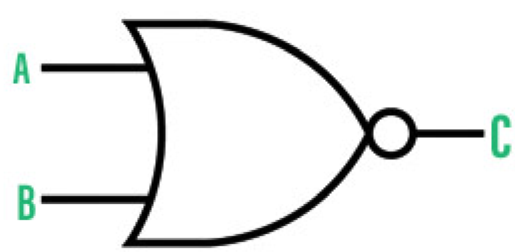
$\boldsymbol{C = \overline{A + B}}$

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, $C=\overline{AB}$

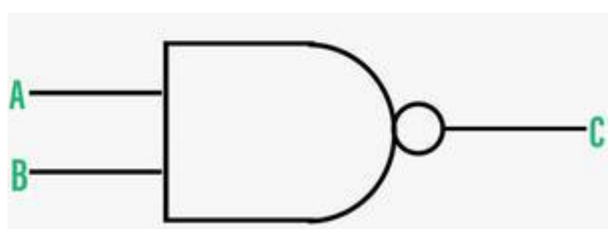
In this expression, A and B are the input variables and C is the output variable. We can extend this relation to any number of input variables like three, four, or more.

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 $C=\overline{AB}$
A	**B**	**A NAND B**
0	0	1
0	1	1
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. $Y = A\bar{B} + A\bar{B}$. Where, 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, $Y = A\bar{B} + \bar{A}B$**
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, write this expression as follows: $\boldsymbol{Y = AB + \overline{AB}}$
Here, the A and B are inputs and Y is the output.

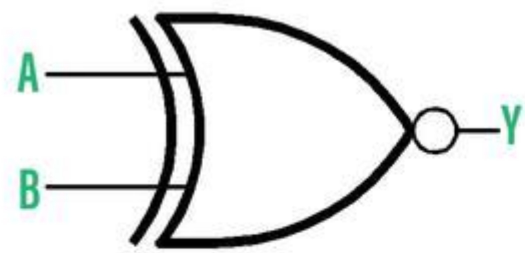
Truth Table of XNOR Gate:

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*, and *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.

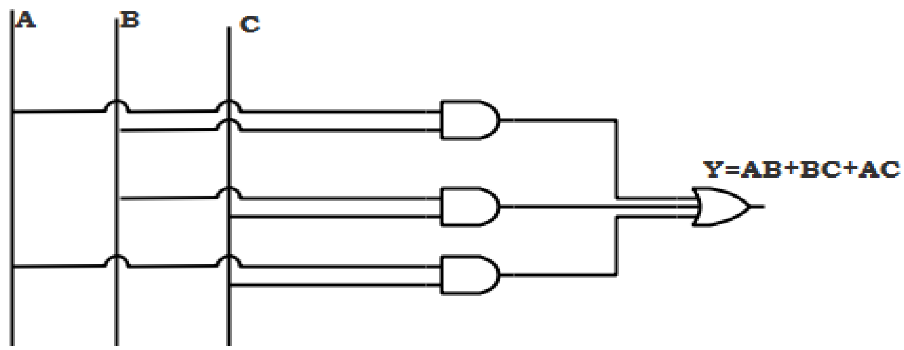
What is the Boolean expression for OR gate?

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

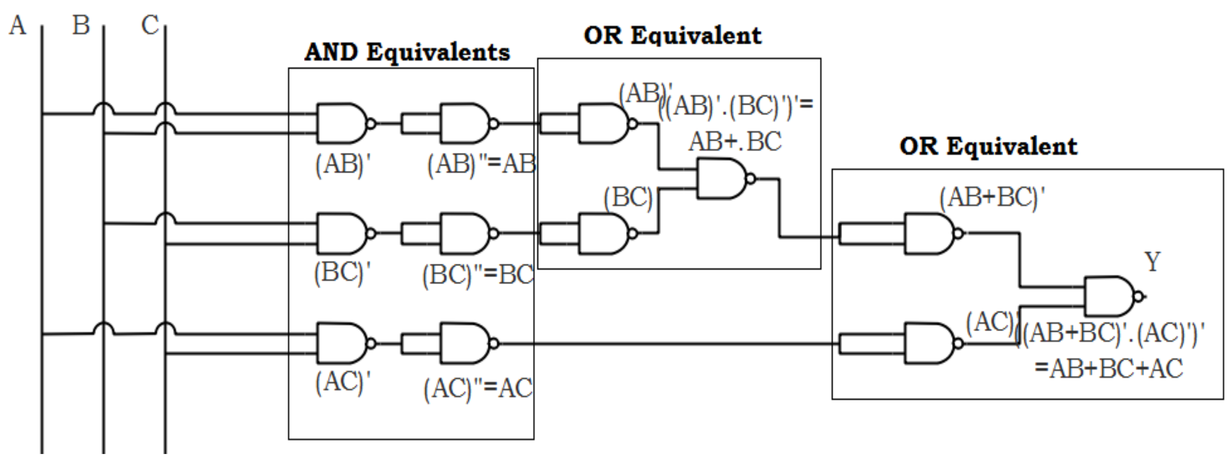


Realize the following Boolean expression using only NAND gates.

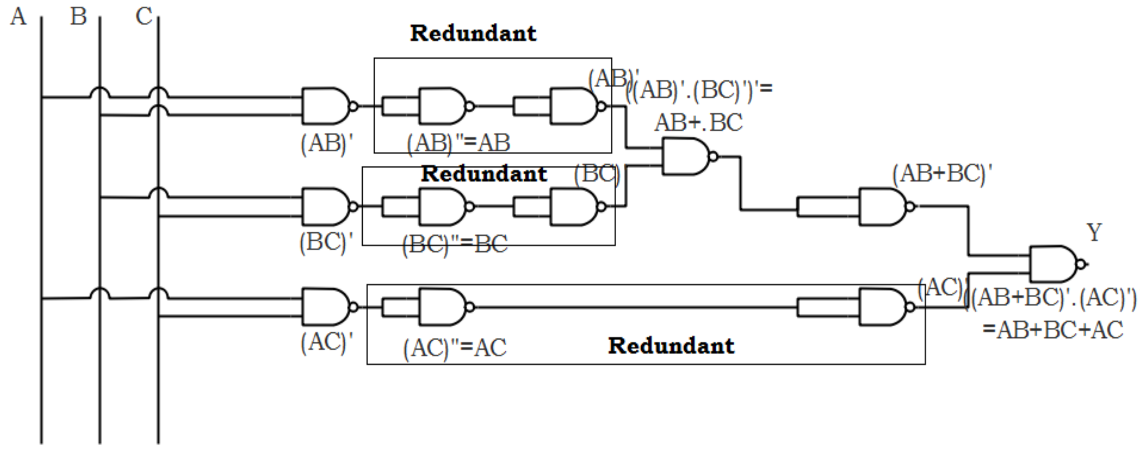
Y = AB + BC + AC

Logic diagram

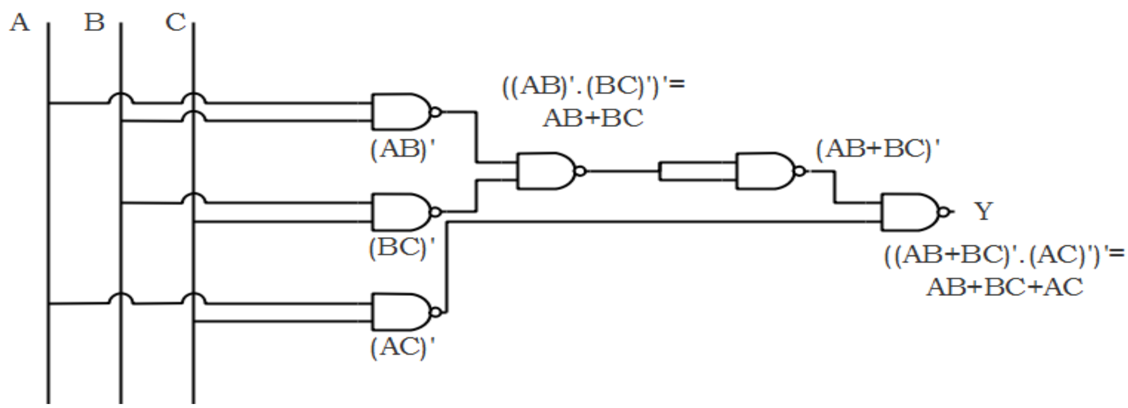
Step-1: Replace basic gates by NAND equivalents



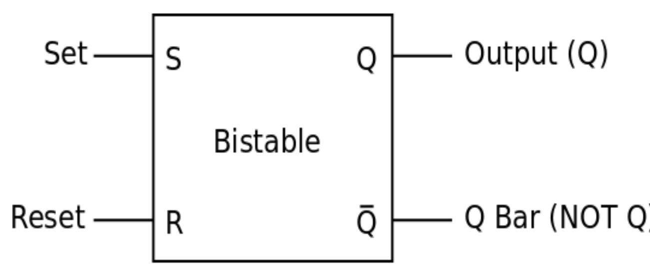
Step-2: Eliminate two single inputs NAND gates are connected in series.



Step-3: Draw the resultant logic circuit.



BISTABLE CIRCUITS



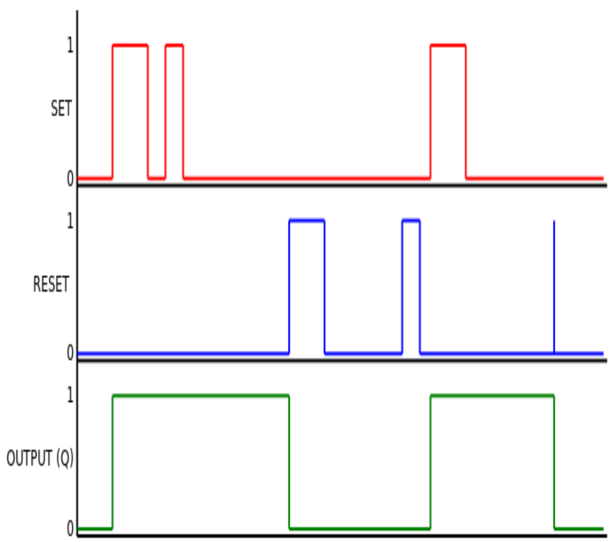
A Bistable is a digital circuit that has two inputs and a digital output.
The SET input makes the output Logic 1 (HIGH) and the output will stay in this state until forced to change. The RESET input makes the output Logic 0 (LOW) and the output will also stay in this state until forced to change. The 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

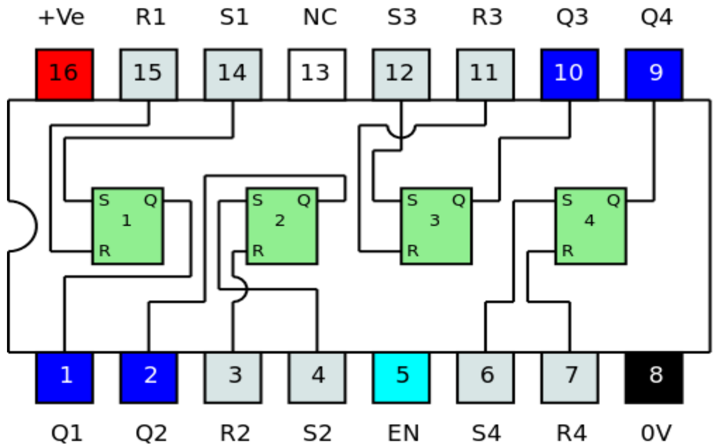
A Bistable has two inputs called **Set (S)** and **Reset (R)**.
The output is called **Q**. There is often a second output which is the opposite of Q or, in logic terms, **NOT Q**.
The NOT Q output is written as $\bar{Q}$ and pronounced "Q-bar"
In the most common bistables, Set and Reset are usually LOW and must go HIGH to change the output.



NOTE

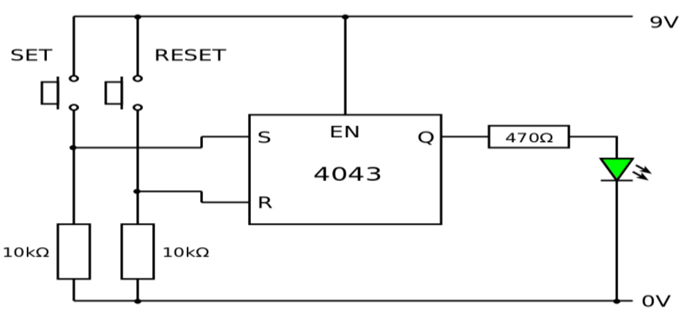
1. In normal operation, SET and RESET are usually both held LOW
2. Q is always the opposite of 퀸
3. SET and RESET should not both be high at the same time - if they are the state of the outputs is undecided
4. There are also bistables where SET and RESET are usually HIGH and go LOW to change the output.

The timing diagram shows how the SET and RESET inputs cause Q and $\bar{Q}$ 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.

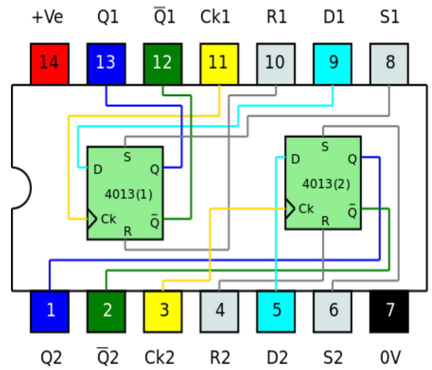
4043 Bistable IC



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.

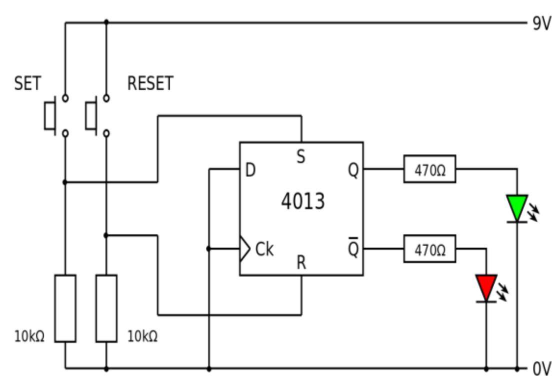
Using 4013 as a Bistable



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 퓐 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.

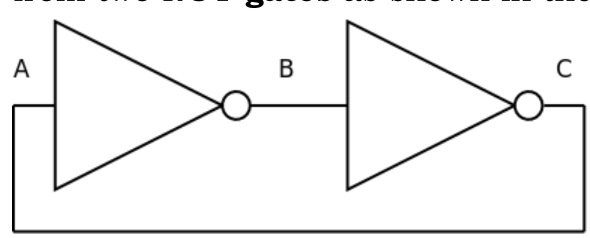
SET is normally LOW, making SET go HIGH forces the output Q HIGH and 퓐 LOW. RESET is normally LOW, making RESET go HIGH forces the output Q LOW and 퓐 HIGH.
Making both SET and RESET HIGH at the same time is a disallowed state - in this case the outputs Q and 퓐 both go HIGH with the final state being determined by which input goes LOW first.

The diagram shows a simple test circuit with CK and D connected to ground.

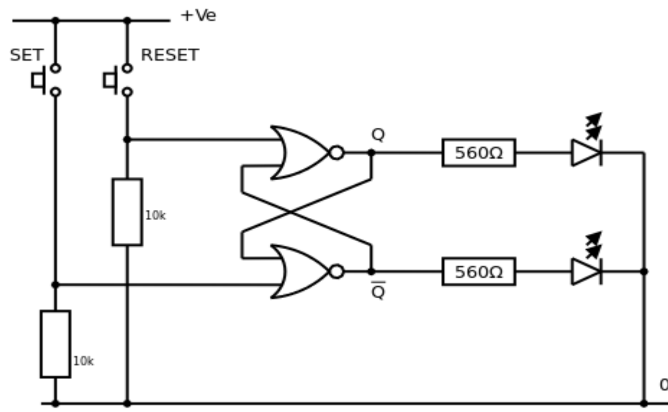


Simple logic gate Bistable

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:



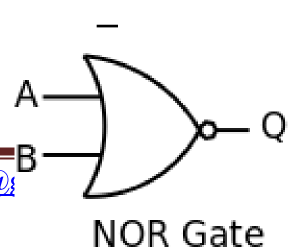
Assume A = 0 and therefore B = 1. B = 1 and therefore C = 0 … C is connected to A, and so A = 0 as required.
Situation 2:
Assume A = 1 and therefore B = 0. B = 0 and therefore C = 1 … C is connected to A, and so A = 1 as required.
Whether A = 0 or A = 1, the circuit works in both cases. To make this 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.

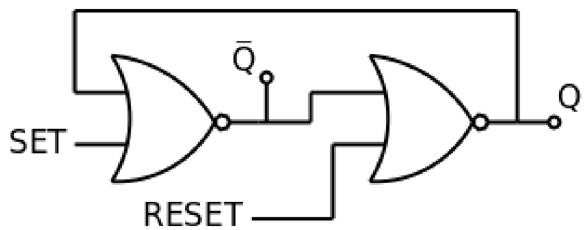
When SET and RESET are both LOW the NOR gates act as NOT gates and the bistable has two stable states.
SET and RESET can safely be made HIGH as they are not directly connected to the output of the NOR gates - they are only inputs.
Situation 1:
Consider SET = 0, RESET = 0, Q = 0 and therefore $\bar{Q}$ = 1. Making SET = 1 forces $\bar{Q}$ = 0.



A	B	Q
0	0	1
0	1	0
1	0	0
1	1	0

Both inputs to the right do not hand NOR gate are now LOW and so Q = 1. The feedback does not ensure that at least one of the inputs of the left hand NOR gate is now HIGH and so 퓐 = 0. Therefore, making SET = 1 forces Q = 1 as required.

Situation 2:



Consider SET = 0, RESET = 0, Q = 1 and therefore 퓐 = 0. Making RESET = 1 forces Q = 0. Both inputs to the left hand NOR gate are now LOW and so 퓐 = 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.

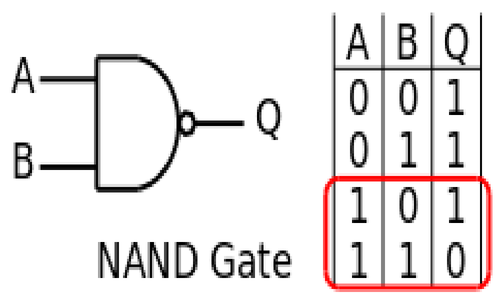
Logic circuits or devices where the inputs are normally LOW and go HIGH to make something happen are not often referred to as having "NOR gate logic" or "NOR logic" because in the NOR gate bistable SET and RESET are normally LOW.

Note that the 4043 and 4013 ICs employ 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!

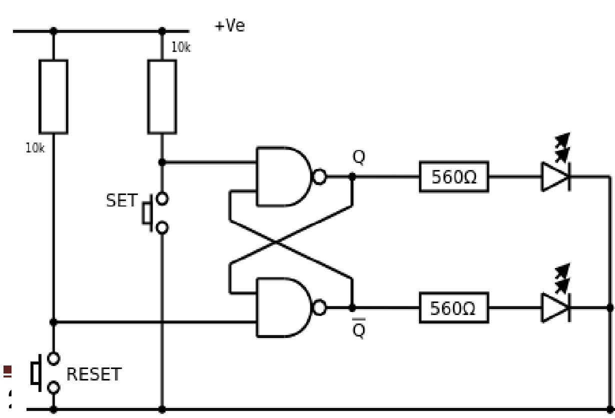
Pull down resistors ensure SET and RESET are normally LOW and go HIGH when the buttons are pressed (NOR Logic).

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:

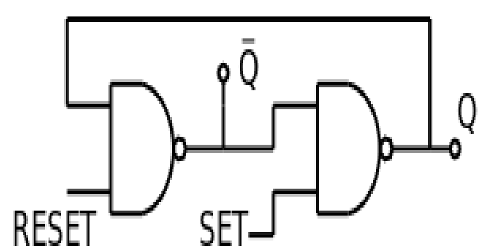
Consider SET = 1, RESET = 1, Q = 0 and therefore 퓐 = 1. Making SET = 0 forces Q = 1. Both inputs to the left hand NAND gate are now HIGH and so 퓐 = 0. The feedback ensures that at least one of the inputs of the right hand NAND gate is now LOW and so Q = 1. Therefore, making SET = 0 forces Q = 1 as required.

Situation 2:

Consider SET = 1, RESET = 1, Q = 1 and therefore 퓐 = 0. Making RESET = 0 forces 퓐 = 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 퓐 = 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).



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