

# PRINCIPLES AND PERSPECTIVES OF PHYSICS

## SENIOR ONE

### 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)

### INTRODUCTION

Physics is the branch of science concerned with understanding the fundamental principles of the universe. It studies matter, energy, forces, and the interactions between them, explaining natural phenomena from the smallest particles to massive galaxies. Physics seeks to understand how things work and why things happen, often through experimentation, mathematical modeling, and observation.

#### Branches of Physics

*Classical Mechanics:* Deals with the motion of objects and the forces acting upon them, based on Newton's laws of motion. It is applied in understanding daily-life objects and engineering systems.

*Thermodynamics:* Studies heat, temperature, and their relationship to energy and work, exploring how energy is transferred and transformed, and is foundational for engines, refrigerators, and power plants.

*Electromagnetism:* Examines electric and magnetic fields and their effects on objects. It is essential for understanding electricity, magnetism, and light, forming the basis for technologies like electric motors, communication systems, and lighting.

*Optics:* Focuses on the study of light and its interactions with matter, essential in the development of lenses, microscopes, and fiber-optic technology.

*Quantum Mechanics:* Investigates the behavior of particles at the atomic and subatomic level, explaining phenomena that cannot be described by classical physics, and is crucial for advancements in electronics, computing, and material science.

# PRINCIPLES AND PERSPECTIVES OF PHYSICS

- d) Understand how the particle theory of matter explains the properties of solids, liquids and gases, changes of state, and diffusion(u)
- e) Understand the meaning and importance of plasma in physics (u, v/a)

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

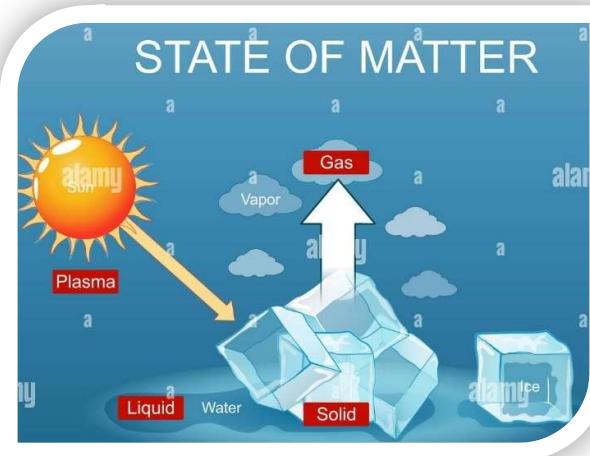
## MATTER

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. 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 physical objects and materials around us like glass, water and the air manifest the existence of matter in its three states. The process of subdividing matter into smaller and smaller units continues indefinitely, suggesting that matter is not continuous, but is made up of even smaller parts.

### 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.

*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, and 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.

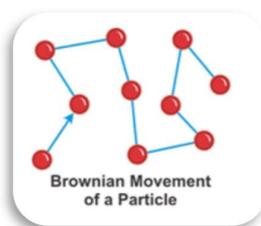
# PRINCIPLES AND PERSPECTIVES OF PHYSICS

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.

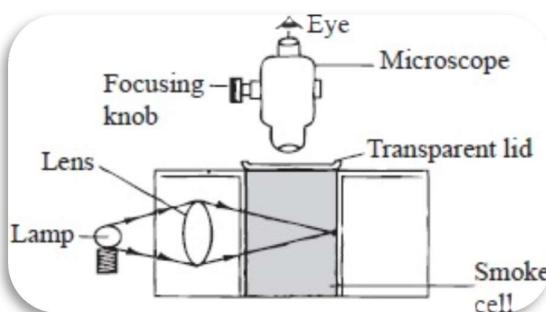


The random motion is caused by the uneven and continuous bombardment of the suspended particles by the molecules of the surrounding fluid, which are in constant motion. Brownian motion provided evidence for the existence of atoms and molecules and supported the kinetic theory of matter, which posits 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 of 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

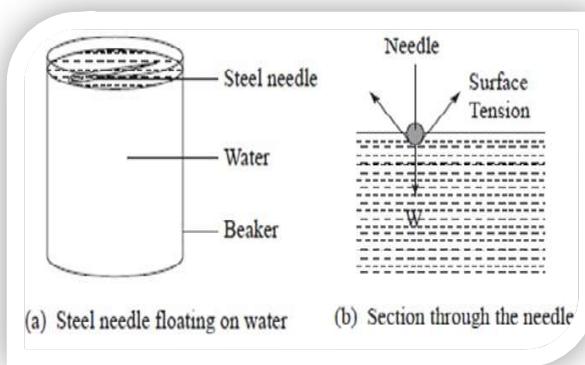
# PRINCIPLES AND PERSPECTIVES OF PHYSICS

## Experiments 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.



## Observation

The needle floats on the surface of the water and remains floating so long as the water surface is not broken.

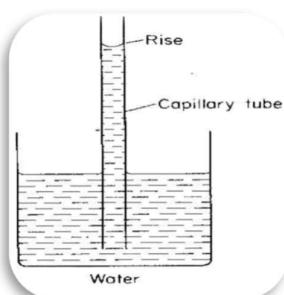
When the surface of the water where the needle lies is observed carefully (a magnifying lens would help), the water surface is found to be slightly depressed and stretched like an elastic skin. When drops of paraffin or soap solution are put on the surface of the water around the needle, the needle sinks on its own after a few seconds. If, alternatively, the tip of the needle is depressed lightly into the water, the needle sinks very quickly to the bottom of the water.

## Explanation

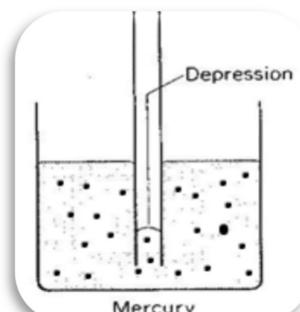
The steel needle or the razor blade floats because the surface of the water behaves like a fully stretched, thin, elastic skin. This skin always has a tendency to shrink, i.e., to have a minimum surface area or elastic membrane. The force which causes the surface of a liquid to behave like a stretched elastic skin is called surface tension. This force is due to the force of attraction between individual molecules of the liquid (cohesion).

The needle or the blade sinks when a drop of kerosene or soap solution is put in the liquid near the needle because the kerosene or soap solution reduces the surface tension of the water. When the tip of the needle is pressed into the water, it pierces the surface skin and sinks.

## CAPILLARITY/CAPILARY ACTION



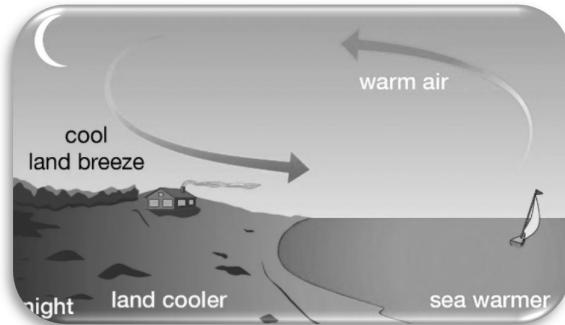
This is the rising or depression of a liquid in a capillary tube or bore. The rise of water in a capillary tube is because the cohesive force between the water molecules is less than the adhesive force between



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.

# PRINCIPLES AND PERSPECTIVES OF PHYSICS

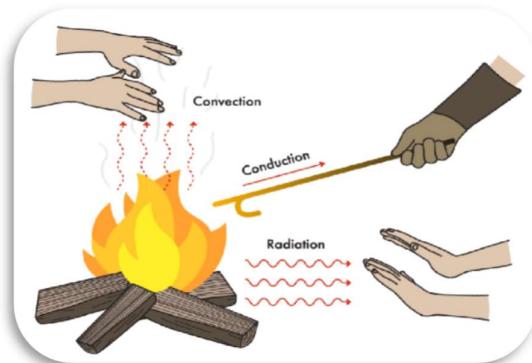
**Land breeze:** Land breezes are local winds that occur at night when the land cools more rapidly than the adjacent body of water. At night, *land loses heat faster* than seawater (*high specific heat capacity*) causing land to be cooler than the sea. As a result, air above the sea becomes warm and less dense, so it rises. The air above the land, which is cold, replaces the warm air resulting in the land breeze. As the temperature over the land decreases, the cooler, denser air flows from the land to the sea, creating a pressure difference. This phenomenon is most prevalent in coastal areas, where the temperature disparity between land and water is significant. In contrast, sea breezes occur during the day when the land heats up faster than the water. The warm air over the land rises, creating a low-pressure area, while the cooler air over the sea moves in to replace it. This cycle of air movement is essential for regulating coastal temperatures and can influence local weather patterns. Both land and sea breezes are examples of how temperature differences can create wind patterns, demonstrating the dynamic relationship between land and water in shaping our environment.



**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:

Radiation is the emission or transmission of energy in the form of waves or particles, a phenomenon that is integral to our environment. It can originate from natural sources, such as cosmic rays and radon gas, or be produced by human-made devices.



Radiation plays a role in various fields, including medicine, where it is used for diagnostic imaging and cancer treatment. Recent advancements in cancer treatment have led to the development of a revolutionary one-second therapy that could potentially replace traditional radiation methods. **Radiation is energy that travels through space or material in the form of waves or particles.** It can originate from unstable atoms undergoing radioactive decay or be produced by machines. Common sources of radiation include natural elements like radon gas, cosmic rays, and medical x-rays. Radiation encompasses various types, including electromagnetic radiation (like light and heat) and particle radiation. This energy can penetrate different materials, making it significant in fields such as medicine, astronomy, and environmental science. For instance, astronomers recently demonstrated infrared radiation to educate the public about its properties and applications. While exposure to certain types of radiation can be harmful, many forms are natural and essential for life. Awareness and education about radiation help mitigate risks and promote safety in its use. This is the transfer

Moreover, diffuse reflection is utilized in advanced technologies, such as machine learning for surface defect detection. By analyzing the scattered light patterns, systems can identify imperfections on various surfaces, enhancing quality control in manufacturing processes.

In photography, for instance, diffusers are employed to soften and evenly distribute light, minimizing harsh shadows and creating a more flattering illumination for subjects. This technique is essential for achieving high-quality images, particularly in portrait and product photography. Diffuse reflection plays a significant role in the design of auditoriums and theaters. By ensuring that sound and light are evenly distributed throughout the space, it enhances the overall auditory and visual experience for audiences. Diffuse reflective photoelectric switches are increasingly utilized in smart home systems for effective lighting control, showcasing the versatility and importance of diffuse reflection in modern technology.

### 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<sub>1</sub> and p<sub>2</sub> vertically

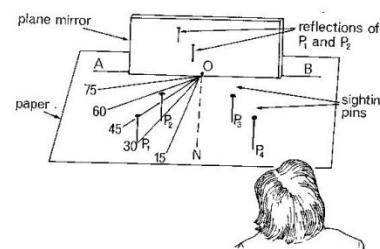
Insert a plain mirror along AB with the reflecting surface facing you.

Looking through the plain mirror in the opposite side, fix pins p<sub>3</sub> and p<sub>4</sub> such that they appear to be in line with images of p<sub>1</sub> and p<sub>2</sub>.

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, hence verifying the laws of reflection

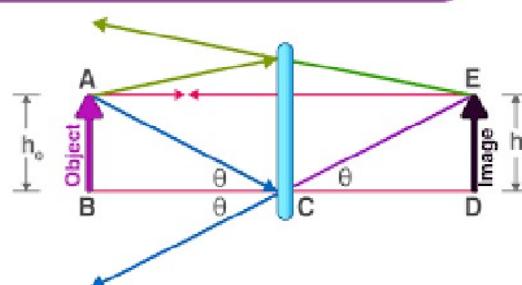


### NATURE OF IMAGE FORMED BY A PLANE MIRROR

Firstly, the image is virtual, meaning it cannot be projected onto a screen as it appears to be located behind the mirror. This occurs because the light rays reflecting off the mirror diverge, creating the illusion of an image at a specific location.

Secondly, the image is upright and maintains the same orientation as the object. This means that if the object is positioned upright, the image will also appear upright. However, it is important to note that the image is laterally inverted, which means that the left and right sides are reversed. For example, if a person raises their right hand, the image in the mirror will show the left hand raised.

#### PLANE MIRROR : CHARACTERISTICS OF IMAGES



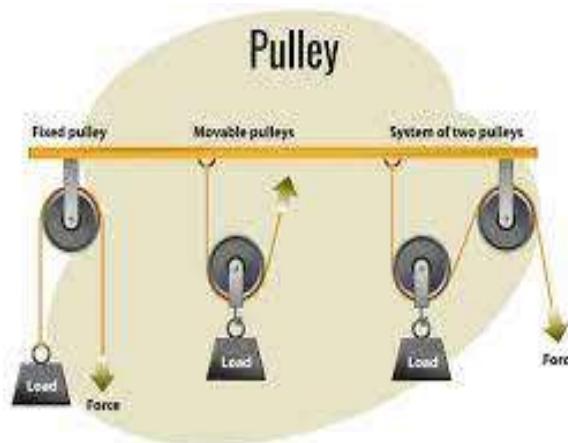
end of the rope is pulled down, the load on the opposite end is lifted, demonstrating the mechanical advantage pulleys provide. In an ideal scenario, where pulleys and ropes are considered weightless and frictionless, the effort required to lift an object decreases as more pulleys are added. This is because each additional pulley increases the length of rope used, effectively reducing the force needed to raise the load. Overall, pulley systems exemplify the principles of mechanical advantage, allowing users to lift heavy objects with less effort, making them invaluable in various applications, from construction to everyday tasks. There are three types of pulleys namely; Single fixed pulley, Single movable pulley. And block and tackle pulley.

### SINGLE FIXED PULLEY:

This is a type of pulley system in which the pulley is fixed on the rigid support.

In a single fixed pulley, the load is tied to one end and the effort applied to another end of the rope. As the rope is pulled downwards, the load is raised upwards.

Therefore, a single fixed pulley eases work by changing the direction of the application of the effort.



Assuming, there is no friction in the groove and the rope is weightless;

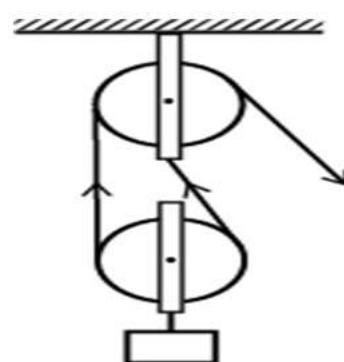
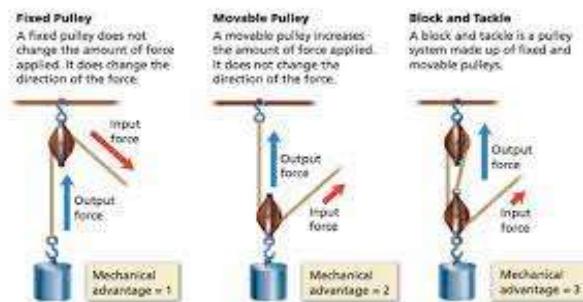
At equilibrium; In real practice, the effort is always greater than the load because it is used overcome friction in the groove and also used to lift the weight of the groove. Therefore, mechanical advantage is always less than 1. However, the distance moved by the effort is always equal to the distance moved by the load.

### SINGLE MOBILE PULLEY:

This is the type of pulley system in which the pulley moves along with the rope.

One end of the rope is fixed to a rigid support and the effort is applied on the other end. The advantage of this pulley system is that less effort is required to lift the load thus raising it easily. Assuming, there is no friction in the groove and the rope is weightless;

At equilibrium; In real practice, the effort is always greater than the load because it is used overcome friction in the groove and also used to lift the weight of the groove. Therefore, mechanical advantage is always less than 2. However, the distance moved by the effort is always twice the distance moved by the load.

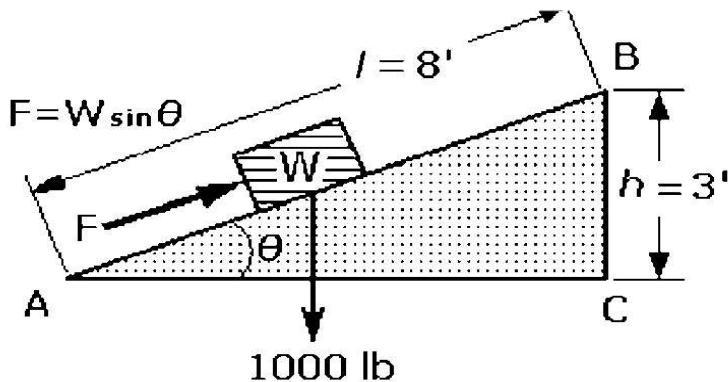


### BLOCK AND TACKLE PULLEY SYSTEM:

This is the type of pulley system where two or more pulleys are combined to form a machine with high velocity ratio and high mechanical advantage. It consists of two blocks namely; fixed block, and movable block.

## Basics of Robotic Mechanisms - INCLINED PLANE

Diagram for calculating mechanical advantage of an inclined plane.



For example, if a weight  $W$  of 1000 lb is to be raised vertically through a height  $BC$  of 3 ft without using an inclined plane, a force  $F$  of 1000 lb must be exerted over that height.

However, with an inclined plane, the weight is moved over the longer distance of 8 ft, but a force  $F$  of only  $3/8$  of 1000 or 375 lb would be required because the weight is moved through a longer distance. To determine the mechanical advantage of the inclined plane, the following formula is used:

$$F = W \sin \theta \quad \sin \theta = \frac{\text{height } h}{\text{length } l}$$

where height  $h = 3 \text{ ft}$ , length  $l = 8 \text{ ft}$ ,  $\sin \theta = 0.375$ , and weight  $W = 1000 \text{ lb}$ .

$$F = 1000 \times 0.375$$

$$F = 375 \text{ lb}$$

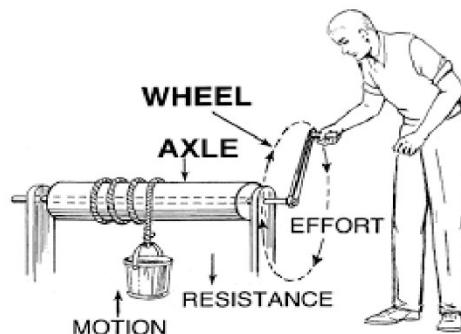
$$\text{Mechanical advantage MA} = \frac{\text{load}}{\text{effort}} = \frac{W}{F} = \frac{1000}{375} = 2.7$$

## WHEEL AND AXLE

The wheel and axle is a fundamental mechanical device that simplifies movement by reducing friction. It consists of a circular wheel attached to a central axle, allowing the wheel to rotate around the axle. This design enables heavy loads to be transported with minimal effort, as the wheel rolls over surfaces rather than dragging.

**Applications of the wheel and axle are vast and varied.**

In transportation, vehicles such as cars, bicycles, and trains utilize this mechanism to facilitate movement. It plays a crucial role in machinery, where it is used in systems like conveyor belts and

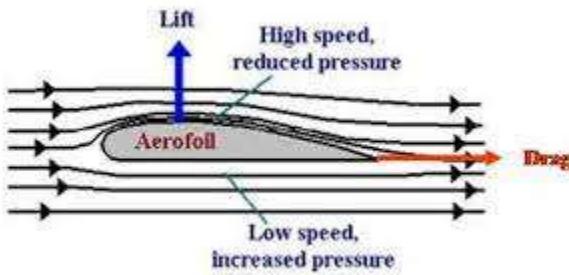


## FLUID MOTION

### BERNOILLI EFFECT

The Bernoulli effect is a fundamental principle in fluid dynamics that explains how changes in fluid speed can affect pressure. According to Bernoulli's principle, as the velocity of a fluid increases, its pressure decreases. This phenomenon is crucial in the functioning of devices like aerofoils and Bunsen burner jets. In aerofoils, the shape of the wing causes air to travel faster over the top surface than the bottom. This speed difference creates lower pressure above the wing, generating lift and allowing airplanes to fly.

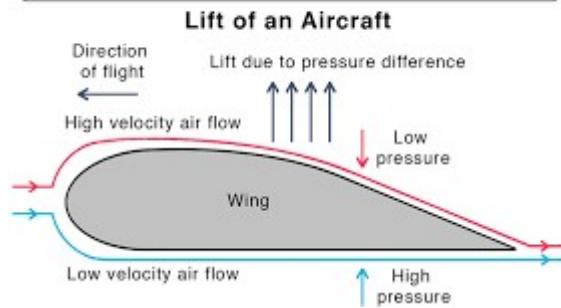
The design of the aerofoil is essential for optimizing this effect, ensuring efficient flight. Similarly, in a Bunsen burner, when the gas valve is opened, gas flows through a narrow opening, increasing its velocity. This rapid flow decreases the pressure, drawing in air through the side openings, which mixes with the gas to create a controlled flame. Thus, the Bernoulli effect plays a vital role in both aviation and combustion technologies.



### Bernoulli's effect and its applications

Consider an ideal, incompressible fluid moving along a streamline. If the fluid moves from point 1 to point 2, the sum of pressure energy, kinetic energy, and potential energy remains constant.

### Bernoulli's Principle Example

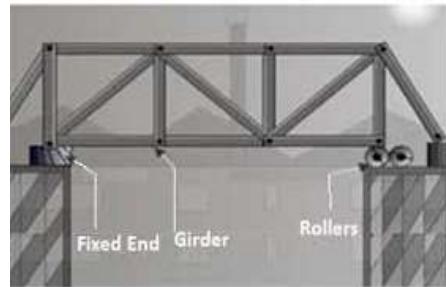


### Applications of Bernoulli's Principle:

Bernoulli's principle, which states that an increase in fluid speed results in a decrease in pressure, has numerous practical applications across various fields. One of the most notable applications is in aviation, where it explains how aircraft generate lift. The shape of an airplane wing causes air to travel faster over the top surface, resulting in lower pressure above the wing compared to the higher pressure below, thus lifting the plane. In addition to aviation, Bernoulli's principle is utilized in fluid dynamics to analyze flow behavior in pipes and ducts. Devices like venturimeters, which measure fluid flow rates, rely on this principle to determine velocity changes as fluid passes through constricted sections. Furthermore, it plays a crucial role in sports, such as in the design of golf balls and soccer balls, where surface features are optimized to enhance lift and reduce drag. Overall, Bernoulli's principle is fundamental in engineering, transportation, and sports, demonstrating its wide-ranging impact on technology and daily life.

## GIRDERS

Girders are essential structural components in construction, serving as the primary support for buildings and bridges. They are defined as large horizontal beams, girders bear significant vertical loads and can accommodate dynamic and rolling loads, making them crucial for structural integrity. They connect to smaller beams, forming a framework that distributes weight effectively throughout the structure.



Unlike standard beams, which primarily support smaller loads, girders are designed to handle concentrated forces and larger spans. This distinction allows girders to play a pivotal role in maintaining stability and safety in various constructions, from skyscrapers to bridges. Typically made from materials like steel or reinforced concrete, girders are engineered to withstand substantial stress. Their robust design ensures that they can support the weight of the structure above while transferring loads to the foundation below, making them indispensable in modern architecture and engineering. Hence, 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

Hollow beams, particularly hollow structural sections (HSS), offer numerous advantages in construction and engineering. One of the primary benefits is their uniform strength distribution, which enhances structural integrity. This design minimizes the likelihood of bending or deformation under load, making them ideal for various applications.

Additionally, hollow beams are lightweight, facilitating easier transportation and installation. Their reduced weight does not compromise strength, allowing for significant load-bearing capabilities while conserving material. This efficiency translates to cost savings in both material and labor. Hollow beams are versatile and aesthetically appealing, fitting seamlessly into modern architectural designs. They can be easily fabricated and customized, making them a popular choice for builders and architects alike. Furthermore, their recyclability aligns with sustainable construction practices, contributing to a greener environment.

### Disadvantages of solid beams

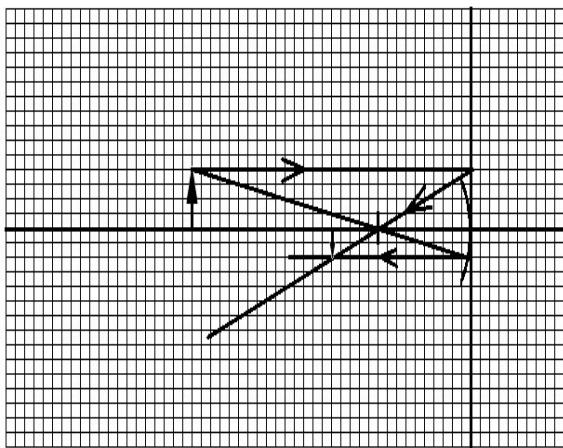
They are heavier, economically expensive and sometimes weak

### Disadvantages of a material used in the neutral axis

It is a wastage and un necessary

# PRINCIPLES AND PERSPECTIVE OF PHYSICS

## 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

$M = \frac{h_i}{h_o}$ , where  $h_i$  – image height,  $h_o$  – object height

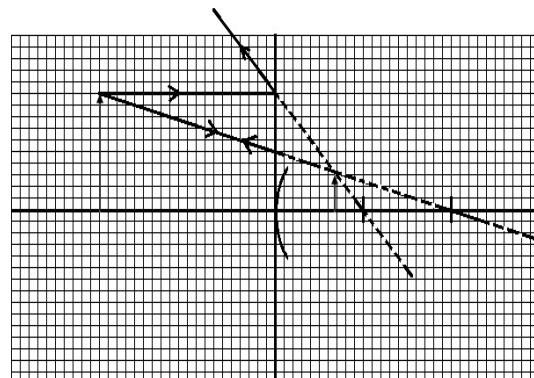
**OR**

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)

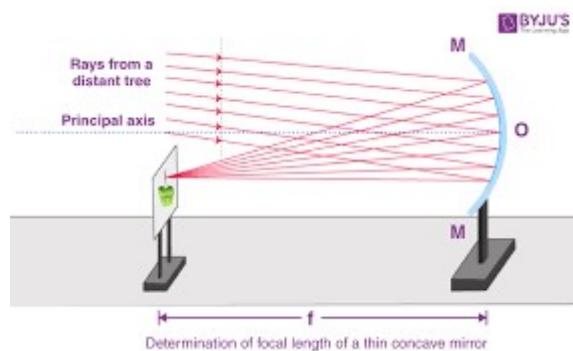


## MEASURING FOCAL LENGTH OF A CONCAVE MIRROR

### 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



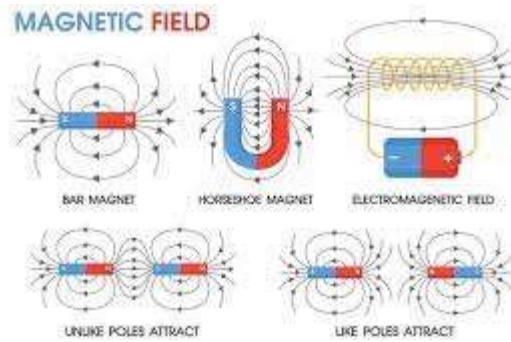
# PRINCIPLES AND PERSPECTIVE OF PHYSICS

Magnetic fields are generated by moving electric charges, which is why they are closely associated with electricity. In a magnet, the movement of electrons within the atoms, particularly their spin and orbital motion, creates the magnetic field. In larger-scale systems, such as electromagnets, magnetic fields are produced when an electric current flows through a conductor, such as a coil of wire. The strength of this field can be increased by increasing the current or by using a ferromagnetic material like iron as a core.

Magnetic fields are generated whenever electric charges are in motion. This phenomenon occurs at both macroscopic and microscopic levels. For instance, the movement of electrons around an atomic nucleus creates a magnetic field, while larger currents flowing through wires also produce magnetic fields.

When electric current flows through a conductor, such as a wire, it generates a magnetic field that encircles the wire. This effect can be amplified by coiling the wire into loops or coils, which concentrates the magnetic field lines and enhances the overall strength of the magnetic field produced.

Additionally, intrinsic magnetic moments of elementary particles, such as electrons, contribute to the creation of magnetic fields. These moments arise from the particles' spin and charge, further illustrating the fundamental relationship between electricity and magnetism. Thus, magnetic fields are a direct result of moving charges and the properties of particles at the quantum level.



## Types of Magnetic Materials

Magnetic materials can be classified into several categories based on their magnetic properties. The primary types include diamagnetic, paramagnetic, ferromagnetic, and ferrimagnetic materials. Ferromagnetic materials, such as iron, cobalt, and nickel, have strong magnetic properties because their atomic magnetic moments align to form magnetic domains. When exposed to an external magnetic field, these domains align in the same direction, creating a strong overall magnetic field. Paramagnetic materials, such as aluminum and platinum, have weak and temporary alignment with the magnetic field, while diamagnetic materials, like copper and bismuth, are repelled by the field due to induced opposing magnetic moments.

Diamagnetic materials, such as copper and bismuth, exhibit a weak repulsion to magnetic fields, making them the least magnetic. In contrast, paramagnetic materials, like aluminum and platinum, are weakly attracted to magnetic

TYPES OF MAGNETIC MATERIALS WITH EXAMPLES			
Ferrimagnetics	Fe <sub>2</sub> O <sub>3</sub> , PbFe <sub>1-x</sub> O <sub>x</sub> , BaFe <sub>1-x</sub> O <sub>x</sub> , BaO·δFe <sub>2</sub> O <sub>3</sub> , SrO·δFe <sub>2</sub> O <sub>3</sub>	Antiferromagnetics	MnO, FeO, CoO, FeMn, NiO, MnS, MnF <sub>2</sub>
Diamagnetics	Copper, Mercury, Bismuth, Zinc, Magnesium, Gold, Silicon, Phosphorus, Water, Graphite, Proteins	Paramagnetics	Platinum, Aluminium, Air, Sodium, Tin, Oxygen, Hydrogen
			Ferromagnetics
			Iron, Cobalt, Nickel, Gadolinium, Dysprosium, Erbium, Holmium

# PRINCIPLES AND PERSPECTIVE OF PHYSICS

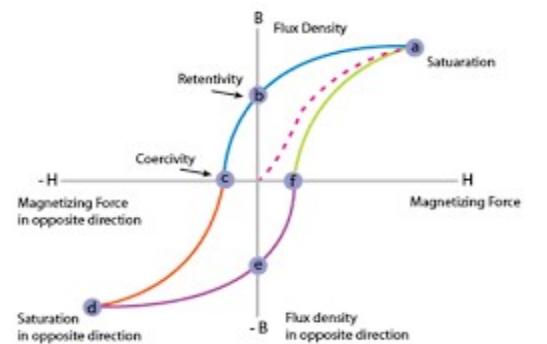
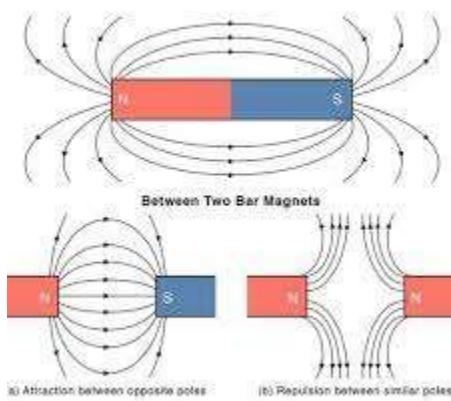
When a magnet is placed in a magnetic field, it experiences forces that depend on the orientation of its poles relative to the field. If the magnet's north pole is near the north pole of another magnet, they will repel each other, causing the magnet to move away. If the north pole of one magnet is near the south pole of another, they will attract and move closer. These interactions demonstrate the alignment tendencies of magnetic dipoles in external magnetic fields. Additionally, the strength of the magnetic interaction diminishes with distance, following an inverse square law. Magnets exhibit fascinating behavior when placed in a magnetic field, which can be categorized into permanent and temporary types.

Permanent magnets retain their magnetic properties indefinitely, while temporary magnets, such as electromagnets, only exhibit magnetism when an electric current is applied. The strength and direction of a magnet's influence are quantified by its magnetic moment, which is determined by the alignment of electron spins within the material. When magnets interact with a magnetic field, they can attract or repel other magnetic materials, such as iron, nickel, and cobalt. This interaction is governed by the orientation of the magnetic field lines, which emerge from the magnet's north pole and re-enter at the south pole. The behavior of magnets is not only limited to solid materials; researchers have even discovered ways to manipulate the movement of bacteria using magnetic fields, showcasing the diverse applications of magnetism in science.

## Magnetic Materials and Magnetization

Magnetic materials are characterized by the presence of atomic magnetic dipoles, which can align to produce a net magnetism that is observable on a macroscopic scale. The origin of magnetism is rooted in the orbital and spin motions of electrons, as well as their interactions. This alignment of dipoles is crucial for the material to exhibit magnetic properties. There are several classes of magnetic materials, including ferromagnetic, paramagnetic, and diamagnetic substances. Ferromagnetic materials, like iron, can become permanently magnetized, while paramagnetic materials exhibit weak magnetism in the presence of an external magnetic field. Diamagnetic materials, on the other hand, are repelled by magnetic fields.

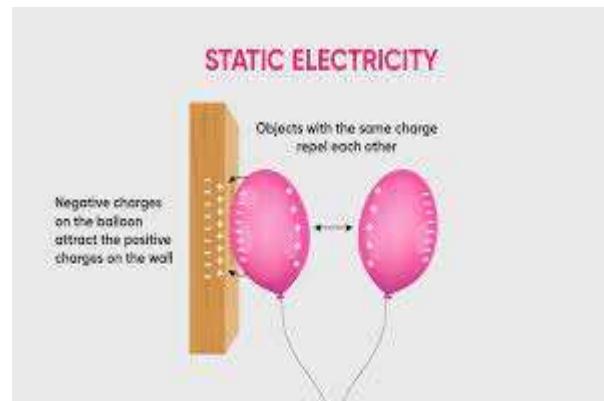
## Electromagnetic Interaction



# PRINCIPLES AND PERSPECTIVE OF PHYSICS

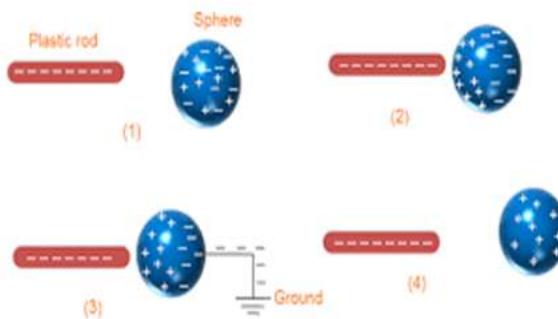
## ELECTRIFICATION

Electrification is the process of transforming a neutral body into a charged one, a phenomenon that occurs universally. This process involves the transfer of electric charge, typically through the movement of electrons. When an object gains or loses electrons, it becomes electrically charged, resulting in an imbalance of charges. This imbalance can lead to static electricity, where charges remain on the surface of materials until they find a path to neutralize. Static electricity arises from the interaction between negatively charged objects and positively charged ones, often through friction. For instance, rubbing materials together can cause electrons to transfer, creating a charge imbalance. This principle is illustrated in the triboelectric series, which ranks materials based on their tendency to gain or lose electrons.



## Methods of producing Electric charges

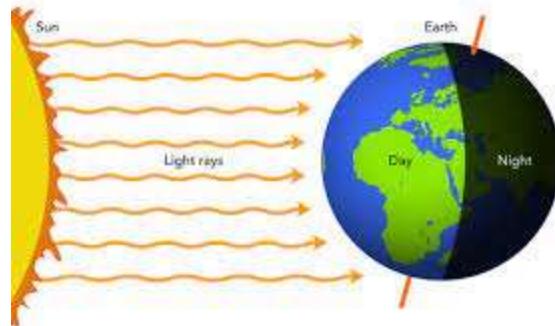
Electric charges can be produced through several methods, charging by friction, where two uncharged objects are rubbed together, causing electrons to transfer from one object to another. This results in one object becoming positively charged and the other negatively charged. Another method is charging by conduction, which occurs when a charged object comes into direct contact with an uncharged object. The charged object transfers some of its charge to the uncharged object, resulting in both objects carrying a similar charge. Charging by induction involves bringing a charged object close to an uncharged conductive material without direct contact. This causes a redistribution of charges within the uncharged object, leading to a temporary charge separation.



# PRINCIPLES AND PERSPECTIVE OF PHYSICS

## Day and night

The formation of day and night on Earth is a result of its rotation on an imaginary line known as the axis. As the Earth spins, different parts of the planet are exposed to sunlight, creating the cycle of day and night. When a specific area faces the Sun, it experiences daylight, while the opposite side remains in darkness, resulting in nighttime.



This rotation occurs approximately every 24 hours, which is why we have a consistent cycle of day and night. The spherical shape of the Earth ensures that only half of it can receive sunlight at any given moment. As the Earth continues to rotate, the areas that were once in darkness gradually move into the light, transitioning from night to day. 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 do not get to you. 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.

## Seasons in some parts of the earth

The formation of seasons on Earth is primarily due to the planet's axial tilt of approximately 23.5 degrees. This tilt causes different parts of the Earth to receive varying amounts of sunlight throughout the year. As Earth orbits the Sun, the angle at which sunlight strikes the surface changes, leading to the distinct seasons we experience: spring, summer, autumn, and winter. During summer, the hemisphere tilted towards



the Sun receives more direct sunlight, resulting in warmer temperatures. Conversely, during winter, the same hemisphere is tilted away from the Sun, leading to cooler temperatures and shorter days. The transition periods of spring and autumn occur as the Earth moves between these extremes, with varying sunlight and temperatures. This consistent pattern of changing seasons is a result of Earth's revolution around the Sun combined with its axial tilt, creating a dynamic and ever-changing climate that influences ecosystems and human activities alike.

# PRINCIPLES AND PERSPECTIVE OF PHYSICS

universe was formed from an infinitely dense and hot core of the material. The bang in the title suggests there was an explosive, outward expansion of all matter and space that created atoms. Spectroscopy confirms that hydrogen makes up about 74% of all matter in the universe. Since its creation, the universe has been expanding for 13.8 billion years and recent observations suggest the rate of this expansion is increasing.

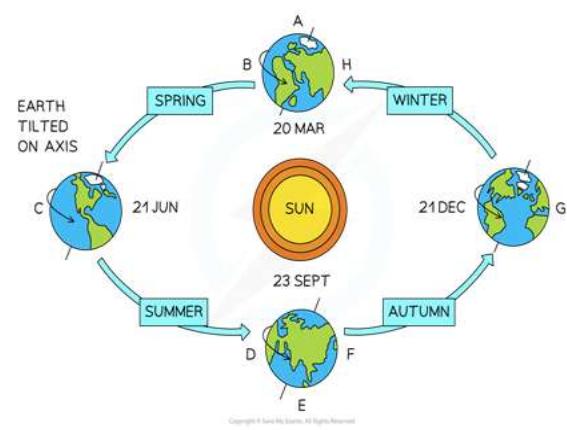
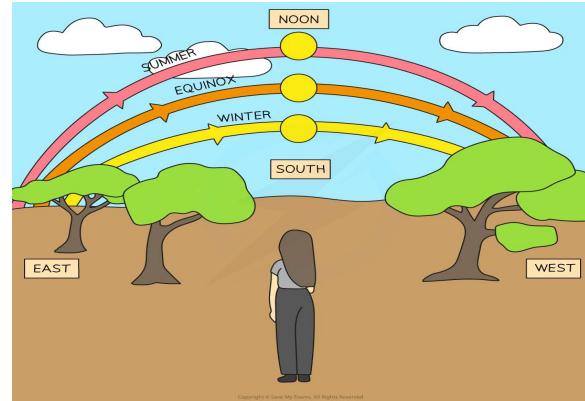
## The Earth's Axis

The Earth is a rocky planet that rotates in a near circular orbit around the Sun. It rotates on its axis, which is a line through the north and south poles. The axis is tilted at an angle of approximately  $23.5^\circ$  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.

## Rising and Setting of the Sun

The Earth's rotation on its axis makes the Sun look 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 21<sup>st</sup> 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 21<sup>st</sup> December. This is known as the **Winter Solstice** and is where the Sun is at its lowest point in the sky all year.



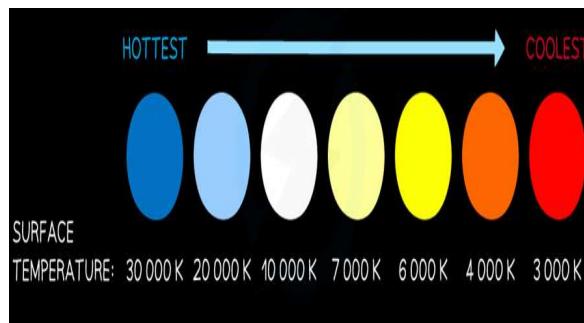
## The Earth's Orbit

# PRINCIPLES AND PERSPECTIVE OF PHYSICS

## Our Sun

Stars come in a wide range of sizes and colours, from yellow stars to red dwarfs, from blue giants to red supergiant. 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.

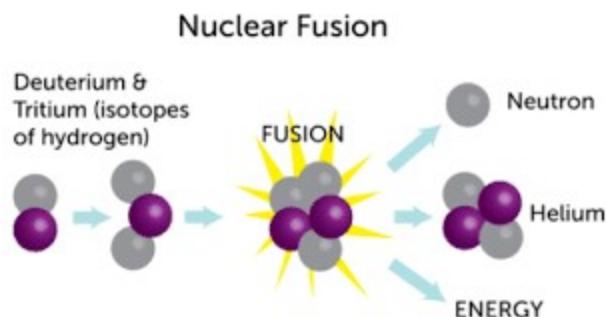


## Nuclear Fusion in Stars

Nuclear fusion is the fundamental process that powers stars, including our Sun. It occurs when two light atomic nuclei, typically hydrogen, collide and merge to form a heavier nucleus, such as helium. This reaction releases vast amounts of energy in the form of light and heat, which is essential for maintaining the star's temperature and preventing gravitational collapse. In the core of stars, extreme temperatures and pressures facilitate these fusion reactions. The energy produced not only sustains the star's brightness but also contributes to the creation of heavier elements through a process known as stellar nucleosynthesis. As stars evolve, they can fuse heavier elements, enriching the universe with diverse chemical elements.

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.**

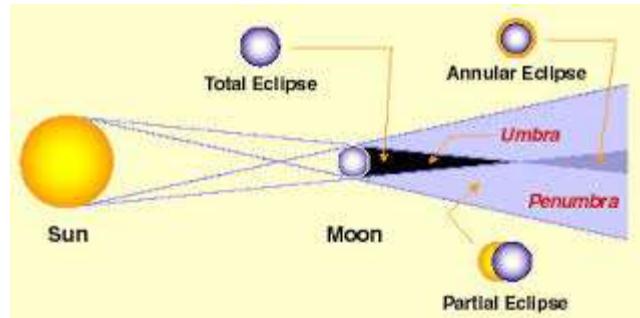
They can be formed through other fusion reactions in the star. A huge amount of energy is released in the reaction. This provides a pressure that prevents the star from collapsing under its gravity. The fusion of deuterium and tritium to form helium with the release of energy.



During a lunar eclipse, the Moon can take on a striking reddish hue, often referred to as a "blood moon." This phenomenon occurs due to Rayleigh scattering, where sunlight passes through the Earth's atmosphere and bends, allowing some light to reach the Moon while filtering out other colors. The result is a captivating display that has intrigued humanity for centuries. Lunar eclipses can occur several times a year, but total eclipses, where the Moon is completely covered by Earth's shadow, are less frequent.

### ANNULAR ECLIPSE

An annular solar eclipse is a fascinating celestial event that occurs when the Moon passes between the Earth and the Sun, but is at or near its farthest point from Earth. During this type of eclipse, the Moon appears smaller than the Sun, resulting in a striking "ring of fire" effect, where the outer edges of the Sun remain visible around the Moon. This phenomenon contrasts with a total solar eclipse, where the Moon completely covers the Sun. The annular eclipse is a unique spectacle, as it allows observers in specific regions to witness this stunning visual display. The next notable annular solar eclipse will occur on October 14, 2023, crossing parts of North, Central, and South America. Observers in the path of annularity will experience the full effect of the ring of fire, while those outside this path will see a partial eclipse.



### ACTIVITY

1. Imagine you are tasked with leading a space mission to explore Mars and establish a permanent colony on one of Jupiter's moons, Europa. Task;
  - i). What challenges might you face in landing a rover on Mars and sustaining human life on Europa?
  - ii). How would you address issues like communication delays, extreme weather conditions, resource management (food, water, oxygen), and the design of long-term habitats?
2. A massive rogue planet enters the solar system, altering the gravitational balance. Task;
  - i). How might this affect the orbits of planets, including Earth?
  - ii). If a rare planetary alignment occurred during this event, how could it influence Earth's tides and climate?
  - iii). What technologies or strategies would you use to monitor and mitigate these effects?
3. NASA has discovered a moon with liquid water beneath its icy surface and potential signs of microbial life. Simultaneously, a solar storm is predicted to disrupt Earth's satellites and power grids. Task;
  - i). Design an experiment to search for life on the moon and explain how the findings might reshape our understanding of extraterrestrial life.

**Uniform motion** refers to the movement of an object traveling in a straight line at a constant speed. In this type of motion, the object covers equal distances in equal intervals of time, meaning its velocity remains unchanged. This can be represented graphically as a straight line on a distance-time graph, indicating that the object is not accelerating or decelerating. For example, a car moving at a steady speed of 60 km/h on a straight highway exemplifies uniform motion. In contrast, non-uniform motion occurs when an object's speed or direction changes, resulting in varying distances covered in equal time intervals.

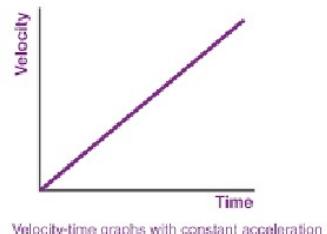
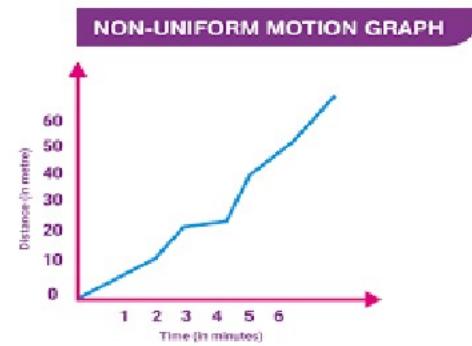
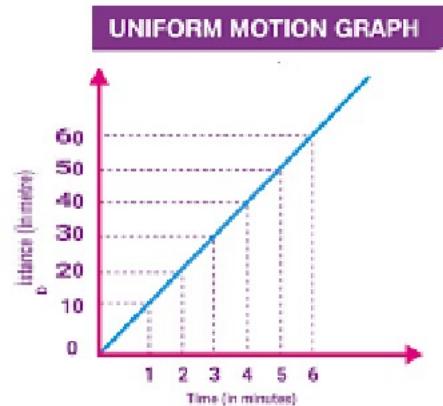
**Constant velocity motion** occurs when an object moves at a steady speed in a straight line, while uniformly accelerated motion involves a consistent change in velocity over time. Free fall describes the motion of an object under the influence of gravity alone. In practical applications, linear motion systems are essential in various technologies, including automation and robotics. These systems often incorporate components like linear bearings, actuators, and slides, which facilitate smooth and precise movement. Examples include screw drives and linear motors, which are crucial for tasks requiring accurate positioning.

**Non-uniform motion** refers to the movement of an object that changes its speed or direction over time. Unlike uniform motion, where an object travels equal distances in equal intervals, non-uniform motion involves varying distances covered in the same time frame. This can occur due to acceleration or deceleration, resulting in a change in velocity. For example, consider a car navigating through city traffic. It may speed up on a clear road and slow down at traffic lights, demonstrating non-uniform motion. The velocity of the car is not constant, as it fluctuates based on external conditions. Graphically, non-uniform motion can be represented by a curve on a distance-time graph, indicating the changes in speed.

**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:  $s=vt$ , 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

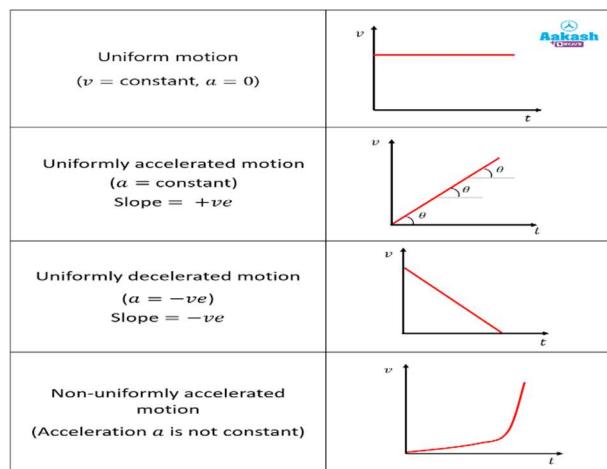


Velocity-time graphs with constant acceleration

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

- For a body at rest If a body is at rest its distance from a certain point does not change as time passes
- 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.
- Body moving with non-uniform velocity; varying distances are moved in equal intervals of time
- 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

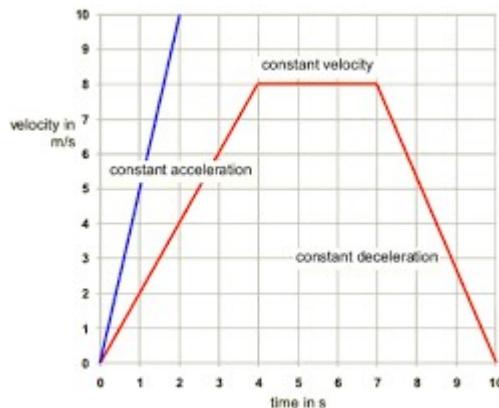
- Body moving with uniform velocity
- Body moving with uniform acceleration
- Body moving with uniform deceleration.

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.

A velocity-time graph is a crucial tool in physics that illustrates how an object's velocity changes over time.

The graph's shape provides valuable insights into the object's motion. For instance, a horizontal line indicates constant velocity, meaning the object is moving at a steady speed without acceleration. A straight diagonal line signifies uniform acceleration, where the object's velocity increases or decreases at a constant rate. The slope of the line on a velocity-time graph is particularly significant, as it represents the object's acceleration. A steeper slope indicates greater acceleration, while a flatter slope suggests less acceleration. If the graph curves, it indicates that the acceleration is changing over time, which can occur in various real-world scenarios.



### Activity

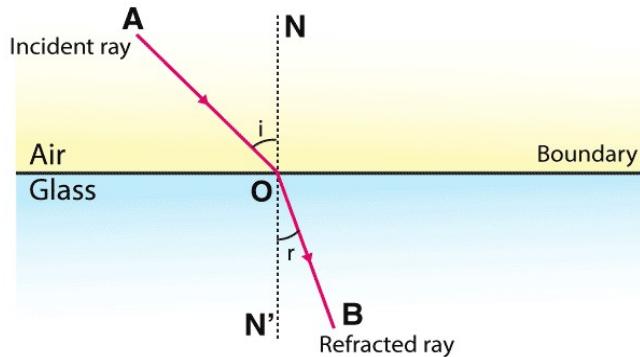
- A car starts from rest and steadily accelerates for 10s to a velocity of 20m/s. It continues with this velocity for a further 20s before it is brought to rest in 20s
  - Draw a velocity time graph to represent this motion.
  - Calculate (i) acceleration, (ii) deceleration, (iii) distance travelled, (iv) average speed

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.

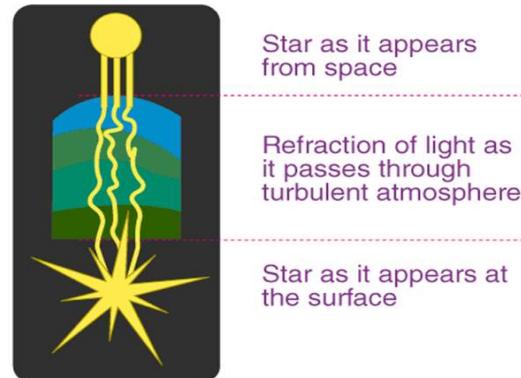
**Refraction** can also be defined as the change in speed of light when it moves from one medium to another of different optical densities. When a ray of light enters an optically denser medium, it is bent towards the normal and when it enters a less dense medium it is bent away from the normal



## CONSEQUENCES OF REFRACTION OF LIGHT

Refraction of light is the bending of light rays as they transition between different media, resulting in a change in their path. This phenomenon is crucial in various applications, including the creation of lenses, magnifying glasses, and prisms. Our eyes also rely on refraction to focus light, enabling us to see clearly. The consequences of refraction extend beyond optical devices. It plays a significant role in natural occurrences, such as the formation of rainbows and the twinkling of stars.

Additionally, optical illusions like mirages and looming effects are direct results of light refraction, showcasing its impact on our perception of reality.



### Why do stars twinkle?

As a star's light penetrates the Earth's atmosphere, every individual stream of starlight is refracted; caused to change direction, slightly by the various temperature and density layers in Earth's atmosphere. You might think of it as the light travelling a zig-zag path to our eyes, instead of the straight path the light would travel if Earth didn't have an atmosphere.

The atmosphere of the earth is made of different layers. It is affected by winds, varying temperatures, and different densities as well. When light from a distant source (a star) passes through our turbulent (moving air) atmosphere, it undergoes refraction many times. When we finally perceive this light from a star, it appears to be twinkling! This is because some light rays

When the light exits the prism, the colors separate further due to a second refraction at the boundary between the glass and air.

### Practical applications of dispersion of white light

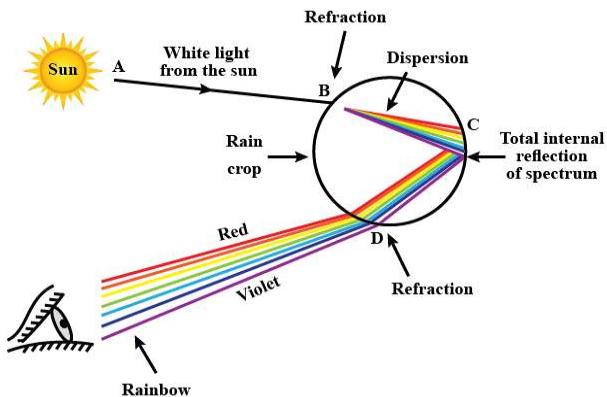
One significant application is in fields like optics and spectroscopy, in spectrometers, prisms are used to analyze the spectral composition of light, which helps in identifying materials or chemical compositions. By scanning the grating, these instruments can identify the composition of materials based on their light absorption and emission characteristics.

Dispersion plays a crucial role in medical imaging techniques, such as quantitative phase imaging, which enhances the visualization of biological samples. Moreover, the principles of light dispersion are harnessed in optical technologies, including fiber optics and sensors, improving data transmission and detection capabilities.

Dispersion also underpins the functioning of devices like prisms in binoculars and the design of lenses in cameras to minimize chromatic aberration (unwanted dispersion of light).

### Everyday Examples

**Rainbows:** A rainbow is formed through the interaction of sunlight with water droplets in the atmosphere, involving the processes of refraction, reflection, and dispersion. When sunlight enters a water droplet, it slows down and bends due to refraction, as light moves from the less dense air into the denser water. Inside the droplet, the light undergoes dispersion, splitting into its constituent colors because different wavelengths of light refract by different amounts. This reflection further enhances the dispersion of colors, creating the vibrant arc we see as a rainbow. The spherical shape of raindrops plays a crucial role in this process, as it allows for the consistent bending and reflecting of light. Shorter wavelengths, such as violet and blue, refract more than longer wavelengths like red and orange. The light then reflects off the inner surface of the droplet, reversing its path. As the reflected light exits the droplet, it refracts again, bending away from the droplet and further separating into distinct colors. This combination of refraction, internal reflection, and dispersion creates the vibrant spectrum of colors that form a rainbow. The angle at which the light exits the droplet determines the position of the colors, with red appearing on the outer edge and violet on the inner edge. Rainbows are typically seen when the observer has their back to the sun, as the refracted light from millions of droplets converges to create a circular arc of colors.



**CDs and DVDs:** The reflective surfaces of these discs cause dispersion due to diffraction, which also separates light into its colors.

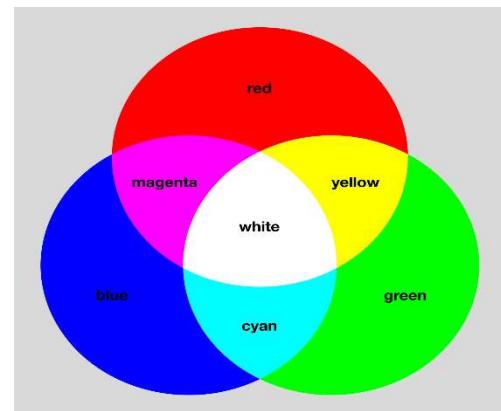
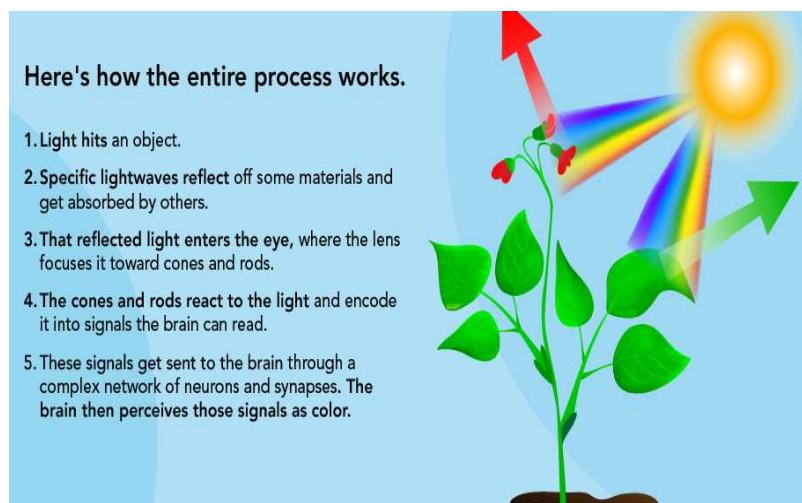
**Crystal Chandelier Effects:** Light passing through the faceted surfaces of a crystal chandelier disperses into a colorful display.

A **pure spectrum** is a display of distinct and separate colors produced when white light is dispersed through a prism or diffraction grating, with each wavelength clearly visible and not overlapping. It consists of the full range of visible colors arranged in order of increasing wavelength, from violet to red, without blending between them.

## COLORS OF OBJECTS

The color of an object is determined by the wavelengths of light it reflects, absorbs, or transmits. When white light, which contains all colors, strikes an object, certain wavelengths are absorbed while others are reflected. For instance, a red ball appears red because it absorbs green, blue, and violet wavelengths, reflecting only the red wavelengths back to our eyes.

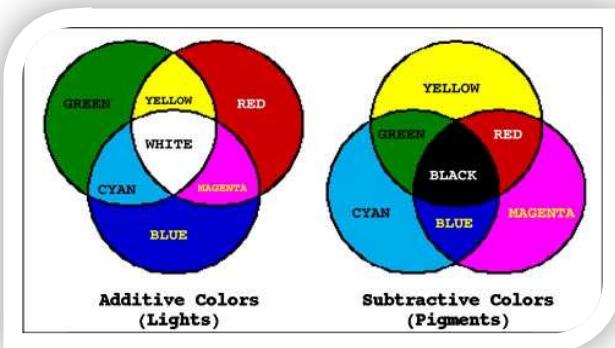
This interaction between light and objects is fundamental to our perception of color. The wavelengths that are reflected determine the color we see. For example, a blue object reflects blue light and absorbs other colors, while a yellow object reflects yellow light. The colour it transmits or reflects 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. This principle applies to all colored objects, making color perception a fascinating aspect of physics and biology. A white object reflects all the colours of the spectrum into the eyes and absorbs none.



## Types of colours

Primary colors are the foundation of color theory, consisting of red, yellow, and blue. These colors cannot be created by mixing other colors together, making them unique in the color spectrum. They serve as the building blocks for all other colors, including secondary colors.

Mixing colored pigments involves the principles of subtractive color mixing, where pigments absorb certain wavelengths of light and reflect others. When pigments are combined, they absorb more wavelengths, resulting in a new color. For instance, mixing yellow and blue pigments produces green because yellow absorbs blue light while blue absorbs yellow light, leaving only green to be reflected. In contrast, additive color mixing occurs with light, where different wavelengths are combined to create new colors. For example, mixing red and green light results in yellow. This distinction is crucial in various applications, such as painting, printing, and photography, where understanding how colors interact can lead to desired outcomes. The rarity of certain colors in nature, like blue, can also be explained through physics. Blue pigments are less common because they require specific structural properties to reflect blue light, making them a unique phenomenon in the natural world.

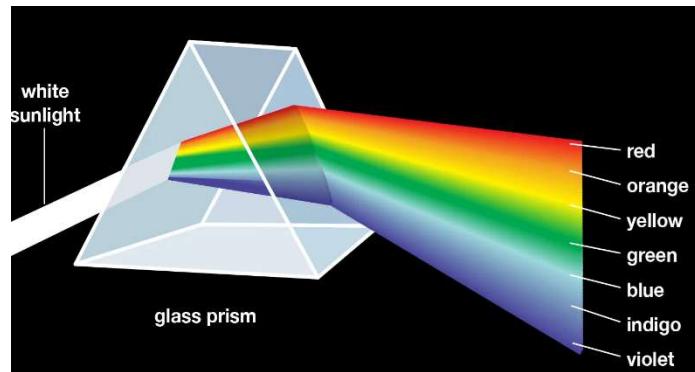


**A pigment is a substance which gives its colour to another substance .A pigment absorbs all the colours except its own which it reflects.**

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

The appearance of color pigments in white light is a fascinating interplay of reflection and absorption. White light, which consists of all visible wavelengths, appears white because it reflects all colors equally. When an object is white, it reflects the entire spectrum of light, allowing us to perceive it as such. In contrast, colored pigments work by selectively absorbing certain wavelengths of light while reflecting others. For instance, a red pigment absorbs blue and green wavelengths but reflects red light. This selective absorption is what gives the pigment its color. Therefore, when white light hits a red object, the red wavelengths are reflected back to our eyes, making the object appear red. This principle of color subtraction explains why objects appear colored under white light. The interaction between light and pigments is essential in various applications, from art to technology, influencing how we perceive and utilize color in our environment.



## 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

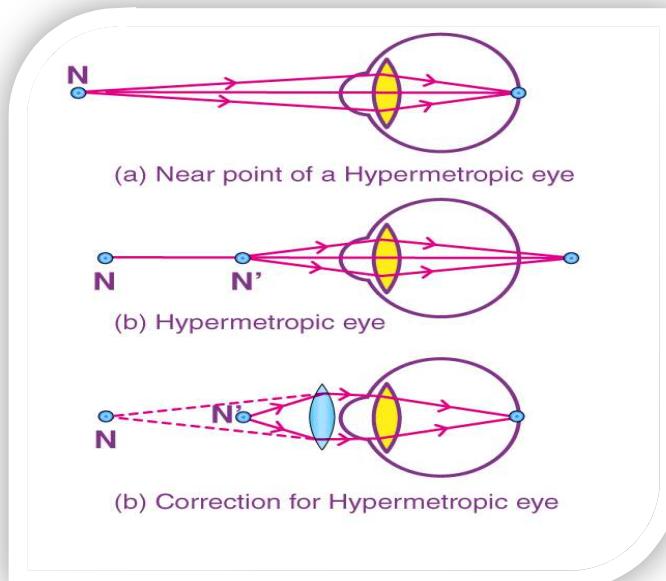
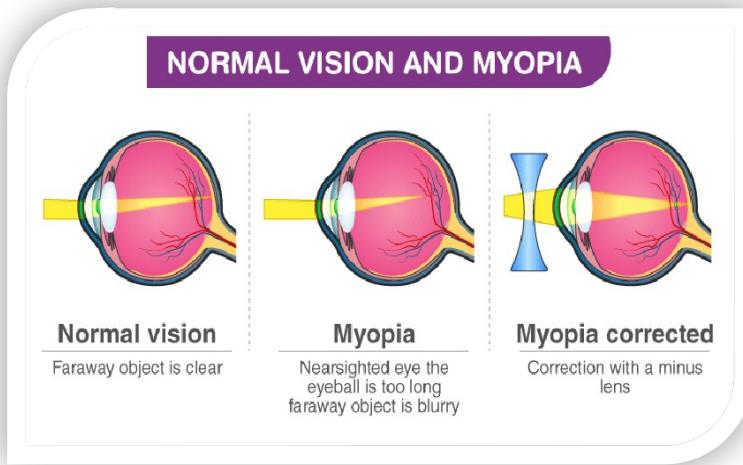
### SHORT SIGHTEDNESS (MYOPIA)

Myopia, commonly known as shortsightedness, is a refractive error that affects the ability to see distant objects clearly. This condition occurs when the eyeball is elongated or the cornea is overly curved, causing light to focus in front of the retina instead of directly on

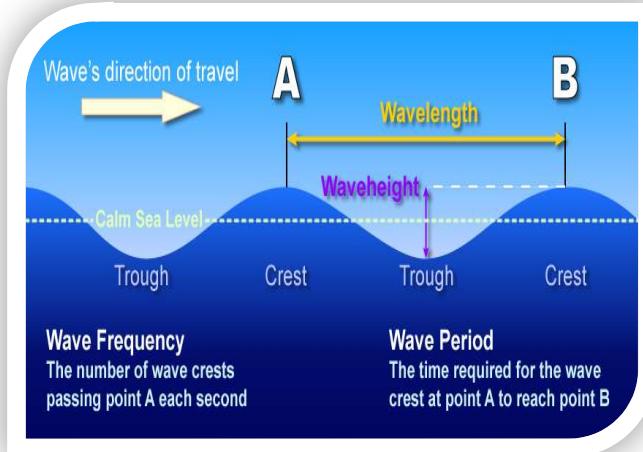
it. As a result, individuals with myopia struggle to see faraway objects, such as street signs or faces in a crowd. Symptoms of myopia typically include blurred vision at a distance, squinting, and eye strain. It is increasingly prevalent, particularly among children, due to factors like excessive screen time and limited outdoor activities. **Treatment options** for myopia include corrective lenses, such as glasses or contact lenses, and in some cases, refractive surgery. Lifestyle changes, like spending more time outdoors and reducing screen exposure, can also help manage the condition and slow its progression.

### LONG SIGHTEDNESS

Long sightedness (hyperopia), is a common vision condition where distant objects may be seen more clearly than those that are near. This occurs when the eyeball is too short or the cornea has too little curvature, causing light rays to focus behind the retina instead of directly on it. As a result, individuals may experience difficulty with tasks such as reading or sewing, leading to eye strain and discomfort. Symptoms of long sightedness can include blurred vision, headaches, and difficulty concentrating on close-up tasks. Children may not always recognize their vision



A wave is a disturbance that travels through a medium, transferring energy from one location to another without the permanent displacement of particles. This phenomenon can be observed in various forms, such as sound waves in air, water waves on the surface of a lake, and light waves in a vacuum. Each type of wave exhibits unique characteristics, including wavelength, amplitude, and frequency, which define its behavior and properties. Waves can be classified into two main categories: mechanical and electromagnetic. Mechanical waves, like sound and water waves, require a medium to propagate, while electromagnetic waves, such as light, can travel through a vacuum. The study of waves is essential in various fields, including physics, engineering, and acoustics, as they play a crucial role in communication, energy transfer, and many natural phenomena.

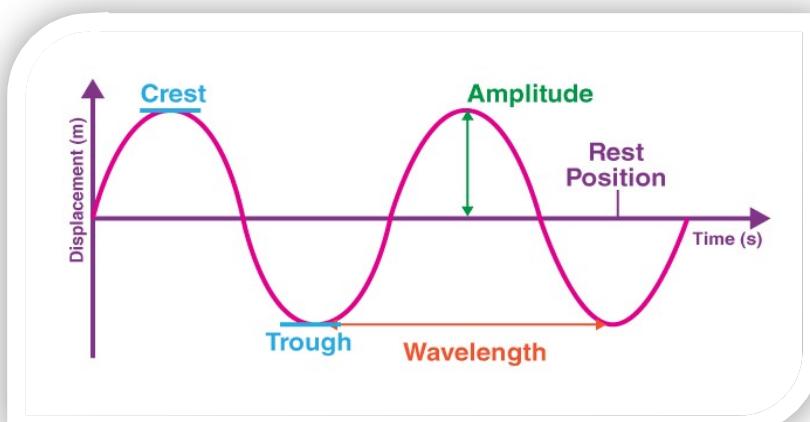


### How Waves Transmit Energy

Waves are fundamental phenomena that transmit energy through various mechanisms. In mechanical waves, energy is transferred through the vibrations of particles within a medium, such as air or water. For instance, sound waves propagate by causing air molecules to oscillate, transferring energy from one location to another without moving the particles themselves. Electromagnetic waves, on the other hand, transfer energy through oscillating electric and magnetic fields. This type of wave does not require a medium, allowing it to travel through the vacuum of space. The energy carried by these waves is directly related to their frequency and amplitude; higher frequency waves, such as gamma rays, carry more energy compared to lower frequency waves like radio waves.

### The basic features of waves

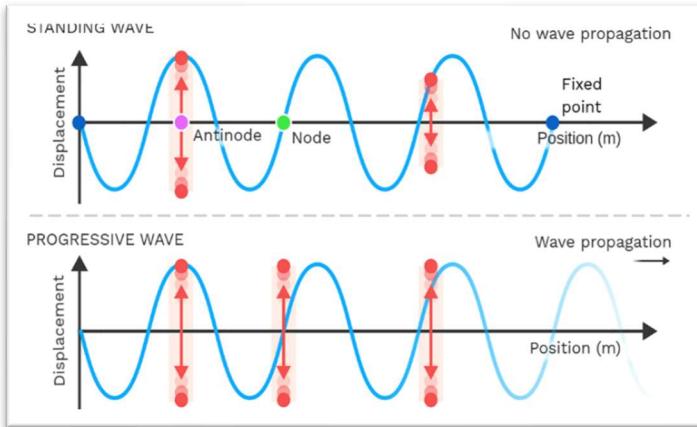
Waves are characterized by several key features.



reflection, refraction, interference, and diffraction. By using an overhead light source, the ripples created in the water can be illuminated, making it easier to study their behavior. In a ripple tank, waves are generated by a vibrating source, creating patterns that can be analyzed. For instance, when waves encounter obstacles or openings, they exhibit diffraction, spreading out and creating interference patterns. Ripple tanks are widely used in physics education, providing a hands-on approach to learning about wave mechanics.

## PROGRESSIVE AND STATIONARY WAVES

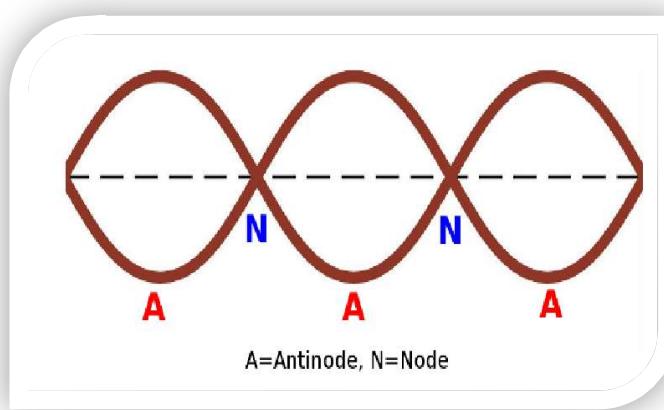
Progressive waves are defined as waves that travel continuously through a medium in the same direction without any change in amplitude. These waves are essential for transferring energy from one location to another, while the medium itself remains largely undisturbed. The particles in the medium oscillate around their equilibrium positions, allowing energy to propagate without the actual movement of matter. There are two primary types of progressive waves: transverse and longitudinal. In transverse waves, the oscillation occurs perpendicular to the direction of wave travel, while in longitudinal waves, the oscillation occurs parallel to the direction of travel. Both types exhibit unique characteristics, such as wavelength, frequency, and speed, which are crucial for understanding wave behavior.



The mathematical representation of progressive waves involves equations that describe their properties, including wave speed and frequency.

## Stationary (Standing) Waves

Standing waves, also known as stationary waves, are unique waveforms that do not appear to travel through space. **A standing wave is the superposition of two travelling waves of the same frequency and amplitude travelling in opposite directions.** Unlike traveling waves, which propagate from one point to another, standing waves oscillate in place, creating fixed points known as nodes where there is no



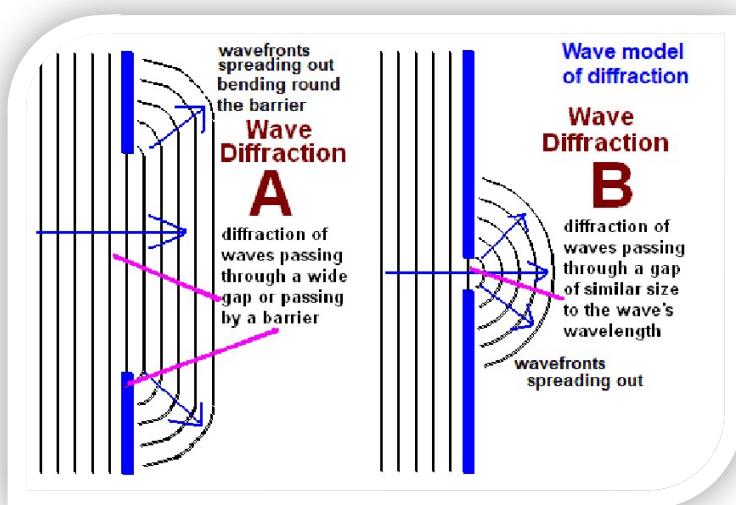
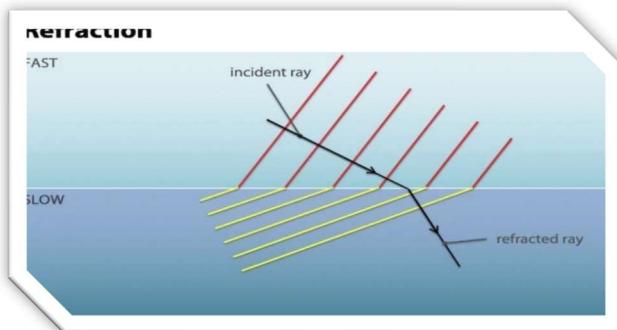
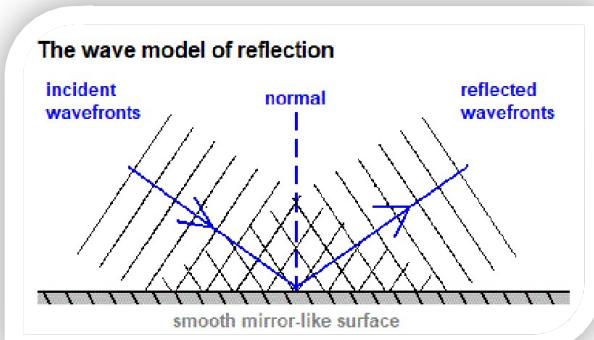
## PROPERTIES OF WAVES

Reflection, refraction, and diffraction are fundamental concepts in wave physics that describe how waves interact with different media.

**Reflection** occurs when a wave encounters a boundary and changes direction, bouncing back into the original medium. This phenomenon is crucial in various applications, from acoustics to optics, as it determines how sound and light behave when they meet surfaces.

**Refraction**, on the other hand, involves a change in direction as waves pass from one medium to another, influenced by the media's properties. This bending of waves is essential in understanding phenomena such as the bending of light in lenses and the behavior of sound in different environments.

**Diffraction** refers to the spreading of waves when they encounter obstacles or openings. These three processes; reflection, refraction, and diffraction play a vital role in wave behavior, impacting technologies ranging from telecommunications to medical imaging. 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. When waves undergo diffraction, wavelength and velocity remain constant.



## 3.5 SOUND WAVES

### Learning Outcomes

- 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)

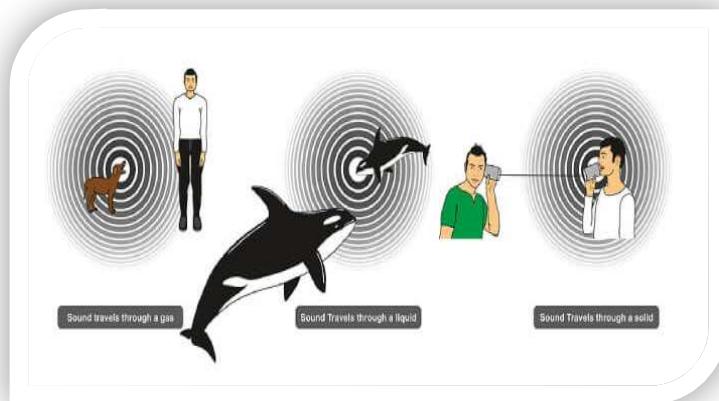
### Introduction

Sound waves are vibrations that travel through various media, including gases, liquids, and solids. These waves consist of alternating compressions and rarefactions, creating regions of high and low pressure that propagate at specific speeds. For instance, sound travels faster in water than in air, illustrating the influence of the medium on sound wave velocity. Recent advancements in sound wave research have led to exciting developments. Engineers at the University of Connecticut are exploring wave control and energy localization, which could have significant implications for various technologies. Researchers have successfully simulated chaotic sound wave propagation, confirming theories of acoustic turbulence, which could enhance our understanding of sound behavior in complex environments.

### What are sound waves?

Sound waves are patterns of disturbance caused by the movement of energy through various media, such as air, water, or solids. These waves consist of alternating compressions and rarefactions, which are regions of high and low pressure, respectively.

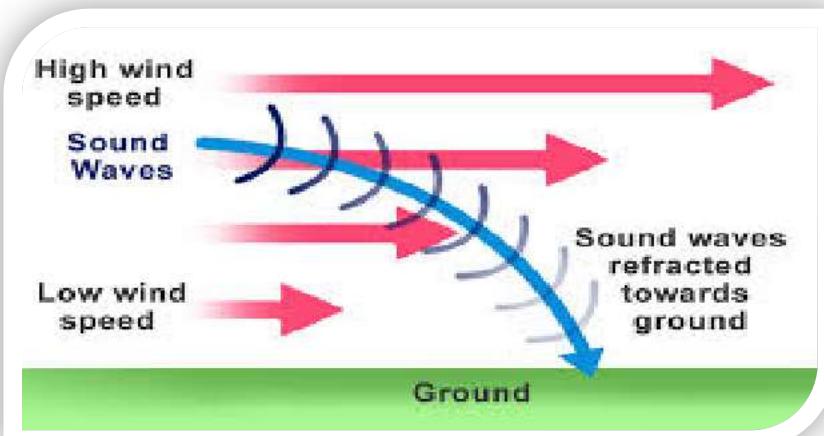
As sound waves travel, they transfer energy from one location to another, allowing us to perceive sounds. There are two primary types of waves: transverse and longitudinal. Sound waves are classified as longitudinal waves, meaning the particle displacement is parallel to the direction of wave propagation. This characteristic allows sound to travel efficiently through different materials, with speed varying based on the medium's density and elasticity. 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.



- 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.
- 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.

### Transmission of sound through air, water, and solids

Sound is transmitted through waves that travel across different mediums: gases, liquids, and solids. In air, sound waves travel relatively slowly due to the greater distance between molecules. This allows for the propagation of sound, but at a limited speed of approximately 343 meters per second. In contrast, sound travels faster in water, reaching speeds of about 1,480 meters per second, as the molecules are closer together, facilitating quicker energy transfer. When sound waves move through solids, they travel even faster, often exceeding 5,000 meters per second. This is because the tightly bonded molecules in solids allow for more efficient transmission of sound energy. The differences in speed across these mediums highlight the importance of molecular structure in sound propagation.



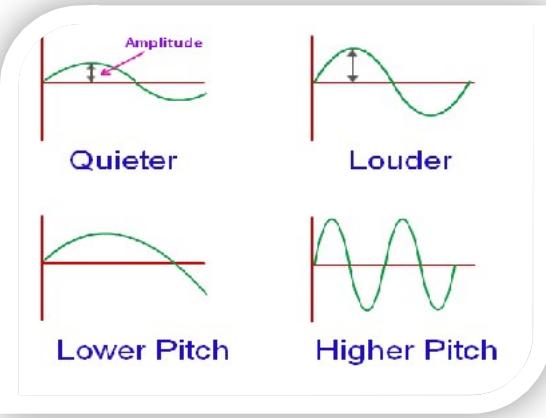
### An experiment to determine the transmission of sound through air, water, and solids

By utilizing simple materials like tuning forks, students can observe how sound waves travel differently through various mediums.

A tuning fork is struck and held near the surface of water, the vibrations can be felt more intensely than in air, demonstrating that sound travels faster in water.

To measure sound speed, students can conduct a straightforward experiment using two blocks of wood and a stopwatch.

Amplitude is a physical property of a sound wave that indicates the maximum displacement of particles in the medium caused by the wave. It determines the energy carried by the wave, with higher amplitudes representing greater energy. On a graph, amplitude is the height of the wave from its equilibrium point, and it is a key factor influencing the perception of sound intensity.

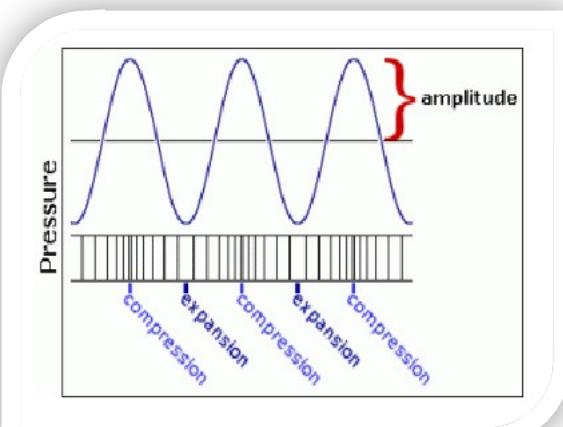


Loudness, on the other hand, is the subjective perception of how strong or soft a sound appears to a listener. It depends on the amplitude of the sound wave but is also influenced by factors like frequency and individual sensitivity to sound. For instance, the human ear is more sensitive to frequencies between 2,000 and 5,000 Hz, making sounds in this range seem louder even at the same amplitude as lower or higher frequencies.

While amplitude is an objective measure often expressed in terms of sound pressure levels, loudness is measured in psychoacoustic units like phons or sones. A sound wave with a higher amplitude generally produces a louder sound, but this relationship is not perfectly linear due to the complexities of human hearing.

### Amplitude and intensity

Amplitude refers to the maximum displacement of particles in a medium caused by a sound wave, essentially measuring the wave's energy. The greater the amplitude, the louder the sound perceived. **Sound intensity is defined as the sound power per unit area, indicating how much energy passes through a specific area over time.** As amplitude increases, so does intensity. This relationship can be mathematically expressed, showing that intensity is proportional to the square of the pressure amplitude. This means that even small increases in amplitude can lead to significant increases in intensity, affecting how we perceive sound. These concepts help in various fields, from acoustics to neuroscience, where changes in sound intensity can influence brain function and perception. On a graph, amplitude is represented by the height of the wave, and larger amplitudes indicate stronger vibrations. Intensity measures the amount of energy transmitted by the wave per



### **Applications of Sound Spectrum:**

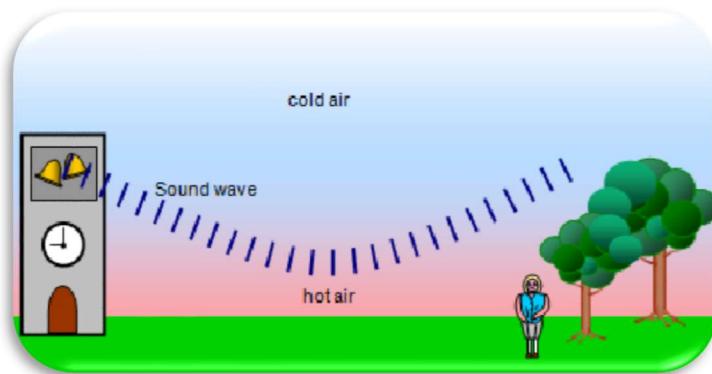
In music, the spectrum is used to analyze the different harmonic components of musical notes and instruments. The richness of a musical sound comes from the combination of multiple harmonics, each contributing a unique frequency to the sound.

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.

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.

### **REFRACTION OF SOUND WAVES**

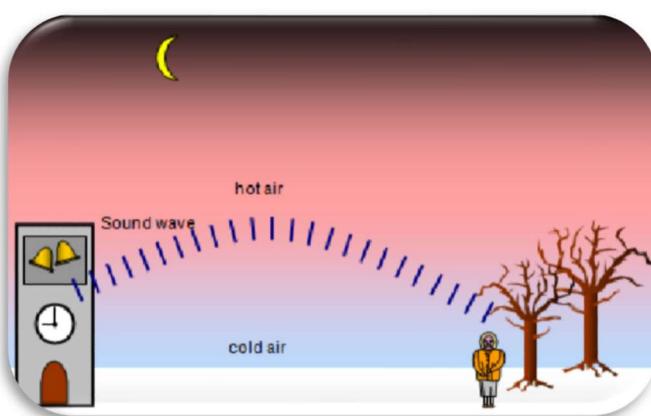
Refraction of sound waves is a fascinating phenomenon that occurs when sound travels through different media or varying temperatures. This bending of sound waves is primarily due to changes in wave speed, which can be influenced by factors such as air temperature. For instance, sound waves may refract when moving over water, as they transition between air and the water surface, altering their speed



and direction. The critical angle plays a significant role in sound refraction, determining how sound waves behave as they encounter different media. When sound waves reach this angle, they can either reflect or refract, depending on the properties of the media involved.

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.

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. During night, the ground is cool and



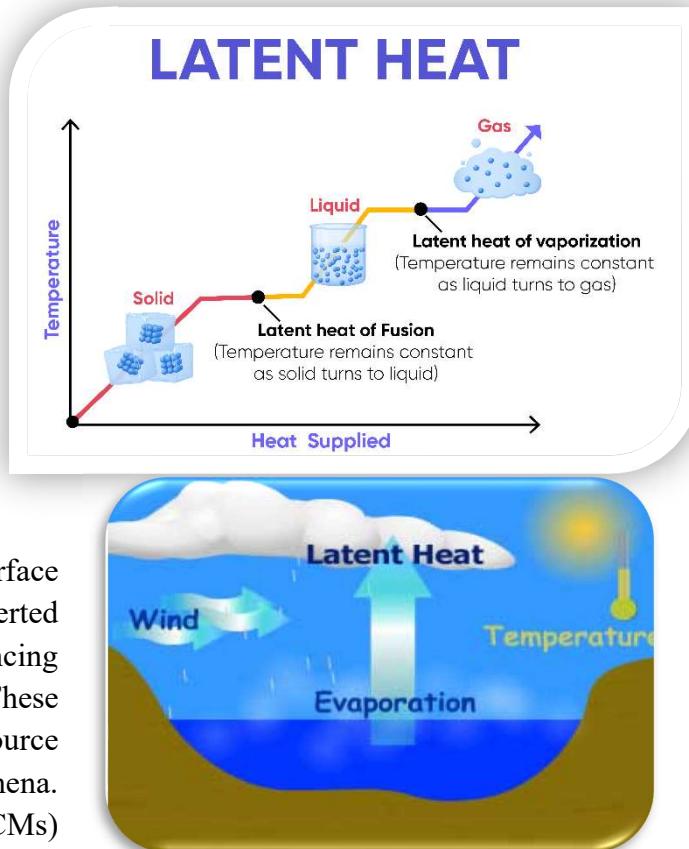
this makes layers of air near the ground to be cool while above to be warm. The wave fronts from the source are refracted towards the ground making it easier to hear sound waves over long distances.

At night, land cools down more quickly than water. The heat absorbed during the day dissipates rapidly from the land, while the ocean retains heat longer due to its higher specific heat capacity. This difference in cooling rates contributes to the formation of sea breezes, where cooler air from the sea moves toward the warmer land, creating a refreshing breeze on hot days.

## LATENT HEAT

**Latent heat refers to the hidden energy absorbed or released by a substance during a phase change, such as melting or vaporization, without altering its temperature or pressure.**

This is crucial in understanding various physical processes, particularly in meteorology and thermodynamics. For instance, when ice melts into water, it absorbs latent heat, which is essential for the transition from solid to liquid. The significance of latent heat extends to climate science, where it plays a vital role in energy exchange between the Earth's surface and the atmosphere. Solar radiation is converted into both sensible and latent heat, influencing weather patterns and climate dynamics. These processes help in effective water resource management and predicting weather phenomena. In engineering, phase change materials (PCMs) utilize latent heat to enhance energy efficiency in thermal management systems. By absorbing or releasing heat during phase transitions, PCMs can help regulate temperatures in various applications, from building materials to refrigeration systems.



## Demonstrating Latent Heat

Latent heat refers to the heat absorbed or released by a substance during a phase change (e.g., melting, boiling) without a change in temperature. The demonstration of latent heat typically involves observing these phase changes and measuring the heat involved.

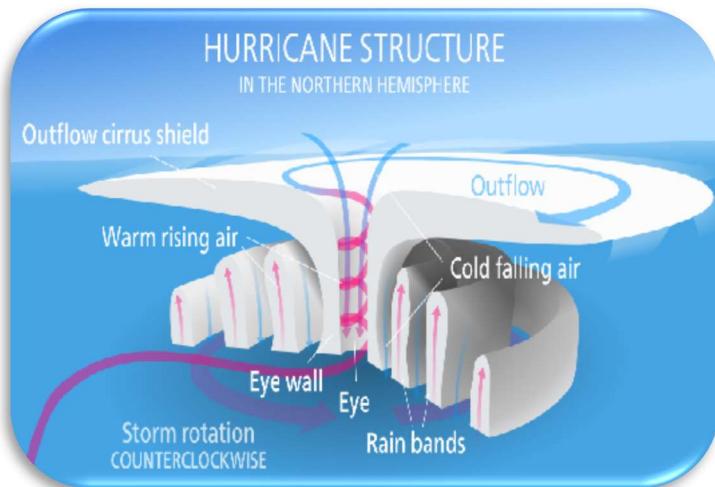
**Objective:** To demonstrate latent heat during melting (solid to liquid) and boiling (liquid to gas) processes and understand the concept of heat absorption without a temperature change.

The **latent heat of fusion** refers to the energy required to change ice at 0°C into liquid water at the same temperature. During this phase change, the ice absorbs heat without a change in temperature. This energy is essential for breaking the hydrogen bonds that hold the water molecules in a solid structure. As heat is applied to the ice, it begins to melt, transitioning into water. This process continues until all the ice has converted to liquid. The temperature remains constant at 0°C during this phase, despite the continuous absorption of heat. Once all the ice has melted, the resulting water can then increase in temperature as it continues to absorb heat. This increase occurs at a rate of 1.00 cal/g·°C, leading to further heating until it reaches its boiling point at 100°C.

The **latent heat of vaporization** is a crucial process in the transformation of water into steam. When liquid water reaches 100°C, it requires an additional 540 calories of heat per gram to convert into steam without changing its temperature. This energy is absorbed by the water molecules, allowing them to overcome the hydrogen bonds that hold them together in the liquid state. During this phase change, the temperature remains constant at 100°C, even as heat is continuously supplied. This phenomenon illustrates the concept of latent heat, which refers to the hidden energy required for a substance to change its state without altering its temperature. Once the water molecules gain enough energy, they break free from the liquid phase and enter the gaseous state as steam. This process is essential in various applications, including cooking, power generation, and even weather patterns, highlighting the importance of understanding latent heat in both scientific and practical contexts.

### ENERGY IN THE STORM

Hurricanes derive their energy primarily from warm ocean waters. When surface water temperatures rise, the storm acts like a straw, drawing in heat energy from the ocean. This process generates moisture in the air, which is crucial for storm development. As the warm, moist air rises, it cools and condenses, forming clouds and thunderstorms. The condensation of water vapor releases latent heat, further warming the surrounding air. This additional heat causes more air to rise, creating a cycle that intensifies the storm. The continuous influx of warm, moist air fuels the hurricane, allowing it to grow stronger and more organized. As the storm progresses, the energy from the ocean is transformed into powerful winds and heavy rainfall. This dynamic process illustrates the intricate relationship between ocean temperatures and storm intensity, highlighting the significant impact of climate change on hurricane formation and strength.



This process occurs without any change in temperature, highlighting the idea of "hidden" energy. For instance, the specific latent heat of fusion for water i.e. solid into a liquid at its melting point (e.g., ice to water), is approximately 334 kJ/kg (334,000 J/kg), meaning that this amount of energy is needed to melt 1 kg of ice into water. For example, materials like sodium nitrate and nanoparticles are being explored for their thermal performance in heat storage, leveraging their latent heat properties to enhance efficiency. In practical terms, the concept of latent heat is vital in everyday phenomena, such as ice melting or the freezing of water, and plays a significant role in climate and weather patterns, influencing how energy is transferred in the environment. Mathematically;  $Q = mL_f$ , and where  $L_f = \frac{Q(J)}{m(kg)}$ .

### 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), and Joulemeter or heating element

#### Method:

- Measure the mass of the calorimeter  $m_c$  and stirrer, add some warm water in it and weigh again  $m_w$
- Record the initial temperature of the water in calorimeter  $\theta_1$
- Add ice  $0^{\circ}C$  into the water and allow it to melt completely while stirring to ensure even distribution of temperature.
- Record the final temperature  $\theta_2$  of the water after all the ice has melted.
- Measure the mass of the calorimeter and its contents  $m_2$  to determine the mass of the melted ice, from  $m_{ice} = m_2 - (m_c + m_w)$ .

Using the formula  $Q = mc\Delta\theta$ , 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.

From energy conservation, Energy supplied=Energy gained.

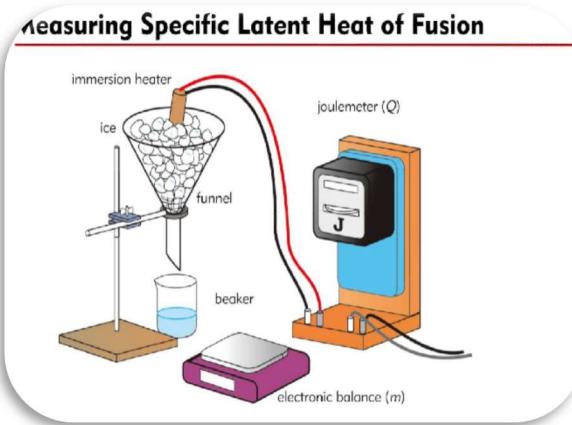
Total Energy gained by ice to melt and boil to  $100^{\circ}C$ ,  $E = m_{ice}l_f + m_{ice}c_{water}\theta_2$ .

Energy supplied  $E_{supplied} = (m_c c_c + m_w c_w)(\theta_1 - \theta_2)$

Finally use the equation to find latent heat of fusion of ice;

$$m_{ice}l_f + m_{ice}c_{water}\theta_2 = (m_c c_c + m_w c_w)(\theta_1 - \theta_2)$$

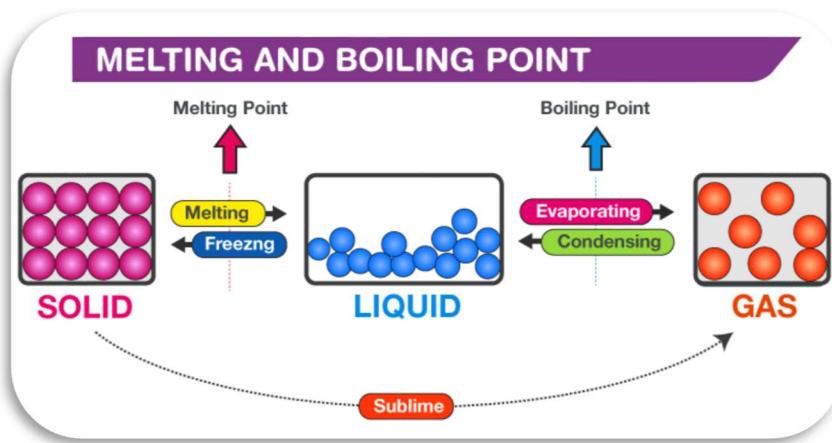
### Examples



## Boiling and melting

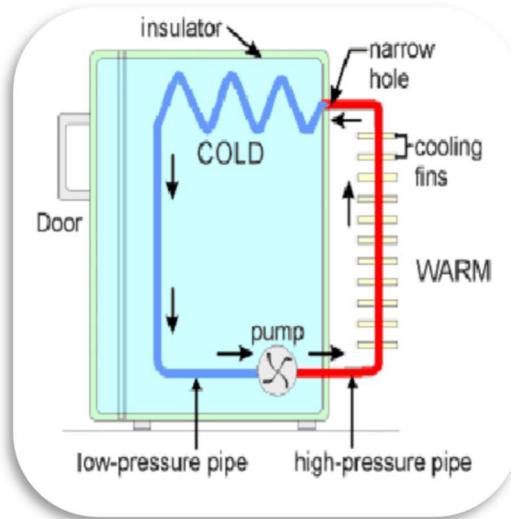
The kinetic theory of matter explains the behavior of particles in different states: solids, liquids, and gases. In solids, particles are closely packed and vibrate in fixed positions, resulting in a definite shape and volume. When heat is applied, the particles gain energy,

leading to melting, the transition from solid to liquid. At the melting point, the added energy breaks the bonds holding the particles together, allowing them to move more freely. Boiling, on the other hand, occurs when a liquid reaches its boiling point. At this temperature, the particles gain enough energy to overcome the attractive forces between them, transitioning into the gas phase. This process involves the formation of vapor bubbles within the liquid, which rise and escape into the air. Both melting and boiling illustrate how energy input affects particle movement and state changes, highlighting the dynamic nature of matter as described by the kinetic theory.



## Application of latent heat in refrigerators

Latent heat in the functioning of refrigerators works through the process of phase change. In refrigeration systems, latent heat is the energy absorbed or released when a refrigerant transitions between liquid and gas states. This phase change is essential for effectively transferring heat from the interior of the refrigerator to the outside environment, thereby maintaining a cool temperature inside. When warm products, such as food items, are placed in a refrigerator, they transfer heat to the refrigerant. As the refrigerant absorbs this heat, it evaporates, changing from a liquid to a gas. This process requires latent heat, which is drawn from the surrounding environment, effectively cooling the interior. The gas is then compressed and condensed back into a liquid, releasing the absorbed heat outside. Integrating latent heat cold storage systems in refrigerated warehouses can enhance energy efficiency and reduce operational costs, especially during peak demand periods.

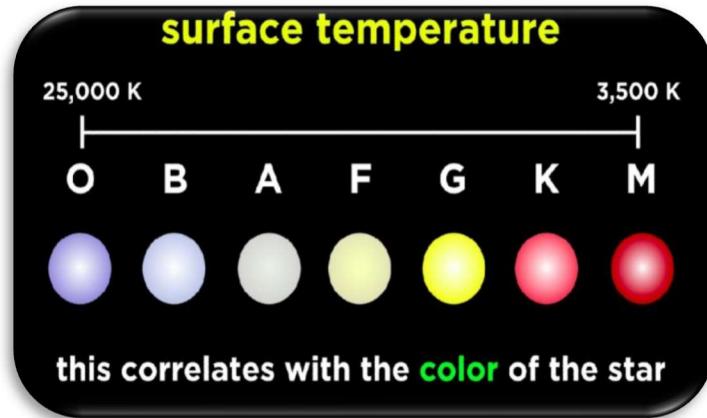


are visible to the naked eye, while others require telescopes to be seen. The life cycle of a star includes stages such as formation, main sequence, and eventual death, which can result in phenomena like supernovae or the formation of black holes.

## Classification of stars

Stellar classification is a systematic approach to categorizing stars based on their temperature, color, and luminosity. The primary classification system divides stars into seven main types: O, B, A, F, G, K, and M. This sequence, from hottest to coolest, is often remembered by the mnemonic “Oh Be A Fine Guy, Kiss Me.” O and

B stars are rare, extremely hot, and luminous, while M stars are the most common and cooler. Each class is further divided based on luminosity, indicated by Roman numerals. For instance, supergiants are classified as I, bright giants as II, giants as III, and subgiants as IV. This classification not only helps astronomers understand the physical properties of stars but also their lifecycle and evolution.



The standard classes are (temperatures are in Kelvin):

O – Blue Stars: > 30,000 K, B – Blue-White Stars: 10,000 – 30,000 K, A – White Stars: 7,500 – 10,000 K, F – Yellow-White Stars: 6,000 – 7,500 K, G – Yellow Stars: 5,200-6,000 K, K – Orange Stars: 3,700 – 5,200 K, M – Red Stars: 2,400 – 3,700 K

### Additional Classes:

L – Sub-Red Dwarf Stars: 1,300 – 2,400 K, T – Brown Dwarf Stars: 700 – 1,300 K, and Y – Sub-Brown Dwarf Stars: < 700 K

## Average stars

An average star, often referred to as an intermediate-mass star, has an initial mass ranging from 0.5 to 8 times that of the Sun. These stars are primarily powered by nuclear fusion occurring in their cores, which allows them to shine brightly for billions of years. The Sun itself is considered an average star, a classification that highlights its typical characteristics compared to the vast diversity of stars in the universe. Stars are born in stellar nurseries, such as the Orion Nebula, where clouds of gas and dust collapse under



## The sun as source of energy

The sun is the ultimate source of energy for Earth, driving essential processes that sustain life. Through nuclear fusion, hydrogen atoms collide and release vast amounts of energy, which radiates as sunlight. This solar radiation is crucial for the Earth's climate system, influencing weather patterns and supporting photosynthesis in plants, which forms the foundation of our food chain. Harnessing solar energy has become increasingly important as we seek sustainable alternatives to fossil fuels. Technologies such as solar panels convert sunlight into electricity, providing a clean and renewable energy source. Innovations in solar energy, including the potential to produce hydrogen fuel through water splitting, promise to revolutionize our energy landscape. As we face the challenges of climate change and dwindling resources, the sun remains a powerful ally.



## Importance of solar energy

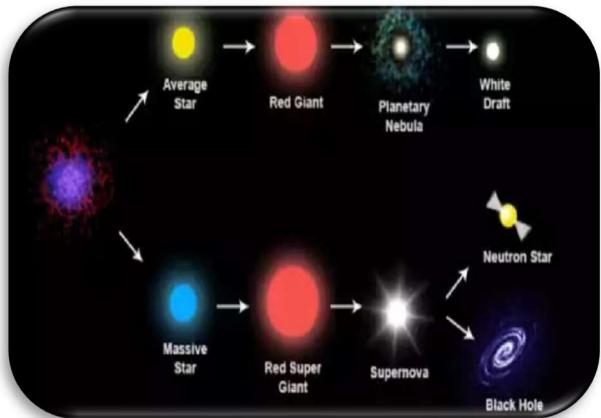
One of its primary advantages is its environmental benefits; solar power significantly reduces carbon emissions, helping combat climate change. As a renewable energy source, it is inexhaustible and can be harnessed anywhere sunlight is available, making it a versatile option for energy generation. Solar energy is a reliable and cost-effective alternative to traditional fossil fuels. By investing in solar systems, homeowners can reduce their electricity bills and enjoy long-term savings. This energy independence not only fosters economic stability but also enhances national security by reducing reliance on imported fuels. In addition to its economic and environmental benefits, solar energy promotes energy innovation. As technology advances, solar solutions become more efficient and accessible, paving the way for a cleaner, more sustainable future.



## The size of the sun

The Sun is an immense celestial body, measuring approximately 864,400 miles (1,391,000 kilometers) in diameter. This size makes it about 109 times wider than Earth, showcasing its colossal scale. In terms of mass, the Sun weighs around 333,000 times more than our planet, highlighting its dominant presence in the solar system. With a mean radius of about 432,450 miles (696,000 kilometers), the Sun's vastness is difficult to comprehend. It contains 99.86% of the total

common. These typically form from stars with at least three times the mass of our Sun. In contrast, supermassive black holes, found at the centers of galaxies, may have formed through more complex processes, possibly involving the merging of smaller black holes or the influence of dark matter. The study of black holes not only enhances our understanding of the universe but also challenges our grasp of physics, particularly regarding gravity and spacetime.

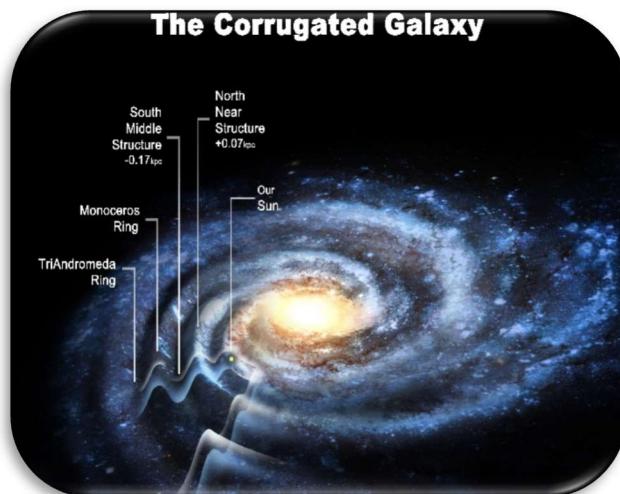


## Galaxies

A galaxy is a massive system composed of stars, stellar remnants, interstellar gas, dust, and dark matter, all bound together by gravity. The term "galaxy" originates from the Greek word for "milky," reflecting our own Milky Way galaxy. Galaxies can vary significantly in size and structure, containing anywhere from millions to trillions of stars, and they often exist in vast cosmic clusters. Galaxies are categorized into several types, including spiral, elliptical, and irregular. Spiral galaxies, like the Milky Way, feature distinct arms that wind outward from the center, while elliptical galaxies appear more rounded and lack the defined structure of spirals. Irregular galaxies do not fit neatly into these categories and often exhibit chaotic shapes.

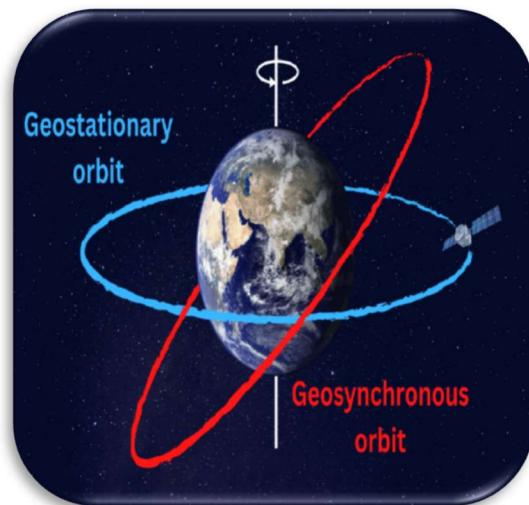
## The Milky Way

The Milky Way Galaxy, a barred spiral galaxy, is home to our Solar System and contains approximately 100 billion stars, including our Sun. Spanning about 100,000 light-years in diameter, it features a distinct hazy band of light visible from Earth, which is composed of countless stars and cosmic dust. This galaxy is estimated to be around 13.6 billion years old, making it a significant part of our cosmic history. At the center of the Milky Way lies a supermassive black hole, surrounded by a bulge of older stars. The galaxy's structure includes large spiral arms that extend outward, hosting various celestial phenomena such as nebulae and star clusters. The Milky Way is accompanied by several satellite galaxies, with the Large and Small Magellanic Clouds being the most notable.

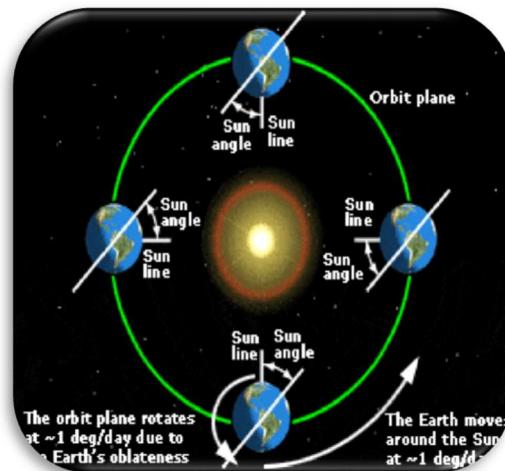


positioning enables MEO satellites to provide a balance between coverage and latency, making them ideal for various applications, including Global Navigation Satellite Systems (GNSS) and Internet of Things (IoT) services. MEO satellites are particularly significant for delivering high-speed connectivity in remote areas where traditional fiber optics are impractical. They utilize Ku-band and Ka-band frequencies to ensure robust data transmission. Recent advancements have seen countries like China launching their first MEO broadband satellites, highlighting the growing interest and investment in this orbital range. As the demand for satellite-based services continues to rise, MEO satellites are poised to play a crucial role in enhancing global communication and navigation capabilities.

**Geostationary Orbit (GEO):** Geostationary orbit (GEO) is a unique orbital position approximately 22,300 miles (35,800 kilometers) above the Earth's equator. In this orbit, satellites maintain a fixed position relative to the Earth's surface, appearing stationary to observers on the ground. This characteristic makes GEO ideal for telecommunications, weather monitoring, and broadcasting, as a single satellite can cover about one-third of the Earth. Satellites in GEO are launched into a temporary orbit before being maneuvered into their designated "slot." The orbital period of these satellites matches the Earth's rotation, allowing them to maintain a constant view of the same geographic area. This stability is crucial for applications requiring continuous data transmission and monitoring. As technology advances, the role of GEO satellites continues to expand, enhancing global communication and observation capabilities.



**Sun-Synchronous Orbit (SSO):** Sun-synchronous orbit (SSO), also known as Helio synchronous orbit, is a specialized polar orbit that allows satellites to maintain a consistent angle with respect to the Sun. This unique characteristic enables satellites to pass over the same point on Earth at the same local solar time, making SSO ideal for Earth observation and reconnaissance missions. Typically, SSO satellites operate at altitudes between 600 to 800 kilometers, with an inclination of about 20 to 30 degrees. The precession of the satellite's orbital plane matches the Earth's rotation around the Sun, ensuring that the satellite's observations are consistent throughout the year. This is particularly beneficial for



services, enhancing efficiency and safety. The GPS market is projected to grow significantly, with estimates reaching USD 472.16 billion by 2033. GPS continues to evolve, integrating with other systems like Europe's Galileo, ensuring users benefit from highly accurate and reliable navigation services worldwide.

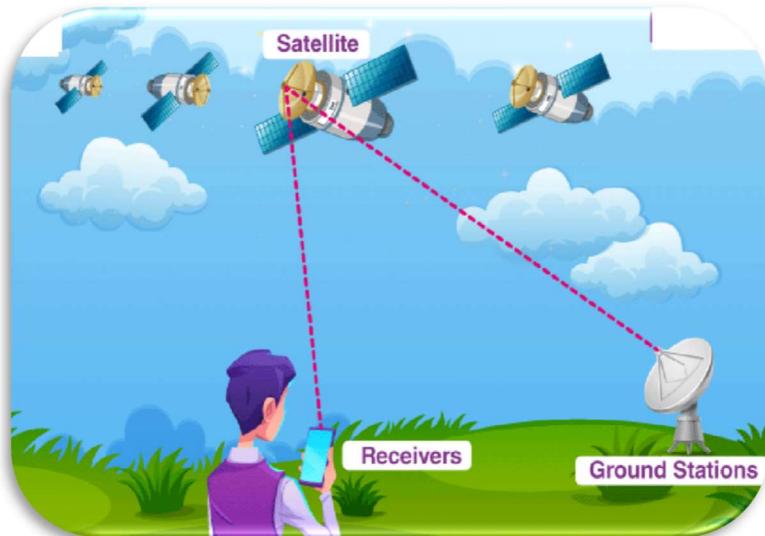
GPS, or the Global Positioning System, is a global navigation satellite system that provides location, velocity and time synchronization.

GPS is everywhere. You can find GPS systems in your car, your smartphone and your watch. GPS helps you get where you are going, from point A to point B. The Global Positioning System (GPS) is a navigation system using satellites, a receiver and algorithms to synchronize location, velocity and time data for air, sea and land travel. The satellite system consists of a constellation of 24 satellites in six Earth-centered orbital planes, each with four satellites, orbiting at 13,000 miles (20,000 km) above Earth and traveling at a speed of 8,700 mph (14,000 km/h). While we only need three satellites to produce a location on earth's surface, a fourth satellite is often used to validate the information from the other three. The fourth satellite also moves us into the third-dimension and allows us to calculate the altitude of a device.

### **What are the three elements of GPS?**

GPS is made up of three different components, called segments, that work together to provide location information. The three segments of GPS are:

**Space (Satellites);** The satellites circling the Earth, transmitting signals to users on geographical position and time of day. **Ground control;** The Control Segment is made up of Earth-based monitor stations, master control stations and ground antenna. Control activities include tracking and operating the satellites in space and monitoring transmissions. There are monitoring stations on almost every continent in the world, including North and South America, Africa, Europe, Asia and Australia. **User equipment;** GPS receivers and transmitters including items like watches, smartphones and telematic devices.



sector. They can be used to map forests, help farmers harvest their fields and navigate aeroplanes on the ground or in the air.

## Space exploration

Space exploration is the investigation of the universe beyond Earth's atmosphere, utilizing both crewed and uncrewed spacecraft. This endeavor has a rich history, particularly in the latter half of the 20th century when advancements in rocket technology enabled humanity to overcome gravitational forces and achieve orbital velocities. The first manned mission to the moon in 1969 marked a significant milestone, showcasing the potential of space travel. The motivations for exploring space are vast. Organizations like NASA emphasize that space exploration inspires global unity, drives groundbreaking discoveries, and creates new opportunities for technological advancements. The ongoing missions and research not only expand our understanding of the cosmos but also lead to innovations that benefit life on Earth. Despite its potential, human spaceflight poses risks and challenges, as evidenced by historical incidents. By studying celestial bodies and phenomena, we unlock the mysteries of black holes, planets, and the origins of life. This knowledge not only satisfies human curiosity but also inspires future generations to pursue careers in science and technology. Space exploration has tangible benefits for life on Earth. Research conducted in space has led to advancements in health care, such as improved vaccines and treatments for conditions like bone loss and eye disorders. The technologies developed for space missions often find applications in everyday life, enhancing weather forecasting, climate monitoring, and telecommunications. Space exploration fosters international collaboration, uniting nations in the pursuit of knowledge and innovation. As we continue to explore the cosmos, we not only gain insights into the universe but also create opportunities for technological advancements that can improve life on our planet.



## Hubble Space Telescope (HST)

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.

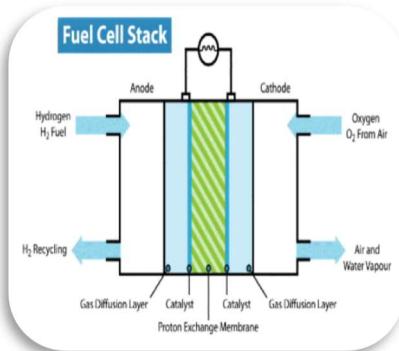
Since its launch in 1990, the Hubble Space Telescope (HST) has revolutionized our understanding of the universe.



Hubble Space Telescope

reaction, resulting in a flow of electrons from the anode (negative terminal) to the cathode (positive terminal).

**Fuel Cells:** Fuel cells convert the chemical energy of fuels (like hydrogen or methanol) directly into electricity through a chemical reaction with oxygen, typically producing water as a byproduct. Example: Hydrogen fuel cells generate e.m.f. by combining hydrogen and oxygen, producing electricity, water, and heat.



### Electromagnetic Sources

**Generators:** Generators convert mechanical energy into electrical energy through electromagnetic induction, where a conductor (like a wire) moves through a magnetic field, inducing an e.m.f. in the conductor. Example: In a simple AC generator, a coil of wire rotates within a magnetic field, producing alternating current due to the changing magnetic flux.

**Alternators:** Similar to generators, alternators produce alternating current by rotating coils within a magnetic field, inducing an e.m.f. that changes direction with time. Example: Alternators are commonly used in vehicles to charge batteries and power electrical systems while the engine runs.

### Thermoelectric Sources

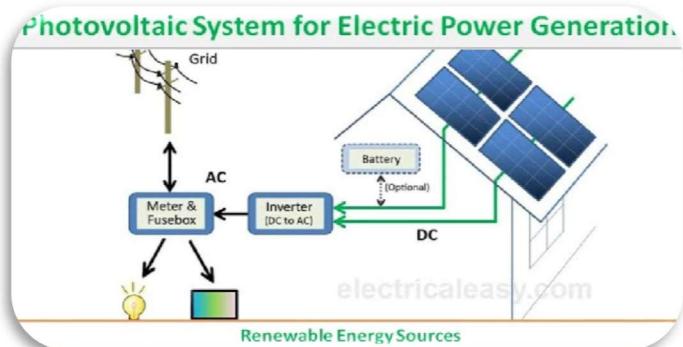
**Thermocouples:** Thermocouples generate e.m.f. by exploiting the Seebeck effect, where a voltage is produced in a circuit made of two different conductors when there is a temperature difference between their junctions. Example: Used in temperature measurement, where the voltage produced correlates to the temperature difference, allowing for precise readings.

**Thermoelectric Generators (TEGs):** TEGs convert heat energy directly into electrical energy using thermoelectric materials that generate e.m.f. when subjected to a temperature gradient.

Example: Used in space applications and waste heat recovery systems to convert waste heat into usable electrical energy.

### Photovoltaic Sources.

Photovoltaic (PV) sources are essential in harnessing solar energy, converting sunlight directly into electricity through solar cells. A PV cell, typically small and made from semiconductor materials, is the fundamental unit of this technology. When sunlight strikes the cell, it excites electrons, generating an electric current. The efficiency of PV systems is a primary focus of ongoing research, aiming to make solar energy more cost-competitive with traditional energy sources. Various materials are utilized in PV cells, each contributing to the overall performance and efficiency of solar panels. As the demand for clean, renewable energy



longer period, and better performance at lower temperatures compared to other types. They are widely used in household devices like remote controls, toys, and flashlights.

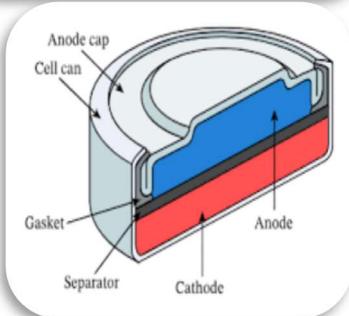
**Zinc-Carbon Cells:** This traditional type consists of a zinc anode, carbon rod as the cathode, and an electrolyte made of a paste of ammonium chloride or zinc chloride. They have lower cost compared to alkaline cells, has a lower energy density and shorter shelf life and voltage drops quickly under load, making it less suitable for high-drain applications. They are commonly used in low-drain devices like clocks, flashlights, and remote controls.



**Lithium Cells:** These cells use lithium metal or lithium compounds as the anode and various materials (like manganese dioxide or cobalt oxide) as the cathode, often with a lithium salt electrolyte. They have a high energy density and long shelf life, can operate in a wide temperature range, and generally have a stable voltage output. Used in a variety of applications, including watches, cameras, calculators, and medical devices.



**Mercury Cells:** Composed of mercury (anode), zinc (cathode), and a potassium hydroxide electrolyte. Stable voltage output, High energy density, and have environmental concerns due to mercury toxicity. Previously used in hearing aids, cameras, and some types of watches, but usage has declined due to environmental regulations.



**Silver-Oxide Cells:** These cells have a silver oxide cathode, zinc anode, and an alkaline electrolyte (typically potassium hydroxide). They have high energy density and stable voltage output, more expensive than other primary cell types. Commonly used in watches, hearing aids, and other small electronic devices due to their compact size and reliability.

## Secondary cells

Secondary cells, commonly known as rechargeable batteries, are essential components in modern technology. Unlike primary cells, which are designed for single-use, secondary cells can be charged and discharged multiple times. This capability is achieved by reversing the chemical reactions that occur during discharge, allowing the battery to restore its energy. There are various types of secondary cells, including lithium-ion, lead-acid, and flow batteries. Each type has unique

## Unit of Electric Current

The magnitude of electric current is measured in coulombs per second. The SI unit of electric current is *Ampere* and is denoted by A. Ampere is defined as one coulomb of charge moving past a point in one second. If there are  $6.241 \times 10^{18}$  electrons flowing through our frame in one second, then the electrical current flowing through it is ‘One Ampere.’ The unit Ampere is widely used within electrical and electronic technology along with the multipliers like milliamp (0.001A), microamp (0.000001A), and so forth.

## Visualizing Electric Current

To gain a deeper understanding of what an electric current is and how it behaves in a conductor, we can use the water pipe analogy of electricity. Certainly, there are some limitations but they serve as a very basic illustration of current and current flow.

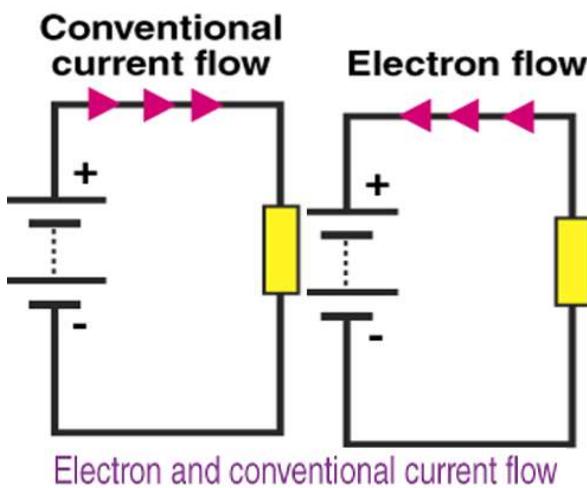
### Conventional current flow versus electron flow

There is a lot of confusion around conventional current flow and electron flow.

*Conventional Current Flow versus Electron Flow.*

### Conventional Current Flow

The conventional current flow is from the positive to the negative terminal and indicates the direction in which positive charges would flow.



### Electron Flow

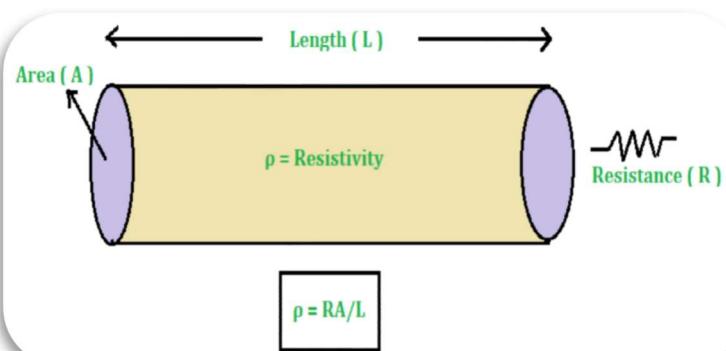
The electron flow is from negative to positive terminal. Electrons are negatively charged and are therefore attracted to the positive terminal as unlike charges attract.

## Properties of Electric Current

After we define electric current, let us learn the properties of electric current. Electric current is an important quantity in electronic circuits. We have adapted electricity in our lives so much that it becomes impossible to imagine life without it. Therefore, it is important to know what is current and the properties of the electric current. We know that electric current is the result of the flow of electrons. The work done in moving the electron stream is known as electrical energy. Electrical energy can be converted into other forms of energy such as heat energy, light energy, etc. For example, in an iron box, electric energy is converted to heat energy. Likewise, the electric energy in a bulb is converted into light energy.

### Factors affecting the resistance of a wire

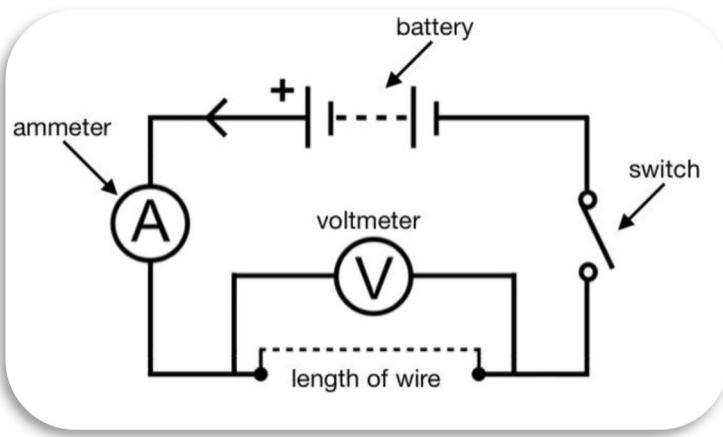
The resistance of a wire is influenced by several key factors. Firstly, the length of the conductor; longer wires exhibit greater resistance due to the increased distance electrons must travel. A wire with a larger cross-sectional area allows more electrons to flow simultaneously, thereby reducing resistance. The material of the wire. Different materials have varying resistivities, with metals like copper and aluminum offering lower resistance compared to insulators. Temperature significantly affects resistance; as the temperature rises, the metal atoms vibrate more vigorously, impeding the flow of electrons and increasing resistance. In summary, the resistance of a wire is determined by its length, cross-sectional area, material composition, and temperature.



### To investigate the factors affecting the resistance of a wire

Conduct a practical experiment focusing on three main variables: length, cross-sectional area, and material.

The resistance of a wire is directly proportional to its length; as the length increases, so does the resistance. This relationship can be demonstrated by measuring the resistance of wires of varying lengths while keeping other factors constant. A wire with a larger cross-sectional area will have lower resistance compared to a thinner wire of the same material and length. This is because a thicker wire allows more electrons to flow through it, reducing resistance. The material of the wire significantly influences resistance. Different materials have varying atomic structures, affecting how easily electrons can move.



#### PART A (using Nickle SWG28)

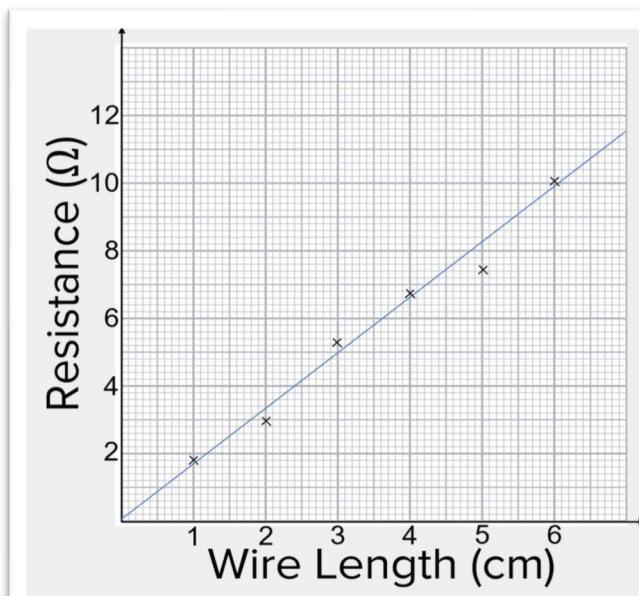
- Measure a length of wire , $L=20.0\text{cm}$ , connect it across the voltmeter as shown in the circuit,
- Close the switch, read and record both the ammeter reading,  $I$ , and voltmeter reading , $V$ .
- Repeat the experiment by adjusting the lengths of the wire  $L=30,40,50,60,\text{and } 70.0\text{cm}$

- d) Tabulate the table of results including both the values of  $\frac{V}{I}$
- e) Plot a graph of  $\frac{V}{I}$  against L
- f) Draw a **line of best fit**. This should be a straight line that **passes through the origin** of the graph.
- g) The line of best fit shows that the resistance is **directly proportional** to the wire length.

**NOTE:**  $R = \frac{V}{I}$

### PART B

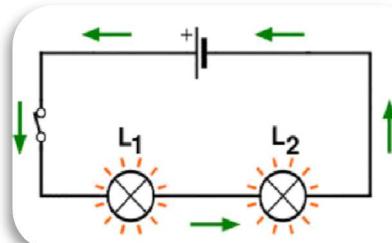
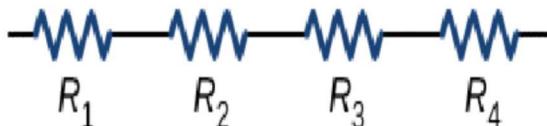
- a) Using the same experimental setup shown above,
- b) Connect another wire of **SWG28** and using a length of  $L=40.0\text{cm}$ , repeat the same procedures, and read and record both values of I and V
- c) Repeat procedure (b) above with different wires of **SWG30**, and **SWG32**
- d) **Tabulate your results including values of  $\frac{V}{I}$**
- e) **Plot a graph of  $\frac{V}{I}$  against SWG number**
- f) **Determine the slope and give your conclusions**



## Arrangement of resistors in circuits

### Series arrangement of resistors

In a series arrangement, resistors are connected end-to-end, creating a single path for current to flow. This means that the same current passes through each resistor sequentially. The total resistance in a series circuit is simply the sum of the individual resistances, which can be calculated using the formula:  $R_{total} = R_1 + R_2 + R_3 + \dots + R_n$ . According to Ohm's Law, the voltage drop across a resistor is proportional to its resistance, meaning larger resistors will have a greater voltage drop. This arrangement is commonly used in applications where the same current is required through multiple components, such as in string lights or certain types of sensors.



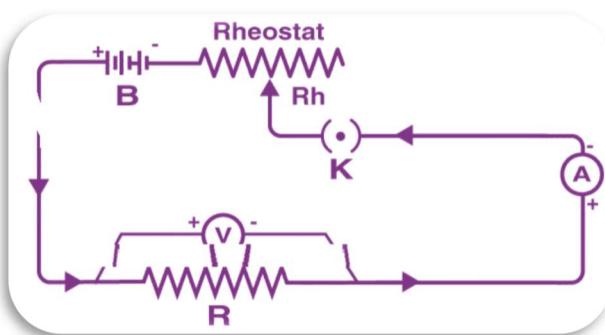
components, increasing the current raises the temperature. An example of this is the filament of a light bulb, in which the temperature rises as the current is increased. In this case, Ohm's law cannot be applied. The lightbulb filament violates Ohm's Law.

### Experimental Verification of Ohm's Law

Ohm's Law can be easily verified by the following experiment: Resistor, Ammeter, Voltmeter, Battery, Plug Key, and Rheostat

#### Procedure

- Initially, the key K is closed and the rheostat is adjusted to get the minimum reading in ammeter A and voltmeter V.
- The current in the circuit is increased gradually by moving the sliding terminal of the rheostat. During the process, the current flowing in the circuit and the corresponding value of potential difference across the resistance wire R are recorded.
- Different sets of values of voltage, V, and current, I, are obtained and a table of results tabulated.
- A graph of the current (I) against the potential difference (V) is plotted, it will be a straight line. This shows that the current is proportional to the potential difference.

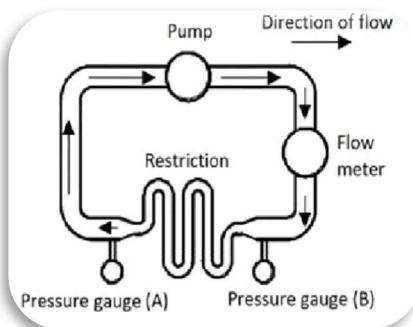
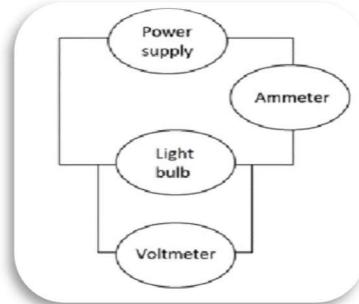


### Water pipe analogy for ohm's law

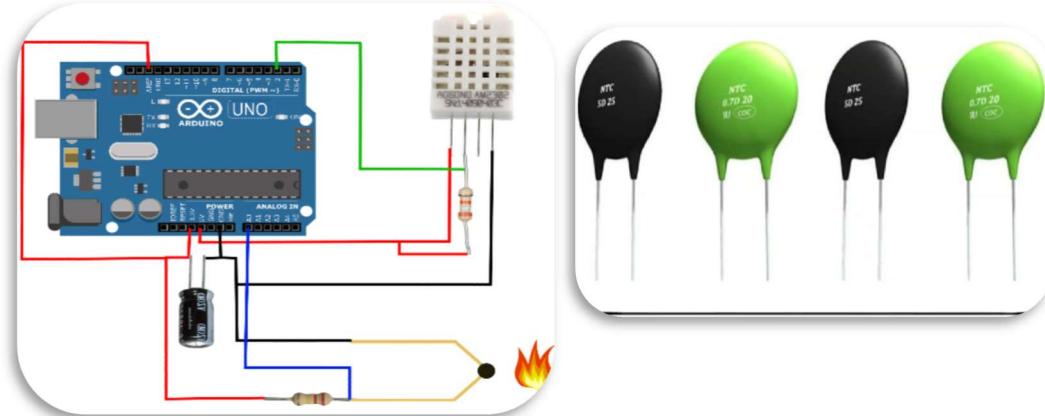
The relationship between current, voltage and resistance is expressed by Ohm's Law. This states that the current flowing in a circuit is directly proportional to the applied voltage and inversely proportional to the resistance of the circuit, provided the temperature remains constant.

$$\text{Ohm's Law: } \text{Current } (I) = \frac{\text{Voltage } (V)}{\text{Resistance } (R)}$$

To increase the current flowing in a circuit, the voltage must be increased, or the resistance decreased. A simple electrical circuit is depicted in Figure (a). The flow of electricity through this circuit is further illustrated by analogy to the pressurized water system in Figure (b). In the electrical circuit the power supply generates electrical pressure (voltage), equivalent to the pump creating water pressure in the pipe; the current is equivalent to the rate of flow of water; and the light bulb provides the resistance in the same way as the restriction in the water system. The ammeter is equivalent to the flow meter and the voltmeter measures the difference in electrical pressure each side of the restriction in the water system.

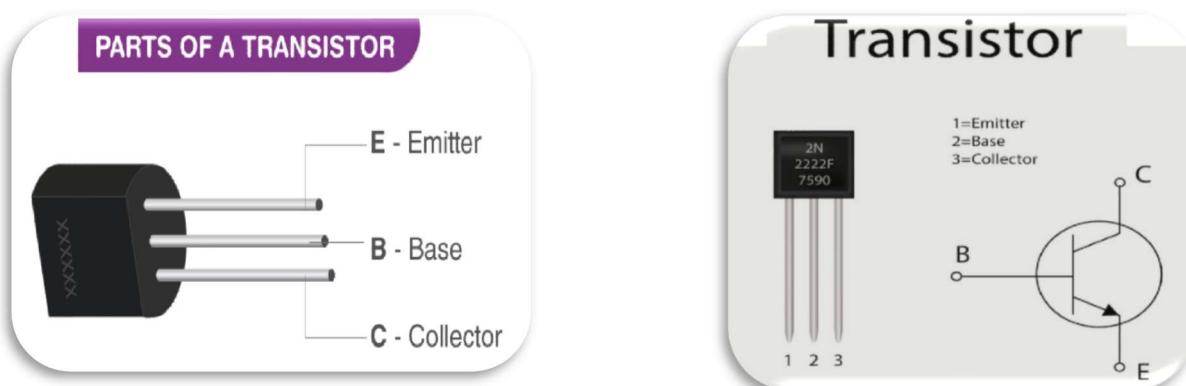


unique property allows thermistors to be used in various applications, including temperature sensing, circuit protection, and in medical devices for monitoring body temperature. In recent years, the demand for disposable thermistors has increased, particularly in hospital settings, where they are favored for their convenience and hygiene. Leading companies in the thermistor market include Vishay, Littelfuse, and TDK, reflecting the growing importance of these devices in modern technology.



## Transistors

A transistor is a crucial semiconductor device that functions as a switch or amplifier for electronic signals. It regulates the flow of electric current or voltage, making it a fundamental building block of modern electronics. Transistors can control the flow of electricity in circuits, allowing them to amplify signals or act as on/off switches. There are various types of transistors, including Bipolar Junction Transistors (BJTs) and Field-Effect Transistors (FETs), each serving specific applications. The working principle of a transistor involves the manipulation of charge carriers (electrons and holes) within a semiconductor material, enabling it to either allow or block current flow based on input signals. Transistor diagrams typically illustrate the three terminals: the collector, emitter, and base for BJTs, or the source, gate, and drain for FETs. Understanding transistors is essential for grasping the operation of countless electronic devices, from simple circuits to complex computing systems.



The light emitting diodes or LEDs are used in sensors and also in laser devices any many other light illumination devices. Zener diodes are used as voltage regulators and varactors are used in electronic tuning and varistors are used in suppressing AC lines. Diodes are the basis of op-amps and transistors.

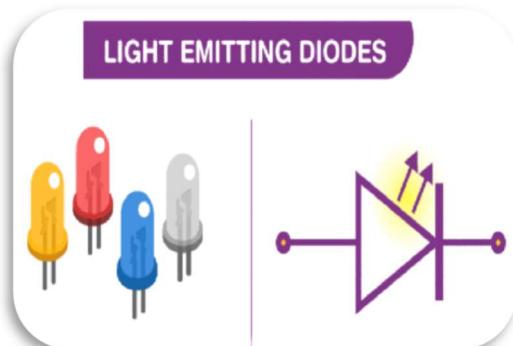
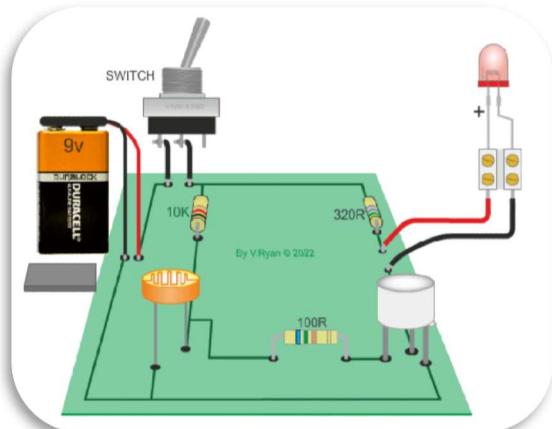
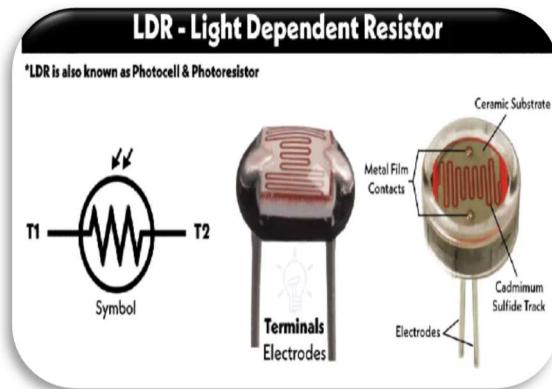
### LDR

LDR (Light Dependent Resistor) as the name states is a special type of resistor that works on the photoconductivity principle means that resistance changes according to the intensity of light. Its resistance decreases with an increase in the intensity of light. It is often used as a light sensor, light meter, Automatic street light, and in areas where we need to have light sensitivity.

LDR is also known as a Light Sensor. LDR are usually available in 5mm, 8mm, 12mm, and 25mm dimensions. A Light Dependent Resistor (LDR), also known as a photoresistor, is a passive electronic component that alters its resistance based on light intensity. When exposed to light, the resistance of an LDR decreases, allowing more current to flow through the circuit. This property makes LDRs essential in various applications, including light sensing, automatic lighting systems, and camera exposure controls. LDRs are commonly used in devices that require light detection, such as streetlights that turn on at dusk and off at dawn. They can also be found in alarm systems and light meters, where they help in monitoring ambient light levels. The simplicity and effectiveness of LDRs make them a popular choice for hobbyists and professionals alike. Their ability to adjust resistance based on light intensity enables innovative solutions across various fields.

### LED

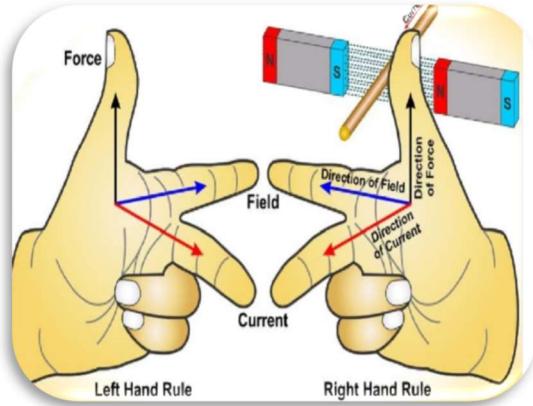
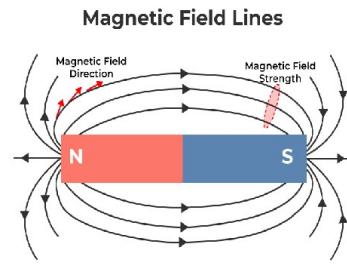
Light Emitting Diodes (LEDs) are semiconductor devices that convert electrical energy into light through a process called electroluminescence. When an electric current flows through the LED, it excites electrons in the semiconductor material, causing them to release energy in the form of light. This technology



circular or helical paths. This principle is crucial in various applications, from electric motors to particle accelerators. Magnetic fields play a significant role in astronomical phenomena, such as the formation of stars and planets, by influencing the dynamics of charged particles in space.

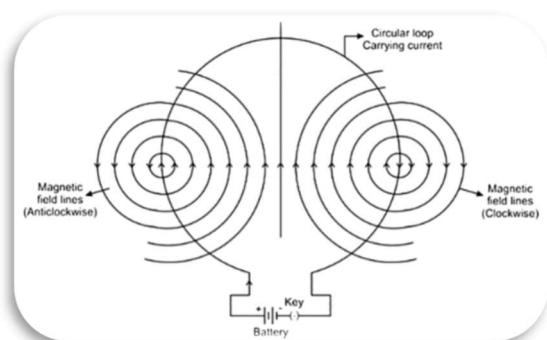
## Magnetic Field of a Current Carrying Conductor (Wire)

When an electric current flows through a wire, it creates a magnetic field that forms concentric circles around the wire. The interaction between a magnetic field and a current-carrying conductor results in a magnetic force. This force is crucial in various applications, including electric motors and generators, where it enables the conversion of electrical energy into mechanical energy. The direction of the magnetic field can be determined using the right-hand rule, which states that *"If a current-carrying conductor is held by the right hand, keeping the thumb straight and if the direction of electric current is in the direction of thumb, then the fingers will curl in the direction of the magnetic field lines"*.



## Magnetic field due to current through a circular loop

When an electric current flows through a circular loop, it generates a magnetic field that is most concentrated at the center of the loop. The magnetic field lines form closed loops around the wire, and their direction can be determined using the right-hand thumb rule: if the thumb points in the direction of the current, the curled fingers indicate the direction of the magnetic field. The strength of the magnetic field at the center of the loop is directly proportional to the current and inversely proportional to the radius of the loop. Every point on the wire carrying current gives rise to a magnetic field around it; as we move away from the wire, the arcs of these circles would appear as a straight line.



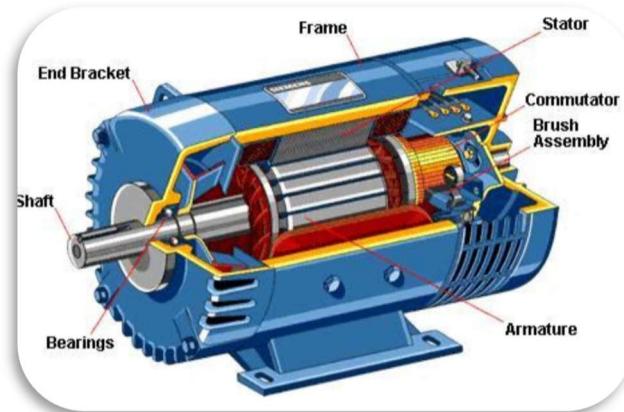
## Magnetic field and number of turns of the coil

The magnitude of the magnetic field gets summed up with the increase in the number of turns of the coil. If there are ‘n’ turns of the coil, the magnitude of the magnetic field will be ‘n’ times the magnetic field in case of a single turn of the coil.

- **The radius of the coil:** The strength of the magnetic field is inversely proportional to the radius of the coil. If the radius increases, the magnetic strength at the center decreases.
- **The number of turns in the coil:** As the number of turns in the coil increase, the magnetic strength at the center increases, because the current in each circular turn is having the same direction, thus, the field due to each turn adds up.
- **The strength of the current flowing in the coil:** As the strength of the current increases, the strength of three magnetic fields also increases.

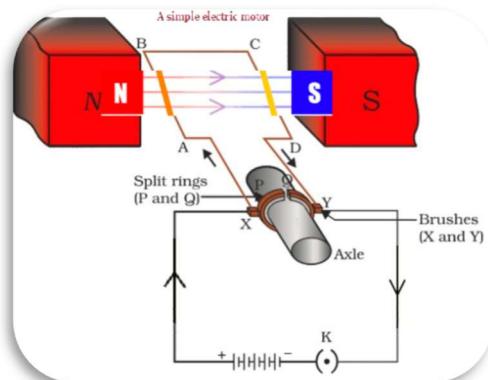
## The Electric Motor

An electric motor is a vital machine that transforms electrical energy into mechanical energy, primarily in the form of rotational motion. This conversion is achieved through the interaction of magnetic fields and electric currents, allowing electric motors to power a wide range of applications, from household appliances to electric vehicles. There are two main types of electric motors: direct current (DC) motors and alternating current (AC) motors. DC motors utilize direct current to generate motion, while AC motors operate on alternating current.



## Operation of a simple Electric Motor

A simple electric motor operates on the principles of electromagnetism, converting electrical energy into mechanical motion. At its core, the motor consists of a coil of wire, a power source (like a battery), and a permanent magnet. When electricity flows through the coil, it generates a magnetic field, turning the coil into an electromagnet. When current is supplied to the armature, one end becomes a north pole, and the other end a south pole, magnetically. Since the armature lies in a magnetic field, there are magnetic forces



a *sine curve*, with the negative part reflected in the time axis. The maximum potential difference or current can be increased by: increasing the rate of rotation, increasing the strength of the magnetic field, and increasing the number of turns on the coil. The diagram shows four different positions of the coil in a dynamo, and the corresponding potential difference produced.

The potential difference-time graph for a dynamo

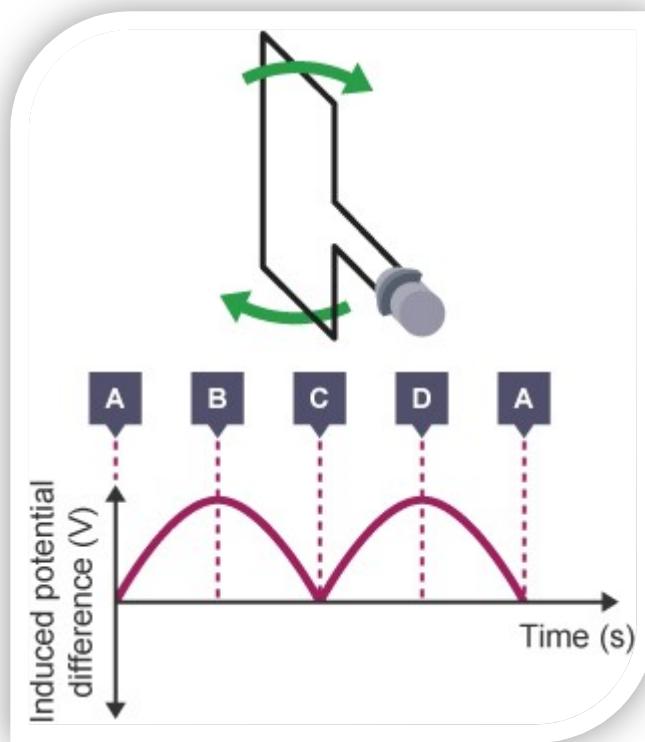
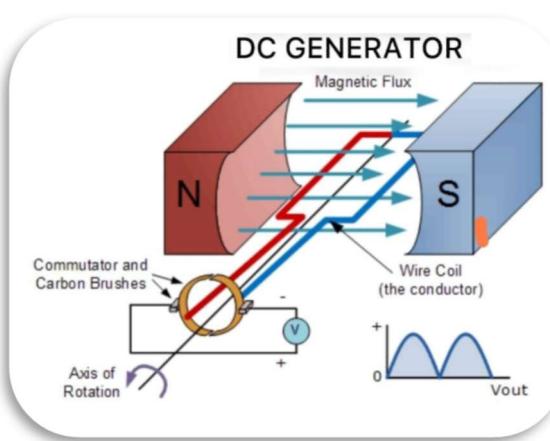
**A** - The coil is at  $0^\circ$ . The coil is moving parallel to the direction of the magnetic field, so no potential difference is induced.

**B** - The coil is at  $90^\circ$ . The coil is moving at  $90^\circ$  to the direction of the magnetic field, so the induced potential difference is at its maximum.

**C** - The coil is at  $180^\circ$ . The coil is moving parallel to the direction of the magnetic field, so no potential difference is induced.

**D** - The coil is at  $270^\circ$ . The coil is moving at  $90^\circ$  to the direction of the magnetic field, so the induced potential difference is at its maximum. Here, the induced potential difference is in the **same** direction as at B.

**A** - The coil is at  $360^\circ$ , ie it is back at its starting point, having done a full rotation. The coil is moving parallel to the direction of the magnetic field, so no potential difference is induced.



## Working Principle of A DC Generator or Dynamo

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

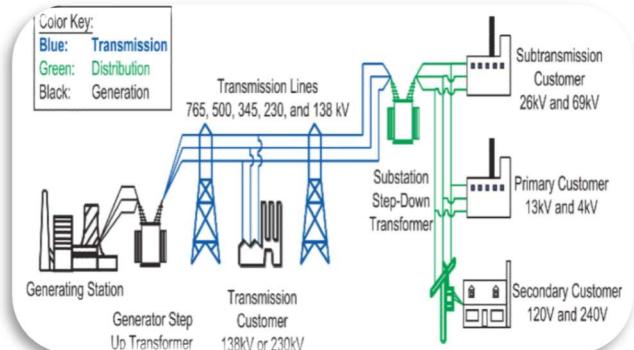
operates at 240 volts and a frequency of 50 hertz, while in the United States, it is typically 110-120 volts at 60 hertz. The term "mains" originates from the historical use of the word to describe principal channels for conveying resources, such as water. This terminology reflects the importance of a reliable electricity supply in modern infrastructure.

Uganda's electricity generation is predominantly reliant on hydropower, which accounts for over 84% of the country's electricity supply. The nation is endowed with abundant water resources, making hydropower a viable and sustainable energy source. This reliance on hydropower has facilitated significant electrification progress, outpacing population growth between 2017 and 2019. In addition to hydropower, Uganda also utilizes thermal power, which contributes around 100 MW to the energy mix. Other sources include biomass, solar energy, and cogeneration, with grid-connected solar contributing approximately 60 MW. Despite these diverse sources, Uganda still faces challenges with one of the lowest electrification rates in Africa, largely due to an overreliance on traditional biomass. Uganda is exploring nuclear energy as a potential source to diversify its electricity generation portfolio, aiming to enhance energy security and meet growing demand.



## Transmission and Distribution of Electricity

Transmission refers to the high-voltage movement of electricity over long distances, akin to motorways transporting vehicles quickly across the country. This system connects power plants to substations, where the voltage is reduced for safe distribution. Once electricity reaches substations, the distribution phase begins. This involves lower-voltage power lines that deliver electricity to homes and businesses.



The distribution network is essential for providing reliable access to electricity, adapting to local demand and ensuring that power is available where it is needed most. As the energy landscape evolves, particularly with the rise of renewable sources, the transmission and distribution systems face new challenges. Utilities and system operators must continuously balance supply and demand, integrating advanced technologies to enhance efficiency and reliability in delivering electricity to consumers.

### 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 be either overhead or underground.

### How power losses are reduced during transmission of electricity:

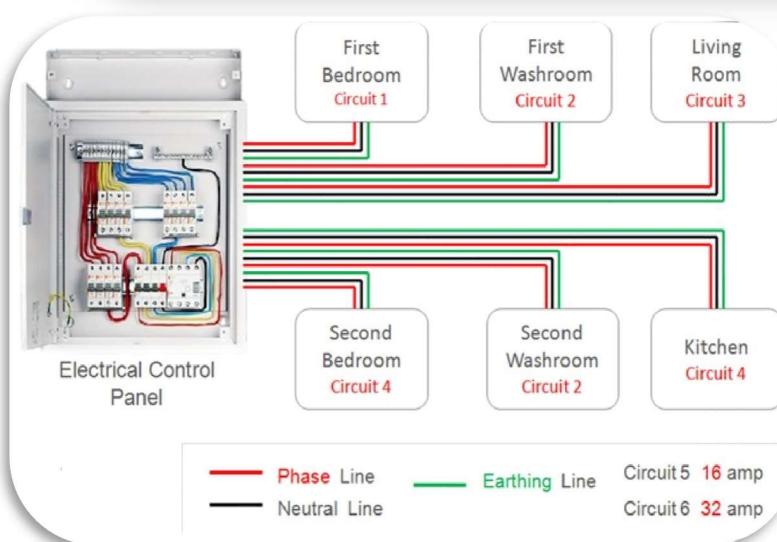
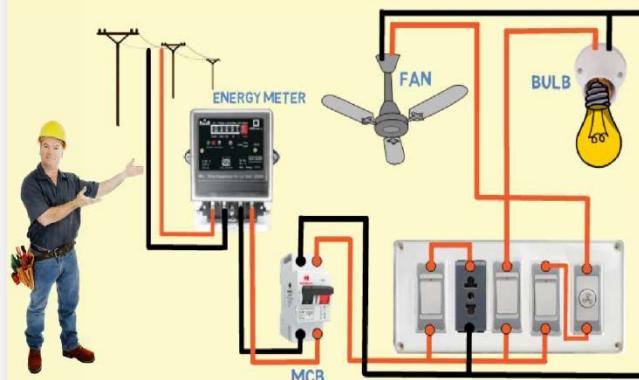
Electricity is transmitted at high voltages to reduce power loss due to the heating effect in the transmission cables. The transmission cables are made thick to reduce its resistance hence minimizing power loss.

### 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. Domestic electrical installation involves a systematic approach to distributing energy throughout a home, powering everything from lights to appliances. Key considerations include selecting the right wire types, understanding circuit layouts, and adhering to safety standards.

When wiring a house, several essential components must be included to ensure safety and functionality. The circuit breaker panel serves as the heart of the electrical system, distributing power through various circuits to different areas of the home. Standard residential wiring consists of wires, cables, outlets, switches, and electrical panels, all of which must comply with local codes. In kitchens, for instance, it is crucial to have a minimum of eight circuits, with kitchen lighting on a separate circuit rated for 15 or 20 amps.

**COMPLETE ELECTRICAL HOUSE WIRING DIAGRAM**



## 4.5 ATOMIC MODELS

### Learning Outcomes

- Understand the structure of an atom in terms of a positive nucleus and negative electrons(u)
- Understand the terms: atomic number, mass number, and isotopes, and use them to represent different nuclides (k,u)
- Understand the methods by which electrons are ejected from /matter atoms and how these electrons are useful (u, v/ a)

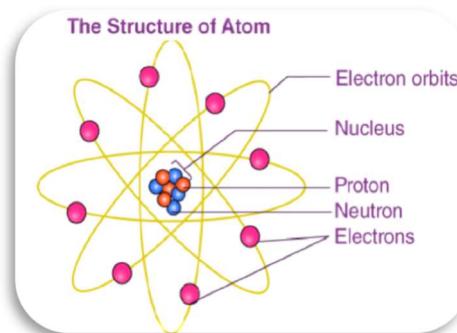
### Introduction

Atomic models are essential in understanding the structure and behavior of atoms, the fundamental building blocks of matter. Over the centuries, these models have evolved significantly, reflecting advancements in scientific knowledge. Early theories, such as Dalton's solid sphere model, proposed that atoms were indivisible particles. However, this notion was challenged by J.J. Thomson's discovery of electrons, leading to the plum pudding model, which depicted atoms as a mix of positive and negative charges. The most significant shift came with Ernest Rutherford's gold-foil experiment in 1911, which revealed the existence of a dense nucleus at the center of the atom, surrounded by orbiting electrons. This nuclear model laid the groundwork for Niels Bohr's model, which introduced quantized electron orbits. Today, the electron cloud model further refines our understanding, depicting electrons as existing in probabilistic clouds rather than fixed paths, illustrating the complexity of atomic structure.



### 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.

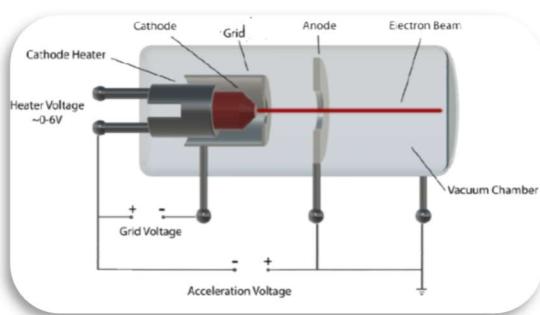
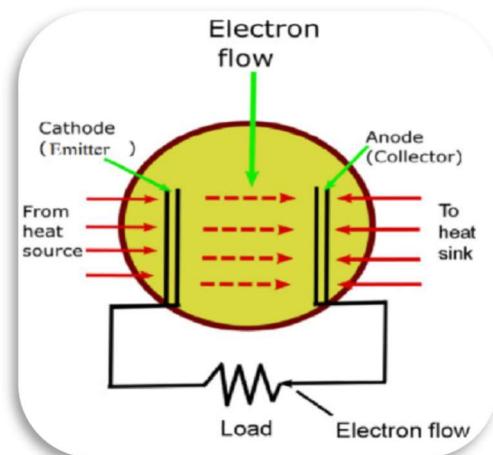
**Electrons (Negative):** Surrounding the nucleus are electrons, which are negatively charged particles. Electrons are much lighter than protons and neutrons (about 1/1836th of the mass of a

## Applications of the Photoelectric Effect

**Used to generate electricity in solar panels.** These panels contain metal combinations that allow electricity generation from a wide range of wavelengths. **Motion and Position Sensors:** In this case, a photoelectric material is placed in front of a UV or IR LED. When an object is placed in between the Light-emitting diode (LED) and sensor, light is cut off, and the electronic circuit registers a change in potential difference. **Lighting sensors**, such as the ones used in smartphones, enable automatic adjustment of screen brightness according to the lighting. This is because the amount of current generated via the photoelectric effect is dependent on the intensity of light hitting the sensor. Digital cameras can detect and record light because they have photoelectric sensors that respond to different colours of light. **X-Ray Photoelectron Spectroscopy (XPS):** This technique uses X-rays to irradiate a surface and measure the kinetic energies of the emitted electrons. Important aspects of the chemistry of a surface can be obtained, such as elemental composition, chemical composition, the empirical formula of compounds and chemical state. Photoelectric cells are used in **burglar alarms**. Used in photomultipliers to detect low levels of light. Used in video camera tubes in the early days of television. **Night vision devices** are based on this effect. The photoelectric effect also contributes to the study of certain nuclear processes. It takes part in the chemical analysis of materials since emitted electrons tend to carry specific energy that is characteristic of the atomic source.

## Thermionic emission

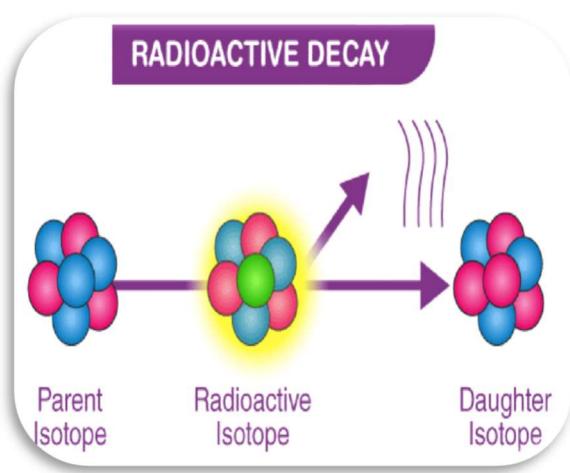
Thermionic emission is the process by which charged particles, primarily electrons, are released from a heated electrode. When a metal, typically a cathode, is heated to high temperatures around  $1,000\text{ }^{\circ}\text{C}$  ( $1,800\text{ }^{\circ}\text{F}$ ) or more its thermal energy provides sufficient kinetic energy for some electrons to overcome the work function of the material and escape into the surrounding vacuum. This phenomenon, historically known as the Edison effect, has significant applications in various technologies, including vacuum tubes and electron guns. In these devices, thermionic emission is harnessed to create a flow of electrons, which can be manipulated for various purposes, such as amplification and signal processing. Thermionic emission is used in structured materials, such as superlattices of elemental metals and compound semiconductors, enhancing our understanding of electron behavior and potential applications in energy conversion processes.



## 4.6 NUCLEAR PROCESSES

### Learning Outcomes

- Understand the processes of nuclear fission and fusion and the associated energy changes(u)
- Understand the spontaneous and random nature of nuclear decay and interpret decay data in terms of half-life ( $k$ ,  $u$ , $s$ )
- Know the applications of radioactivity and the dangers associated with exposure to radioactive materials. (k,u)
- Understand and appreciate that there are significant social, political, and environmental dimensions associated with use of nuclear power. (u,v/a)



### Introduction

Nuclear processes encompass a variety of reactions that involve the interaction of atomic nuclei. A nuclear reaction occurs when two nuclei collide or when a nucleus interacts with a subatomic particle, resulting in the formation of new nuclides. The two primary types of nuclear reactions are fission and fusion. In fission, a heavy nucleus, such as uranium, splits into smaller nuclei upon neutron collision, releasing significant energy in the form of heat and radiation. Fusion involves the merging of two light nuclei to form a heavier nucleus, a process that powers stars, including our Sun. Both fission and fusion yield millions of times more energy than conventional energy sources, making them crucial for energy production. Understanding these nuclear processes is essential for advancements in energy technology and medical applications, as they hold the potential for sustainable energy solutions and innovative treatments.

### RADIOACTIVITY

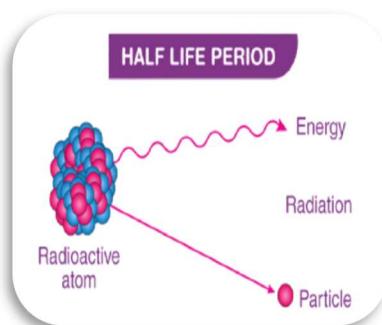
Radioactivity is the phenomenon where unstable atomic nuclei lose energy by emitting radiation, a process known as radioactive decay. This decay can result in the release of various types of radiation, including alpha and beta particles. Materials that contain these unstable nuclei are classified as radioactive, and their emissions can have significant implications for health and safety. The applications of radioactivity are vast, spanning medical, industrial, and research fields. Radioisotopes, are crucial in medical diagnostics and therapies, allowing for targeted treatments and imaging techniques.

### What is Radioactivity?

Due to nuclear instability, an atom's nucleus exhibits the phenomenon of Radioactivity. Energy is lost due to radiation that is emitted out of the unstable nucleus of an atom. Two forces, namely the force of repulsion that is electrostatic and the powerful forces of attraction of the nucleus, keep the

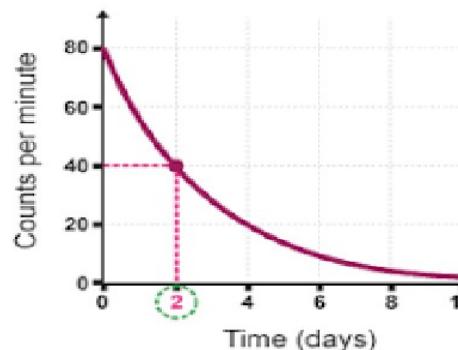
## Half-Life of a Radioactive Material

The half-life of a radioactive material is the time required for half of the radioactive atoms in a sample to decay. During this time, the amount of the original radioactive substance decreases, while the amount of decay products increases. Each type of radioactive material has a characteristic half-life, which can range from fractions of a second to millions of years.



### Understanding the decay curve

Radioactive decay follows an exponential decay model, meaning that the amount of substance does not decrease by a fixed amount each time but rather by a fixed percentage. After each half-life, 50% of the remaining radioactive atoms decay, reducing the sample amount progressively but never completely to zero. If a sample has a half-life of 10 years, then after 10 years, half of the original material will remain. After 20 years (two half-lives), only a quarter (25%) of the original material will remain, and so on. A longer half-life generally indicates greater stability, as the material decays more slowly. Equally, a short half-life suggests the material is less stable and decays quickly. Suppose we have 100 grams of a radioactive substance with a half-life of 5 years: After 5 years: 50 grams remain, after 10 years: 25 grams remain, and after 15 years: 12.5 grams remain. This pattern continues, with each interval of 5 years reducing the remaining amount by half. When a graph of account rate against time or radioactive nuclei is drawn, the half-life of the radioactive nuclei can be determined;



### Activity 1

In a certain town, people are concerned about the waste disposal from the factory into the nearby lake, which is their source of water for home use. They raised this issue to the chairperson Local Council 1 (LC1) who directed the management of the factory to stop disposing waste into the lake. A scientist was contacted to investigate the presence of radioactive material in the water. The scientist found out that the water was indeed radioactive as shown in Table 1 and Table 2.

**Table 1**

Time/days	0	5	10	15	20	25	30
Activity/counts per minute	1200	740	440	260	160	90	60

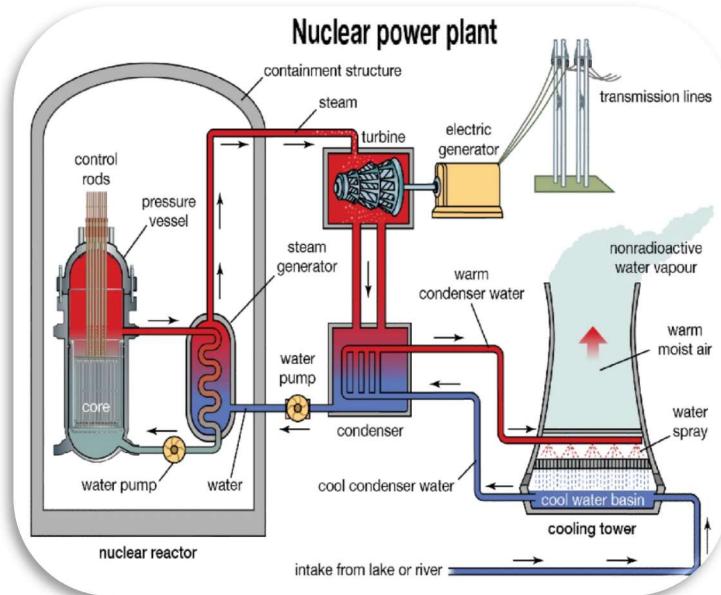
Although the water from the lake remains radioactive for a long time, the scientist recommended that water will be safe for use again when the activity is less than 38 counts per minutes.

other nuclei then the process is called as *nuclear scattering* rather than specifying it as a nuclear reaction. This does not imply radioactive decay. One of the most evident nuclear reactions is the nuclear fusion reaction that occurs in fissionable materials producing induced nuclear fission.

A nuclear chain reaction occurs when a single nuclear reaction causes one or more subsequent reactions, leading to a self-sustaining series of reactions. This process is fundamental to both nuclear reactors and nuclear weapons. The most common type of nuclear chain reaction involves nuclear fission, where a heavy nucleus, such as uranium-235 or plutonium-239, splits into smaller nuclei, releasing energy and neutrons. These released neutrons can then initiate further fission reactions in nearby nuclei, perpetuating the chain reaction.

### Steps in a Nuclear Chain Reaction

A neutron collides with a heavy atomic nucleus (e.g., uranium-235), causing it to become unstable and split into two smaller nuclei (fission products) along with a release of energy and additional neutrons. This fission releases a large amount of energy in the form of kinetic energy and gamma radiation. The fission event releases two or three neutrons, which can then collide with other nearby fissile nuclei, causing them to undergo fission as well. If each fission event leads to at least one more fission, the reaction becomes self-sustaining, creating a chain reaction. A sufficient amount of fissile material (critical mass) is required to sustain the chain reaction, as too few atoms would make it difficult for neutrons to continue colliding with nuclei. In nuclear reactors, the rate of the chain reaction is regulated using control rods that absorb excess neutrons, allowing the reaction to proceed at a steady rate to produce energy safely. In nuclear weapons, the chain reaction is uncontrolled, leading to an explosive release of energy within a fraction of a second.



### Nuclear Reactions -Types

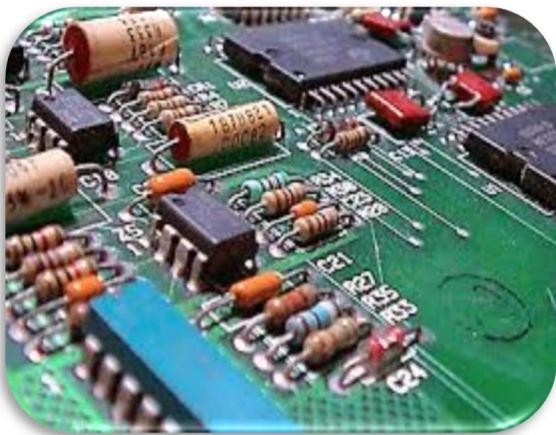
*Inelastic scattering:* This process takes place when a transfer of energy occurs. It occurs above threshold energy called the inelastic threshold energy and is the energy of the first excited state.

*Elastic Scattering:* It occurs when there is energy transfer between a particle and intends nuclei. It is the most vital process for slowing down neutrons. In the case of an elastic scattering total kinetic energy of any system is conserved.

## 4.5 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

#### Introduction

Digital electronics is a vital field that focuses on the study and application of digital signals. It encompasses the design and engineering of devices that utilize these signals, which are essential for modern computing and communication systems. Digital electronics operates on binary data, allowing for efficient processing and manipulation of information, such as numbers and text. The discipline includes various components, such as logic gates, combinational and sequential circuits, which form the backbone of digital systems. Recent advancements in materials science are pushing the boundaries of digital electronics, particularly in high-temperature applications. Innovations beyond traditional silicon technologies are being explored to enhance the resilience and performance of electronic devices, ensuring that digital electronics continues to evolve and meet the demands of modern technology.

#### Potential Divider

A potential divider, also known as a voltage divider, is a fundamental electronic circuit that reduces a higher voltage to a lower voltage. This is achieved by using resistors in series, where the output voltage is a fraction of the input voltage, determined by the resistor values. This simple yet effective design is widely utilized in various applications, including sensor circuits and signal processing. In practical terms, a potential divider allows for the adjustment of voltage levels, making it essential in electronic devices. For instance, it can be used to calibrate sensor outputs or to create reference voltages for operational amplifiers. 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

**Battery Level Indicators:** A potential divider can scale down the voltage of a battery to a safer, readable level for a microcontroller or ADC (Analog-to-Digital Converter). Used in battery-operated devices to monitor and display battery voltage levels. For example, in mobile phones, laptops, and electric vehicles, battery indicators often rely on a potential divider to measure the state of charge.

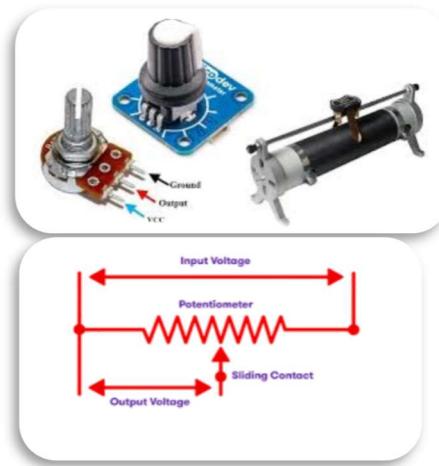
**Reference Voltage for Comparators:** A potential divider can create a fixed reference voltage for a comparator circuit. In control systems, such as thermostats, this reference voltage is compared with an input signal to trigger an action, like turning a heater on or off based on temperature levels.

**Signal Conditioning:** Potential dividers can be used to scale down higher voltages to a level that's compatible with low-voltage circuitry or sensitive input devices. Common in digital electronics, where signals need to be scaled to safe levels for microcontrollers or analog-to-digital converters without damaging sensitive components.

**Level Shifting:** In some digital circuits, a potential divider adjusts signal voltages to match different logic levels. Essential in interfacing components that operate at different voltage levels, such as connecting 5V and 3.3V logic circuits in integrated systems like microcontrollers, sensors, and communication modules.

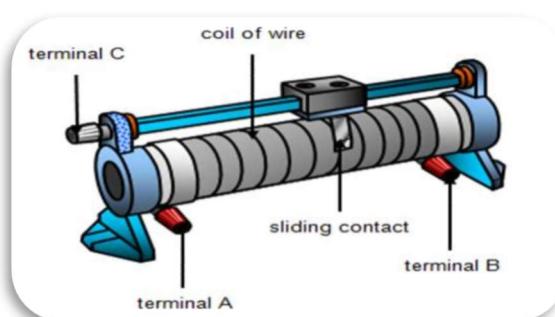
### Variable Resistor / Rheostat

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. 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

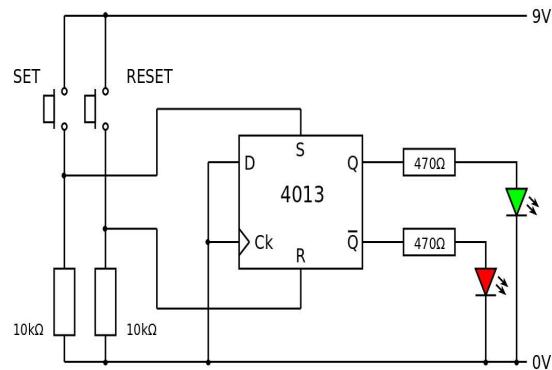
The design of a potentiometer is similar to that of a variable resistor. All the three points, both the ends of resistance wire and the adjustable contact, are connected to the circuit. Two terminals and the contact are connected to the circuit. The length of the wire can be changed by the sliding contact. The resistance increases as the length of the wire increases. The resistance can be set to any value from zero to the total



and  $\bar{Q} = \text{LOW}$ . RESET is normally LOW, making RESET go HIGH forces the output Q LOW and  $\bar{Q} = \text{HIGH}$ .

Making both SET and RESET HIGH at the same time is a disallowed state - in this case, the outputs Q and  $\bar{Q}$  both go HIGH with the final state being determined by which input goes LOW first.

The diagram shows a simple test circuit with CK and D connected to ground.



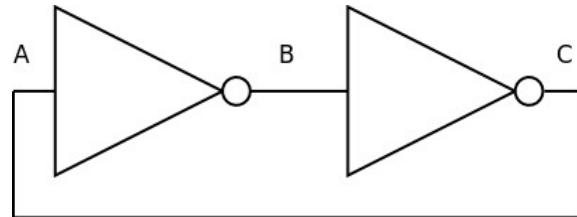
### Simple logic gate Bistable

At the heart of a bistable circuit are two inverting logic gates. The output of each logic gate is connected to the input of the other logic gate. Such a circuit has two states where it is stable.

The most basic logic gate bistable is made from two **NOT gates** as shown in the diagram.

Situation 1:

Assume  $A = 0$  and therefore  $B = 1$ .  $B = 1$  and therefore  $C = 0$  ... C is connected to A, and so  $A = 0$  as required.

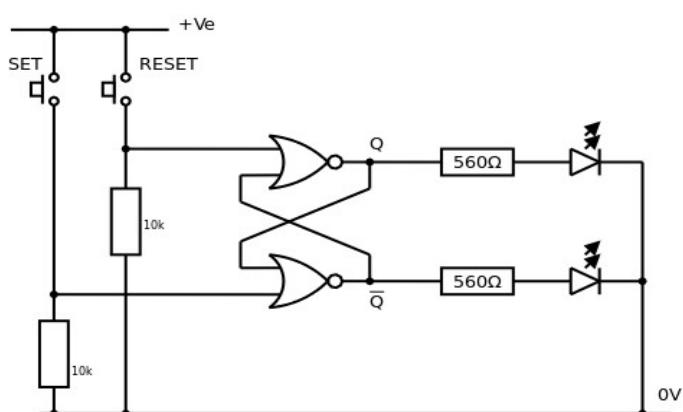


Situation 2:

Assume  $A = 1$  and therefore  $B = 0$ .  $B = 0$  and therefore  $C = 1$  ... C is connected to A, and so  $A = 1$  as required.

Whether  $A = 0$  or  $A = 1$ , the circuit works in both cases. To make this circuit a bistable simply make one of the NOT gate outputs Q and the other  $\bar{Q}$ .

This is not a good circuit. To SET or RESET the bistable requires input A or input B to be forced into either a HIGH or LOW state - but the inputs are also the outputs of the other logic gates and forcing the outputs of logic gates to be either HIGH or LOW can lead to problems.



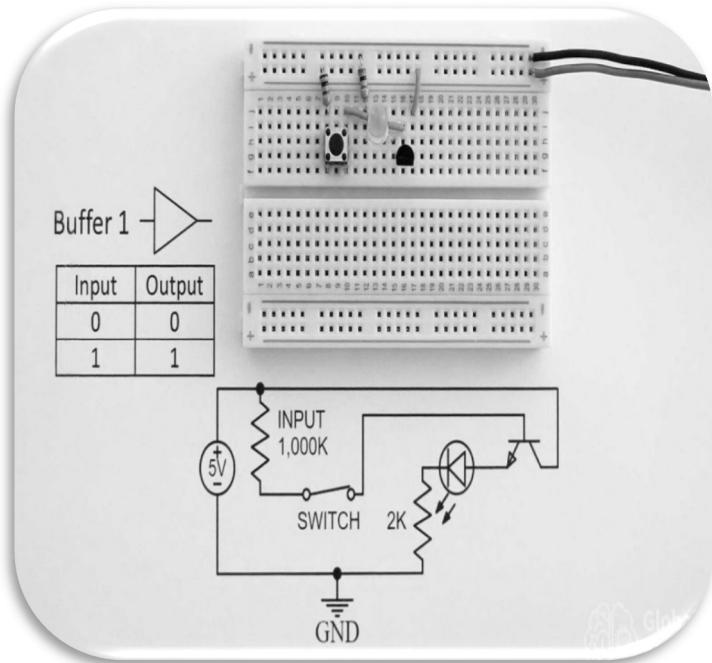
If we assume situation 1 where  $A = 0$  and we force A to be HIGH so that  $A = 1$  then the output C will try and stay LOW so is A HIGH or LOW? An indeterminate state can result and the bistable

### **Construction of digital logic gates on breadboards**

Digital logic gates are what allow a computer to perform computations using transistors. This is done by using the binary or base 2 number system. A transistor only has two states which are on or off. However, when multiple transistors are used together the output of the two inputs can be changed in a logical way. This allows for AND, NAND, OR, NOR, XOR, and XNOR logic. Most logic gates can be made using multiple circuit configurations. Many people understand the basics of digital logic gates but not enough to actually implement them at the transistor level. The logic gate needs to be wired in a configuration so the output can be sent further down the circuit. There are also more advanced configurations that allow for lower power consumption and faster switching time. A circuit diagram is also provided so there is no ambiguity as to where to connect the wires. The name, symbol, and truth table for each logic gate is shown in the picture above. Often times circuits are not drawn at the transistor level and just the logic gate symbol is used. The truth table is very important as it makes it clear what the output should be based on the inputs. This is very useful when trying to build larger circuits such as the half adder, full adder, calculators, and computer processors

### **BUFFER**

A buffer is a simple circuit where the input value is the same as the output value. This means if the input is off the output will be off. If the input is on the output will be on. There are many reasons why a buffer may be added to the circuit. In most cases, it is to ensure a strong output signal. The input voltage or current may be a low value and running the input through the buffer helps ensure a consistent output level. There is more than one way to make a buffer so check out the buffer article for more information.



### NOR Gate

The NOR gate is another universal logic gate. This means that it can make all the other types of logic gates. Like the NAND gate it also only requires two transistors. In the picture, the orange wire connects the collectors of both transistors. There is also ground going to the emitter of both transistors. This makes it so if any input is on the output will be off. The only case where the output will be on is when both inputs are off.

### XOR Gate

The XOR gate is also called an exclusive OR gate. It is similar to an OR gate but is not on when both inputs A and B are on. In the picture, only input A is on which is why the LED is on. This is a common logic gate to see used to build half adders and full adders. It can be built in multiple configurations including using NAND and NOR gates. The one shown uses 6 transistors and the output can be sent to be used as inputs in other circuits.

### XNOR Gate

The XNOR gate is also called the exclusive NOR gate. This means that it is not on when only input A or only input B is on. When both inputs are on or off the output will be on. This circuit only requires 5 transistors and the output can be sent to other circuits. In the photo inputs A and B are both on which is why the LED is lit up.

