Introduction

The word *Physics* comes from the Greek word *Phusis* meaning **nature**. Its Sanskrit equivalent is **Bhautiki** that is used to refer to the study of the physical world. We can broadly describe Physics as **a study of the basic laws of nature and their manifestation in different natural phenomena**. We can get some idea of the scope of Physics by looking at its various sub-disciplines. Basically, there are two domains of interest: macroscopic and microscopic.

The **macroscopic** domain includes phenomena at the laboratory, terrestrial and astronomical scales. The **microscopic** domain includes atomic, molecular and nuclear phenomena. **Classical Physics** deals mainly with the macroscopic phenomena and includes subjects like Mechanics, Electrodynamics, Optics and Thermodynamics.

Mechanics is founded on Newton's laws of motion and the law of gravitation is concerned with the motion (or equilibrium) of particles, rigid and deformable bodies, and general systems of particles. The propulsion of a rocket by a jet of ejecting gases, propagation of water waves or sound waves in air, the equilibrium of a bent rod under a load, etc., are associated with the phenomenon of Mechanics.

Electrodynamics deals with electric and magnetic phenomena associated with charged and magnetic bodies. Its basic laws were given by Coulomb, Oersted, Ampere and Faraday, and encapsulated by Maxwell in his famous set of equations. The motion of a current-carrying conductor in a magnetic field, the response of a circuit to an AC voltage (signal), the working of an antenna, the propagation of radio waves in the ionosphere, etc., are associated with the phenomenon of Electrodynamics.

Optics deals with the phenomena involving light. The working of telescopes and microscopes, colours exhibited by thin films, etc., are topics in Optics.

Thermodynamics, in contrast to mechanics, does not deal with the motion of bodies as a whole. Rather, it deals with systems in macroscopic equilibrium and is concerned with changes in internal energy, temperature, entropy, etc., of the system through external work and transfer of heat. The efficiency of heat engines and refrigerators, the direction of a physical or chemical process, etc., are phenomena of interest in Thermodynamics.

The microscopic domain of Physics deals with the constitution and structure of matter as the minute scales of atoms and nuclei (and even lower scales of length) and their interaction with different probes such as electrons, photons and other elementary particles.

Some physicists from different countries of the world and their major contributions

Name	**Major contribution/ discovery**	**Country of Origin**
Archimedes	Principle of buoyancy; Principle of the lever	Greece
Galileo Galilei	Law of inertia	Italy
Christian Huygens	Wave theory of light	Holland
Isaac Newton	Universal law of gravitation; Laws of motion; Reflecting telescope	U.K.
Michael Faraday	Laws of electro-magnetic induction	U.K.
James Clerk Maxwell	Electromagnetic theory Light as an electromagnetic wave	U.K.
Heinrich Rudolf Hertz	Generation of electro-magnetic waves	Germany
J.C. Bose	Ultra-short radiowaves	India
W.C. Roentgen	X-rays	Germany
J.J. Thomson	Electron	U.K.
Marie Sklodowska Curie	Discovery of radium and polonium; Studies on natural radioactivity	Poland
Albert Einstein	Explanation of photo-electric effect; Theory of relativity	Germany
Victor Francis Hess	Cosmic radiation	Austria
R.A. Millikan	Measurement of electronic charge	U.S.A.
Ernest Rutherford	Nuclear model of atom	New Zealand
Niels Bohr	Quantum model of hydrogen atom	Denmark
C.V. Raman	Inelastic scattering of light by molecules	India
Louis Victor de Borglie	Wave nature of matter	France
M.N. Saha	Thermal ionisation	India

S.N. Bose	Quantum statistics	India
Wolfgang Pauli	Exclusion principle	Austria
Enrico Fermi	Controlled nuclear fission	Italy
Werner Heisenberg	Quantum mechanics; Uncertainty principle	Germany
Paul Dirac	Relativistic theory of electron; Quantum statistics	U.K.
Edwin Hubble Ernest Orlando Lawrence	Expanding universe Cyclotron	U.S.A. U.S.A.
James Chadwick	Neutron	U.K.
Hideki Yukawa	Theory of nuclear forces	Japan
Homi Jehangir Bhabha	Cascade process of cosmic radiation	India
Lev Davidovich Landau	Theory of condensed matter; Liquid helium	Russia
S. Chandrasekhar	Chandrasekhar limit, structure and evolution of stars	U.S.A.
John Bardeen	Transistors: Theory of superconductivity	U.S.A.
C.H. Townes	Maser, Laser	U.S.A.
Abdus Salam	Unification of weak and electromagnetic interactions	Pakistan

Link between technology and physics

Technology	**Scientific Principle(s)**
Steam engine	Laws of thermodynamics
Nuclear reactor	Controlled nuclear fission
Radio and Television	Generation, propagation and detection
Computer	Digital logic
Laser	Light amplification by stimulated emission of radiation
Production of ultra height magnetic fields	Superconductivity
Rocket propulsion	Newton's laws of motion
Electric generator	Faraday's laws of electromagnetic induction
Hydroelectric power	Conversion of gravitational potential energy into electrical energy
Aeroplane	Bernoulli's principle in fluid dynamics
Particle accelerators	Motion of charged particles in electromagnetic fields
Sonar	Reflection of ultrasonic waves
Optical fibres	Total internal reflection of light
Non-reflecting coatings	Thin film optical interference
Electron microscope	Wave nature of electrons
Photocell	Photoelectric effect
Fusion test reactor (Tokamak)	Magnetic confinement of plasma
Giant Metrewave Radio Telescope (GMRT)	Detection of cosmic radio waves
Bose-Einstein condensate	Trapping and cooling of atoms by laser beams and magnetic fields

There are four fundamental forces in nature, which have been described below.

Gravitational Force

The gravitational force is the force of mutual attraction between any two objects by virtue of their masses. It is a **universal force**. Every object experiences this force due to every other object in the universe. All objects on the earth, for example, experience the force of gravity due to the earth. In particular, gravity governs the motion of the moon and artificial satellites around the earth, the motion of the earth and planets around the sun, and, of course, the motion of bodies falling on the earth. It plays a key role in the large-scale phenomena of the universe, such as formation and evolution of stars, galaxies and galactic clusters.

Electromagnetic Force

Electromagnetic force is the force between charged particles. In the simpler case, when charges are at rest, the force is governed by Coulomb's law: attractive for unlike charges and repulsive for like charges. Charges in motion produce magnetic effects and a magnetic field gives rise to a force on a moving charge. Like the gravitational force, electromagnetic force acts over large distances and does not need any intervening medium**. It is enormously strong compared to gravity.** The electric force between two protons is 10^{36} times the gravitational force between them, for any fixed distance. Since the electromagnetic force is so much stronger than the gravitational force, it dominates all phenomena at atomic and molecular scales. Thus **it is mainly the electromagnetic force that governs the structure of atoms and molecules**, the dynamics of chemical reactions and the mechanical, thermal and other properties of materials.

Gravity is always **attractive,** while electromagnetic force can be **attractive or repulsive.** The charge comes in two varieties: positive and negative.

Strong Nuclear Force

The strong nuclear force binds protons and neutrons in a nucleus. It is evident that without some attractive force, a nucleus will be unstable due to the electric repulsion between its protons. This attractive force cannot be gravitational since the force of gravity is negligible compared to the electric force. A new basic force must, therefore, be invoked. The nuclear force is the strongest of all fundamental forces, about **100 times** the electromagnetic force in strength. It is charge-independent and acts equally between a proton and a proton, a neutron and a neutron, and a proton and a neutron. Its range is, however, extremely small, of about nuclear dimensions (10^{-15} m). It is responsible for the stability of nuclei. The electron, it must be noted, does not experience this force. Recent developments have, however, indicated that protons and neutrons are built out of still more elementary constituents called **quarks**.

Weak Nuclear Force

The weak nuclear force appears only in certain nuclear processes such as the beta decay of a nucleus. In beta decay, the nucleus emits an **electron** and an uncharged particle called **neutrino**. The weak nuclear force is not as weak as the gravitational force, but much weaker than the strong nuclear and electromagnetic forces. The range of weak nuclear force is exceedingly small, of the order of 10^{-16} m.

Fundamental forces of nature

Name	Relative strength	Range	Operates among
Gravitational	10^{-39}	Infinite	All objects in the universe
Weak nuclear	10^{-13}	Very short, sub-nuclear size (10^{-16} m)	Some elementary particles, particularly electron and neutrino
Electromagnetic	10^{-2}	Infinite	Charged particles
Strong nuclear	1	Short, size (-10^{-15}m)	Nucleons, heavier than elementary particles

Units and Measurements

Physical Quantity: The quantities which can be measured are known as physical quantities**.** The measurement of any physical quantity involves comparison with a certain basic, arbitrarily chosen, internationally accepted reference standard called **unit**. The units for the fundamental or base quantities are called **fundamental** or **base units**. The units of all other physical quantities can be expressed as combinations of the base units. Such units obtained for the derived quantities are called **derived units**. A complete set of these units, both the base units and derived units, is known as the **system of units**.

Scalars and Vectors

A **scalar** physical quantity has magnitude only and no direction. It is specified completely by a single number, along with a proper unit, e.g. mass, length, time, temperature etc.

A **vector** quantity has both magnitude and a direction and obeys the vector laws of addition (triangle law, parallelogram law), e.g. displacement, velocity, acceleration etc.

The International System of Units

In earlier times scientists of different countries used different systems of units for measurement. Three such systems, the CGS, the FPS (or British) and the MKS system were in use extensively till recently. The base units for length, mass and time in these systems were as follows:

- In **CGS system** they were centimetre, gram and second respectively.
- In **FPS system** they were foot, pound and second respectively.
- In **MKS system** they were metre, kilogram and second respectively.

The system of units which is at present internationally accepted for measurement is *Le Système International d'Unités* (French for International System of Units), abbreviated as SI. The SI, with standard scheme of symbols, units and abbreviations, was developed and recommended by **General Conference on Weights and Measures in 1971** for international usage in scientific, technical, industrial and commercial work. Because SI units used decimal system, conversions within the system are quite simple and convenient.

SI Base Quantities and Units

Base quantity	SI Units Name	Symbol	Definition
Length	metre	m	Metre is the length of the path travelled by light in vacuum during a time interval of 1/299,792,458 of a second. (1983)
Mass	kilogram	kg	Kilogram is equal to the mass of the international prototype of the kilogram (a platinum-tridium alloy cylinder) kept at international Bureau of Weights and Measures, at Sevres, near Paris, France. (1889)
Time	second	s	Second is the duration of 9,192,631,770 periods of the radiation corresponding to the transition between the two hyperfine levels of the ground state of the Caesium-133 atom. (1967)
Electric current	ampere	A	Ampere is that constant current which, if maintained in two straight parallel conductors of infinite length, of negligible circular cross-section, and placed 1 metre apart in vacuum, would produce between these conductors a force equal to 2×10^{-7} Newton per metre of length. (1948)
Thermo-dynamic temperature	kelvin	K	Kelvin, is the fraction 1/273.16 of the thermodynamic temperature of the triple point of water. (1967)
Amount of substance	mole	mol	Mole is the amount of substance of a system, which contains as many elementary entities as there are atoms in 0.012 kilogram of Carbon-12. (1971)
Luminous intensity	candela	cd	Candela is the luminous intensity, in a given direction, of a source that emits monochromatic radiation of frequency 540×10^{12} hertz and that has a radiant intensity in that direction of 1/683 watt per steradian. (1979)

Motion

- Motion has been defined as a change in position of a body with respect to time.
  Motion may be classified into two types:
  1. Linear Motion
  2. Non-Linear motion
- **Linear Motion:** When a body travels along a straight line. For example, when a car travels on a straight road without changing the direction.
- **Non-Linear Motion:** When a body travels along a non-straight line.
  Further motion can be classified into two types:
  (i) Uniform motion
  (ii) Non-Uniform motion
- **Uniform motion:** When the velocity of a body does not change with respect to time.
- **Non-Uniform motion:** When the velocity of a body changes with respect to time.
- **Velocity:** Velocity is displacement per unit time.
  Unit : m/s
- **Acceleration:** Acceleration is the rate of change of velocity or change in velocity per unit time.
  Unit: m/s^2
- Negative acceleration is called **retardation** or **deceleration**.
- **Types of acceleration:** There are two types of acceleration:
  (a) Uniform acceleration
  (b) Non-uniform acceleration or variable acceleration
- **Uniform acceleration:** A body is said to possess uniform acceleration if there are equal changes in its velocity in equal intervals.
- **Variable acceleration:** A body is said to possess non-

uniform or variable acceleration if there are unequal changes in its velocity in equal intervals of time.

- **Speed:** The speed of a body is the distance covered per unit time.
  Unit: m/s

Laws of Motion

Galileo proposed the concept of acceleration. From experiments on motion of bodies on inclined planes or falling freely, he thus arrived at the **law of inertia**.

Newton built on Galileo's ideas and laid the foundation of mechanics in terms of three laws of motion that go by his name. Galileo's law of inertia was his starting point which he formulated as the **First Law of Motion.**

Newton's First Law of Motion or Law of Inertia or Galileo's law

Every body in the universe stays in a state of rest or in uniform motion along a straight line until and unless compelled by an external force to change its state.

- Newton's first law gives the qualitative definition of force, as it tells us about an agent without which, acceleration is not possible. According to the law, force is an agent which tends to change the state of rest or of uniform motion of a body; e.g. a moving car stops only when brakes are applied.

The concept of inertia

Inertia can be understood in the following two ways:

- It is the inability of a body to change, by itself, its state of rest or uniform motion.
- It is the property of a body by virtue of which it opposes any change in its state of rest or of uniform motion.
  Inertia is of three types:
  1. Inertia of rest
  2. Inertia of motion
  3. Inertia of direction

Inertia of rest

The inherent property of a body by virtue of which it cannot change its state of rest is called **inertia of rest**; e.g.

(i) When we dust a carpet, the dust moves out of the carpet. This is because the dust is set into motion whereas the carpet remains in a state of rest due to inertia of rest.
(ii) If a horse suddenly starts galloping, the rider receives a backward jerk.
(iii) An apple falls down from the tree when its branch is shaken.
(iv) When a train starts suddenly, the passengers receive a backward jerk.

Inertia of Motion

The inherent property of a body by virtue of which it cannot change its state of motion is called **inertia of motion**; e.g.

(i) If a horse suddenly stops galloping, the rider receives a forward jerk. This is because the lower part of the rider in contact with the horse comes to rest whereas the upper portion of his body remains in a state of motion.
(ii) When a rotating fan is switched off it continues to rotate.
(iii) A ball thrown vertically upwards in a moving train comes back into the hands of the thrower when the train is having a uniform motion.
(iv) A person falls when he alights a moving train. This is because inside the train his body is in a state of motion. But when he jumps out of the train the lower portion of his body is at rest while the upper motion remains in motion due to inertia of motion.

Inertia of Direction

The inherent property of a body by virtue of which it cannot change its direction of motion is called **inertia of direction**; e.g.

(i) Vehicles are provided with mudguards to save them from being spoilt. This is due to the reason that the mud sticking to the wheels flies off tangentially.
(ii) A stone tied to a string and whirled along a circular path flies off tangentially when its string is suddenly broken.
(iii) While sharpening a knife, sparks fly off tangentially from the grinding stone.

Inertia and Mass

The heavier or more massive objects offer larger inertia. Quantitatively, the inertia of an object is measured by its **mass**.

Momentum

The momentum p of an object is defined as the product of its mass m and velocity v.

i.e. $p = mv$

Momentum has both direction and magnitude.

The SI unit of momentum is **kilogram-metre per second (kms^{-1})**.

By the definition of momentum, it is clear that a moving object can have a large momentum if either its mass is large or its velocity is large or both are large. A truck has more momentum than a car moving with the same speed as that of the truck. Huge objects having a small speed usually have a large momentum.

Example: During the game of table tennis if the ball hits a player it does not hurt him. On the other hand, when a fast moving cricket ball hits a spectator, it may hurt him.

Newton's Second Law of Motion

It states that the rate of change of momentum is directly proportional to the applied force and the change takes place in the direction of the applied force.

Newton's second law gives the quantitative definition of force. The mathematical form of Newton's second law of motion may be written as

m × a = rate of change of momentum, therefore,

Force = rate of change of momentum

or, F = ma

Units of Force

(i) Newton (N) in SI system (ii) Dyne in CGS system (iii) Pound (Lb) in British Engineering System.

If m = 1g, a = 1 cms^{-2} then F = 1 dyne

Newton's Third Law of Motion

According to this law, forces appear in pair. An isolated force does not exist. Whenever one object exerts a force on another, the second object exerts an equal and opposite force on the first. This law states that to every action there is an equal and opposite reaction. It can be expressed mathematically.

Consider two bodies A and B. Let F_{AB} be the force experienced by body A due to body B, and F_{BA} be the force experienced by B due to A. If the system is isolated, then by Newton's third law we have $F_{AB} = -F_{BA}$. This is the mathematical representation of the third law.

Examples of Newton's Third Law

1. When a person throws a package out of a boat, the boat moves in the opposite direction. The person exerts a force on the package. The package exerts an equal and opposite force back on the person, and this force propels the person (and the boat) backward slightly.
2. Rockets work on the same principle. A common misconception is that rockets accelerate because the gases rushing out of the back of the engine push against the ground or the atmosphere. Actually, a rocket exerts a strong force on the gases, expelling them. The gases exert an equal and opposite force on the rockets and it is this force that propels the rocket forward. Thus a space vehicle moves in empty space by firing its rockets in the direction opposite to that in which it wants to move.
3. A person begins walking by pushing with the foot against the ground. The ground then exerts an equal and opposite force back on the person and it is this force on the person that moves him or her forward.
4. An automobile moves forward because of the force exerted on it by the ground which is the reaction to the force exerted on the ground by the tyres.

Law of Conservation of Momentum

The momentum of an object is the product of mass and direction. Momentum is also a vector. Therefore the direction of the object is important for the determination of the total momentum of a system of objects. The Law of Conservation of Momentum infers that the total momentum of a system of objects remains the same. Therefore, if two objects collide the total momentum before the collision is equal to the total momentum after the collision. The velocities of the objects involved in the collision can change in both magnitude and direction. There are two types of collisions: **elastic**, where the objects are only in contact with each other for a brief period of time; and **inelastic,** where they remain fixed together and move as one object with one velocity. The equations for the conservation of momentum are given below:

$m_1v_{1i} + m_2v_{2i} = m_1v_{1f} + m_2v_{2f}$

where i and f are initial and final velocities.

Applications of Law of Conservation of Momentum

- When a bullet is fired from a gun, the gases produced in the barrel exert a tremendous force on the bullet (action force). As a result, the bullet moves forward with a great velocity called the muzzle velocity. The bullet at the same time exerts an equal force on the gun in the opposite direction (reaction force). Due to this the gun moves backwards. This backward motion of the gun is called the recoil of the gun. The velocity with which the gun moves backwards is called the recoil velocity.
- The motion of a rocket is an application of Newton's third law of motion and law of conservation of linear momentum. A **rocket** is a projectile that carries the rocket fuel and the oxidiser, which supplies the oxygen needed for combustion. Liquid hydrogen, liquid paraffin, etc., are used as rocket fuels. Hydrogen peroxide, liquid oxygen etc., are used as oxidisers. The fuel-oxidiser combination in a rocket is called the **propellant**. The simplest form of rocket consists of a combustion chamber in which a solid or liquid propellant is burnt. There is a nozzle at its tail through which the gaseous products of combustion can escape. The rocket forces a jet of hot gases downwards through the nozzle. This is the action. The jet of gases exerts an equal force on the rocket, pushing it forward. This is the reaction. This force gives the rocket a forward acceleration.

Work, Energy and Power

Work

Work is said to be done only when the force applied on a body makes the body move, i.e., there is a displacement of the body.

The amount of work done (W.D.) by a force is equal to the product of the force and the displacement of the point of application of the force in the direction of the force.

The amount of W.D. by a force is zero

(i) **When there is no displacement**

(ii) **When displacement is normal to the direction of force** ($\theta = 90°$),

$\because \cos 90° = 0$.

The amount of W.D. will be maximum when the displacement is in the direction of force applied

$\therefore$ W.D. $= f \times s \cos\theta = f \times s \cos 0°$

W.D. $= f \times s$ $\quad (\because \cos 0° = 1)$

The amount of W.D. will be positive when the angle between force and displacement will be less than 90°.

The amount of W.D. will be negative when the angle between force and displacement will be 180° or greater than 90°.

$\therefore$ W.D. $= f \times s \cos 180°$

$= f \times s(-1)$

W.D. $= -f \times s$ $\quad (\because \cos 180° = -1)$

SI unit: Joule

CGS unit: Erg

Work is a scalar quantity.

Joule

1 Joule of work is said to be done when a force of 1 Newton displaces a body through 1 metre in its own direction.

1 erg of work is said to be done when a force of 1 dyne displaces a body through 1 cm in its own direction.

1 Joule = 1 Nm $\quad$ 1 N = 10^5 dyne

1 m = 10^2 cm $\quad$ $\therefore$ 1 Joule = 10^7 ergs

Energy

Energy of a body is its capacity to do work.

When a body does work, its energy decreases, while if work is done on the body, its energy increases.

Unit of energy:

SI unit – Joule $\quad$ CGS unit – Erg

Commercial unit – kWh

There are two types of energy:

1. Potential energy
2. Kinetic energy

Potential Energy

Potential energy is the energy possessed by a body by virtue of its position or when the body is at rest or in deformed state. It may also be defined as the amount of work done on a body to change its position against the force of gravity.

P.E. = mgh,

where h is the height through which the body is lifted.

m= mass of the body.

g= acceleration due to gravity.

Kinetic Energy

Kinetic energy is possessed by the body when it is in motion. It may also be defined as the amount of work done (W.D.) in increasing the velocity of the body from zero to some value.

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

where v is the velocity of the body.

Different forms of Energy

Thermal Energy: Thermal energy is the energy of an object because of the kinetic energy and potential energy of the molecules. The higher the temperature, the faster the molecules move, the greater the thermal energy of a substance. It is commonly called heat energy.

Chemical Energy: The energy released or absorbed during a chemical reaction, depending on whether the total energy of the reactant is more or less than the product, e.g. hydrolysis, burning of coal.

Electrical Energy: Work needs to be done with respect to attraction or repulsion of electrical changes. The energy by virtue of this work is electrical energy.

Nuclear Energy: The energy produced due to fission of a heavy nucleus molecule to two lighter fragments or fusion of two light nuclei to give a heavier nucleus, is called nuclear energy.

Conservation of Energy

According to the law of conservation of energy, **energy can neither be created, nor be destroyed**; it can only be converted from one form to another, i.e. total energy in a closed system is constant.

The general law of conservation of energy is true for all forces and for any kind of transformation between different forms of energy.

Energy related to Mass: According to Einstein's hypothesis, mass can be converted into energy according to the relation $E = mc^2$, where 'm' is mass and 'c' is the speed of light. The value of 'c' = 3 × 10 m/s. The law cannot be proved mathematically, but is an empirical one. It forms one of the fundamental principles of physics.

Equipment/Instrument	Transformation of energy
Loudspeaker	Electrical energy into Sound energy
Musical Instruments	Mechanical energy into Sound energy
Bulb/Tube	Electrical energy into Light energy
Heater	Electrical energy into Thermal energy
Coal	Chemical energy into Thermal energy
Electric Cell	Chemical energy into Electrical energy
Heat Engine	Thermal energy (Heat energy) into Mechanical energy
Solar cell	Light energy into Electrical energy
Petrol engine	Chemical energy into Mechanical energy
Microphone	Sound energy into Mechanical energy

Power

The rate of doing work is called power. It depends on two factors: (i) **Amount of work done** (ii) **Time taken to do work**.

Power is also calculated from the product of force (f) and average speed (v).

$$P = \frac{W.D.}{time} = f \times v$$

SI unit: Watt or Joule/s or 1 kg m^2s^{-3}. The other unit is horse power (hp).

1 hp = 746 watt
1 KW = 1000 watt
1 MW = 10^6 watt

CGS unit: erg/s

1 W = 1 J/s or 10^7 erg/s

Impulse

The effect of a force applied for a very short period of time is called **impulse**. It is equal to the change in the momentum of a body.

Impulse = $F \times t = mv - mu$

Units: kg m/s or Ns

Application of Impulse

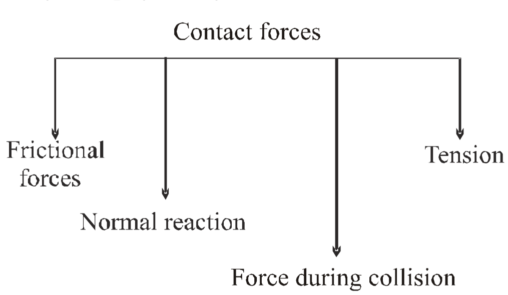
- Thick mattresses with soft surfaces are used in events such as high jump so that the time interval of impact on landing is extended, thus reducing the impulsive force. This can prevent injuries to the participants.
- Goalkeepers will wear gloves to increase the collision time. This will reduce the impulsive force.
- A high jumper will bend his legs upon landing. This is to increase the time of impact in order to reduce the impulsive force acting on his legs. This will reduce the change of getting a serious injury.
- A baseball player must catch the ball in the direction of the motion of the ball. Moving his hand backwards when catching the ball prolongs the time for the momentum to change so as to reduce the impulsive force.

Force and Pressure

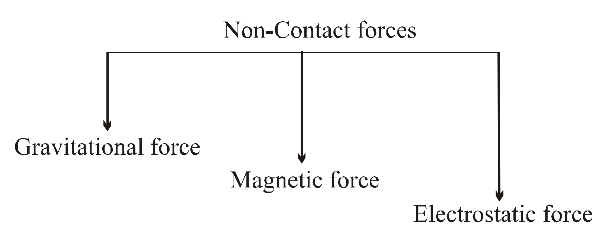
Force

Force is that physical cause which changes or tends to change the state of rest or the state of motion of the body. It can also bring about a change in the dimension of the body.

Contact Force: The force between two bodies when they are physically in contact is called a contact force.



Non-Contact Force: The force which does not involve physical contact between the two objects but acts through empty space is called a non-contact force.



- Force/Weight is a **vector** quantity.
- **1 Newton** is the force which when acting on a body of mass 1 kg produces an acceleration of 1 ms^{-2} in it.
- **1 dyne** is the force which when acting on a body of mass 1 g produces an acceleration of 1 cms^{-2} in it.

- **1 kgf** is the force with which the earth attracts a mass of 1 kg.
- **1 gf** is the force with which the earth attracts a mass of 1 g.
- Relation between Newton and dyne:
  (i) 1 N = 10^5 dyne (ii) 1 kgf = 9.8 N
  (iii) 1 gf = 980 dyne (iv) 1 kgf = 1000 gf

Centripetal Force: For a body to move in a circle, there must be a force on it directed towards the centre. This is called the centripetal force and is necessary to produce continuous change of direction in a circular motion. In case of the moon, **the gravitational force between the earth and the moon acts as the centripetal force**. When a stone tied at one end of a string is whirled in a circle, the pull in the string provides the centripetal force.

The magnitude of the centripetal force, F_c, required to cause an object of mass *m* and speed *v* to travel in a circular path of radius *r* is given by the relation

$$F_c = \frac{mv^2}{r}$$

It is a **real** force.

Centrifugal Force: This force is supposed to be acting on a body revolving in a circle. Centrifugal force is equal and opposite to the centripetal force, i.e. it acts outwards.

It is **not a real** force.

Application of Centrifugal Force

Centrifuge: A device by means of which light particles and heavy particles are separated from each other.

Cream Separator: In a cream separator, a vessel containing milk is rotated fast. Being lighter, the cream collects in a cylindrical layer around the axis, whence it is drawn off and the skimmed milk is drained through an outlet fitted on the wall of the vessel. The particles whose density is less than that of the liquid are driven towards the axis of rotation and those whose density is greater than that of the liquid are driven away from the axis. Cream is lighter than milk, so it is separated from milk and collected at the axis.

Centrifugal Drier: In laundries, wet clothes are dried by packing them in a cylindrical vessel with perforated walls which is rotated at a very high speed. Water particles stick to the clothes with a certain force which is called adhesive force. The water particles are not sufficient to keep them moving uniformly in a circle.

Pressure

The force acting on a unit area of a surface is called pressure.

$$\text{Pressure} = \frac{\text{Force}}{\text{Area}}$$

$$\text{or, } P = \frac{F}{A}$$

SI unit: Nm^{-2} = Pascal = Pa

Thus, the same force acting on a smaller area exerts a larger pressure, and a smaller pressure on a larger area.

Examples which show that decrease in area increases the pressure:

- A sharp knife has a very small surface area on its cutting edge so that high pressure can be exerted to cut the meat.
- The studs on a football boot have only a small area of contact with the ground. The pressure under the studs in high enough for them to sink into the ground, which gives extra grip.
- Nails, needles and pins have very sharp ends with very small surface areas.
- The sole of an ice skater is a fixed narrow metal bar. The high pressure on the surface of the ice makes the ice melt and allows the ice skater to glide smoothly.
- Racing bicycles need very high air pressure inside the tyres, because the narrow tyres have a very small contact area with the road. The hard road surface can support the high pressure under the wheels.

Examples which illustrate that increase in area decreases the pressure:

- Skis have a large area to reduce the pressure on the snow so that they do not sink in too far.
- A wide shoulder pad of a heavy bag will reduce the pressure exerted on the shoulder of the person carrying the bag.

Pressure in Liquids

A liquid in a container exerts pressure because of its weight.

The pressure in a liquid is directly proportional to the depth. The pressure in a liquid increases with depth. The pressure in a liquid is directly proportional to the density of the liquid.

$$\text{Pressure in liquid (P)} = \rho gh$$

Where ρ = density, h = depth, g = gravitational acceleration

Characteristics of pressure in a liquid

- The pressure at any point in a liquid, at a particular depth, acts equally in all directions.
- The pressure in a liquid does not depend on the area of its surface.
- The pressure in a liquid acts equally in all directions and does not depend on the shape of the container.

Applications of pressure in a liquid

- The wall of a dam is much thicker at the bottom than at the top because it must withstand the increased lateral pressure in the depths of water.
- Normally a water tank is placed at a higher level so as to supply water at a greater pressure.

- The submarine is built with a thick wall so as to withstand enormous pressure at a greater depth.
- The liquid solution is at a higher pressure so that it has sufficient pressure to flow into the veins of the patient.

Pascal's Law

The pressure exerted on an enclosed liquid at one place is transmitted equally throughout the liquid. This is called Pascal's law. Hydraulic presses, hydraulic brakes, hydraulic door closers, etc. are applications of this principle.

Atmospheric Pressure and Gauge Pressure: The pressure of the atmosphere at any point is equal to the weight of a column of air of a unit cross-sectional area extending from that point to the top of the atmosphere. At sea level it is 1.013×10^5 Pa (1 atm). Italian scientist **Evangelista Torricelli** (1608-1647) devised for the first time a method for measuring atmospheric pressure. This device is known as a **mercury barometer**. By experiment it is found that the mercury column in the barometer has a height of about **76 cm** at sea level equivalent to one atmosphere (1 atm).

- Atmospheric pressure varies with the height of the object above sea level. It decreases with the altitude or the height above sea level. At higher altitudes, the density and the temperature of the air are lower. As a result, the frequency of collisions of the molecules is lower. Hence, atmospheric pressure is lower.

Common Manifestations of Atmospheric Pressure

- When we suck through a straw, the air pressure in the straw is lowered. Then the pressure of the atmosphere acting on the surface of the drink in the glass pushes the water up the straw and into our mouth.
- When the sucker is pressed into place, most of the air behind it is squeezed out. The sucker is held in position by the pressure of the atmosphere on the outside surface of the rubber. If the seal between the sucker and the surface is airtight, the sucker will stick permanently.
- Pulling up the piston reduces the atmospheric pressure inside the cylinder. The atmospheric pressure on the liquid surface then pushes the liquid up into the syringe. If we then hold the plunger in place and lift the syringe out of liquid, none will fall out. This is again due to atmospheric pressure.
- **Fountain pen:** Ink can be filled in a fountain pen with the help of atmospheric pressure. When the tube of the pen is squeezed, the air in it rushes out of that and the pressure in the tube decreases. The air pressure outside the tube now pushes the ink into the pen. When we go to a higher altitude, the atmospheric pressure decreases, and the pressure inside the pen in comparison to the atmospheric pressure increases. That is why fountain pens leak at higher altitudes.
- A **vacuum cleaner** produces only a partial vacuum. The fan inside the cylinder blows air out of the vents. With less air inside, the air pressure drops. The atmospheric pressure outside then pushes the air up the cleaner hose, carrying dust and dirt with it.
- In an a**ircraft** flying at high altitude, normal atmospheric pressure is maintained by the use of air pumps.
- The atmospheric pressure is measured with an instrument called the **barometer**.
- Since atmospheric pressure varies with altitude, a barometer can be used for determining altitudes. An aneroid barometer calibrated for determining altitudes is called an **altimeter**. Barometers are also used for weather forecasting. If the barometric height falls suddenly, it indicates the coming of a storm. A gradual fall in the barometric height indicates the possibility of rain. A gradual increase in the barometric height indicates fair weather.
- An open-tube **manometer** is a useful instrument for measuring pressure differences.
- 1 bar = 10^5 Pa

Archimedes' Principle

Upthrust and Buoyancy

- The upward force experienced by a body immersed partially or fully in a fluid (liquid or gas) is called **upthrust** or **buoyant force (F_B)**.
- **Buoyancy** is a familiar phenomenon: a body immersed in water seems to weigh less than when it is in air. When the body is less dense than the fluid, it floats. The human body usually floats in water, and a helium-filled balloon floats in air.
- Upthrust depends upon two factors:
  (i) **Volume of the body**
  (ii) **Density of the fluid**
- It is found that the greater the volume of a body, the greater the upthrust it experiences when placed inside a fluid.

- It is also found that the greater the density of the fluid the greater the upthrust it applies on the body. For example when a piece of wood is pushed into different fluids, different forces have to be applied to do so. The denser the fluid, more is the force required to push the body into it. This is the reason that we apply more force to push a body into salt water than into ordinary water.

Examples:

(i) If we place an iron nail on the surface of water, it sinks. This is because the density of iron is greater than that of water, so the weight of the nail is more than the upthrust of water on it. On the other hand a ship made of iron does not sink. This is because the ship is hollow and the empty space contains air which makes the average density of the ship less than that of water. Therefore, even with a small part of its submerged into water, the weight of the water displaced becomes equal to the total weight of the ship and hence the ship floats.

(ii) Due to the presence of minerals, the density of sea water is more than the density of river water, therefore upthrust is large. Therefore, it is easier to swim in sea water than in river water.

(iii) Dead bodies always float on the surface of water, but the head stays within water. The reason is that when the dead body decays its volume increases. Thus, it becomes lighter than water and, hence, floats. However, the head being heavy cannot displace water more than its own weight, hence it remains under water.

(iv) The mass of a balloon filled with helium is less than the mass of the air displaced by it. Hence upthrust acting on the balloon is more than its weight. As a result the balloon experiences a net upthrust which makes it rise. As the balloon rises it experiences lesser and lesser upthrust due to the fact that with height the density of air decreases. At a certain point the weight of the balloon may be completely balanced by the upthrust acting on it. Therefore the balloon stops rising.

Archimedes' Principle

The principle states that when a body is wholly or partially immersed in a fluid, it experiences an upthrust equal to the weight of the fluid displaced. When an object is immersed in a fluid, two forces act on it: (i) the weight (W) of the object acting downward through the centre of the body, and (ii) upthrust (U) acting upward through the centre of gravity of the body. **It is due to upthrust that objects apparently weigh less when immersed in fluids**.

Effect of buoyancy on bodies of different weights:

1. **When W < U**, the body floats.
2. **When W > U**, the body sinks.
3. **When W = U**, the resultant force acting on the body when fully immersed in the fluid in zero. The body is at rest anywhere within the fluid. The apparent weight of the body is zero for all such positions.

Density

The density of a substance is defined as its mass per unit volume.

$$\text{Density}(\rho) = \frac{\text{mass}(m)}{\text{volume}(V)}$$

The density of most of the substances decreases with an increase in temperature and increases with a decrease in temperature. Water is an exception. Water contracts when cooled upto 4°C and expands when cooled further, below 4°C. **Thus the density of water is a maximum at 4°C**. At 4°C, the density of water is 1 gcm^{-3} or 1000 kg m^{-3}.

Law of Floatation

A floating body displaces its own weight of the fluid in which it floats. The Archimedes' principle and the law of floatation can explain several phenomena.

An iron nail sinks in water whereas a ship made of iron and steel floats. This is due to the fact that a ship is hollow and contains air and, therefore, its density is less than that of water.

The density of sea water, due to the presence of impurities like salt, etc. is greater than that of river water. Therefore, lesser volume of ship will be immersed in sea water to balance its weight. So the ship sinks to a great depth in river water than in sea water.

It is because of the higher density of sea water that it is easier to swim in the sea.

A submarine has large ballast tanks. When these tanks are filled with water, the average density of the submarine becomes more than that of water and it can dive easily. When the submarine is ready to surface, compressed air is forced into the ballast tanks, forcing the water out, thus reducing the density of the submarine, which can then rise.

A solid chunk of iron will sink in water but float in mercury because the density of iron is more than that of water but less than that of mercury.

Ice, being less dense than water, floats in it with one tenth of its volume above the surface. When ice melts it contracts by as much of its volume as was above the surface and, therefore, the level of water remains unchanged.

Hydrometer

A hydrometer is an instrument used for measuring the density or relative density of liquids. It is based on the **principle of floatation**. A special type of hydrometer is used to measure the density of acid in a car battery. Another special type of hydrometer called **lactometer** is used for testing the purity of milk by measuring its density.

Flow in Fluids

Streamline Flow

The flow of a fluid is said to be **steady** if at any given point, the velocity of each passing fluid particle remains constant in time. The path taken by a fluid particle under a steady flow is a **streamline**. It is defined as a curve whose tangent at any point is in the direction of the fluid velocity at that point.

Bernoulli's Principle

This states that for all points along a streamline in an incompressible and non-viscous fluid flowing steadily, the sum of pressure energy, potential energy and kinetic energy per unit volume is constant.

Thus, if p be the pressure energy per unit volume, ρ be the density of the fluid, h be the height from the ground level, then by Bernoulli's theorem,

$$p + \frac{1}{2}\rho v^2 + \rho g h = \text{constant}$$

In fact, Bernoulli's theorem is nothing but the law of conservation of energy for an ideal fluid.

Note: Bernoulli's equation ideally applies to fluids with zero viscosity or non-viscous fluids.

Applications of Bernoulli's Theorem

- **Dynamic Lift:** Dynamic lift is the force that acts on a body, such as airplane wing, a hydrofoil or a spinning ball, by virtue of its motion through a fluid. In many games such as cricket, tennis, baseball and golf, a spinning ball deviates from its parabolic trajectory as it moves through air. This deviation can be partly explained on the basis of Bernoulli's principle. When a bowler spins a ball, it changes its direction (swings) in the air due to unequal pressure acting on it.
- **Lift on an Aeroplane Wing:** The shape of the aeroplane wings is such that the upper surface is more curved than its lower surface and its head is thicker than its tail. As the aeroplane moves forward, the speed of air above the wings is larger than the speed of the air below the wings. According to Bernoulli's theorem, the pressure above the wings is less than the pressure below the wings. Due to the pressure difference, the aeroplane gets the vertical lift, which is sufficient to overcome the force of gravity and the aeroplane is lifted up.
- **Blowing Off the Roofs During Storm :** During storms or cyclones, the roofs of the huts or tinned roofs are blown off because of the high-speed wind. According to Bernoulli's theorem, the pressure over the roof becomes less, while the pressure of air under the roof is very large, i.e. $P_1 > P_2$. This pressure difference gives an erratical lift to the roof and it is blown off.
- Bernoulli's principle helps in explaining blood flow in artery.

Capillarity

The word *capilla* means 'hair' in Latin; if the tube were hair-thin, the rise would be very large. The phenomenon of rise or fall of a liquid in a capillary tube is known as **capillarity**.

The melted wax of a candle is drawn up into the wick by capillary action. Oil rises up a lamp wick for the same reason. If one end of a sugar cube is dipped into tea, the entire cube is quickly wet on account of capillary action.

The fine pores of a blotting paper act as tiny capillary tubes. The ink rises into the blotting paper through these pores. The capillary action in soil is important in bringing water to the roots of plants.

Bricks are porous and, therefore, subsoil water can seep up them by capillary action. To avoid dampness in a building, a layer of nonporous material, such as slate, is necessary in its foundation.

A towel soaks water due to capillary action.

Viscosity

Most of the fluids are not ideal ones and offer some resistance to motion. This resistance to fluid motion is like an internal friction analogous to friction when a solid moves on a surface. It is called **viscosity**.

The viscous force exists when there is relative motion between layers of the liquid. Suppose a fluid like oil is enclosed between two glass plates. The bottom plate is fixed while the top plate is moved with a constant velocity *v* relative to the fixed plate. If oil is replaced by honey, a greater force is required to move the plate with the same velocity. Hence we say that honey is more viscous than oil.

It is measured in terms of the coefficient of viscosity, η. Its SI unit is **pa–s (Pascal second)**.

Generally thin liquids like water, alcohol etc. are less viscous than thick liquids like coal tar, blood, glycerin etc.

The viscosity of liquids decreases with temperature while it increases in the case of gases. In a gas, the temperature rise increases the random motion of atoms and viscosity increases.

The viscous force F acting on an object falling through a fluid of coefficient of viscosity η depends on its size r (in case of a ball, r is its radius) and its velocity υ.

$$F = 6\pi\eta r\upsilon$$

This is **Stokes' law**.

Surface Tension

Intermolecular force: The force of attraction or repulsion acting between the molecules is known as intermolecular force. The nature of intermolecular force is electromagnetic.
Cohesive force: The force of attraction between the molecules of the same substance is called cohesive force.
Adhesive force: The force of attraction between the molecules of different substances is called adhesive force.

Examples of Cohesive Force

1. Two drops of liquid coalesce, i.e. join into one, when brought in mutual contact.
2. It is difficult to separate two sticky plates of glass welded with water.
3. It is difficult to break a drop of mercury into a small droplet because of large cohesive force between the mercury molecules.

Examples of Adhesive Force

1. Adhesive force enables us to write on the blackboard with a chalk.
2. A piece of paper sticks to another due to large force of adhesion between the paper and gum molecules.
3. Water wets the glass surface because the force of adhesion between glass molecules and water molecules is greater. But mercury does not wet glass because force of cohesion is greater than force of adhesion.

Surface Tension: The property of a liquid to have minimum surface area and behave as if it were under tension, somewhat like a stretched elastic membrane, is called surface tension.

Phenomena due to surface tension:

- A small liquid drop/raindrop has spherical shape due to surface tension.
- Lead balls are spherical in shape.
- The bristles of shaving brush/painting brush, when dipped in water, spread out; but as soon as the brush is taken out of water, its bristles stick together.
- Similarly, insects can walk on the free surface of water without drowning.

The liquid surface tries to have minimum surface area, and for a given volume, the sphere has minimum surface area.

Surface tension of a liquid is measured by the force acting per unit length on either side of an imaginary line drawn on the free surface of liquid, the direction of this force being perpendicular to the line and tangential to the free surface of liquid. So if F is the force acting on one side of imaginary line of length (L), then

$$T = \frac{F}{L}$$

Note: 1. It depends only on the nature of the liquid and is independent of the area of surface or length of line considered.
2. It is a molecular phenomenon and its root cause is the electromagnetic forces.

SI unit of surface tension is **N/m**.

The value of surface tension depends on temperature. Like viscosity, the surface tension of a liquid usually falls with temperature.

Applications of surface tension

(a) Manufacture of lead shots
(b) Oils and paints: they spread easily and uniformly.
(c) Destruction of mosquito breeding

Effect of impurity

It is found that when inorganic substances such as sodium chloride (common salt) are dissolved into water, the surface tension of water increases. On the other hand, when organic substances such as soap solution is added to water, the surface tension of water decreases. Generally, if a highly soluble substance is added to a liquid, its surface tension increases.

Simple Harmonic Motion

- A motion that repeats itself at regular intervals of time is called **periodic motion**.
- The smallest interval of time after which the motion is repeated is called its **period.**
- The period is denoted by the symbol **T**.

Its SI unit is **second**.

The reciprocal of T gives the number of repetitions that occur per unit time. This quantity is called the **frequency** of the periodic motion. It is represented by the symbol ν.

The relation between ν and T is $\nu = 1/T$

- The unit of ν is thus s^{-1}. It is also known as **Hertz** (abbreviated as Hz).
- If a body in periodic motion moves back and forth over the same path, then the motion is said to be **vibratory** or **oscillatory.**
- Every oscillatory motion is periodic, but every periodic motion need not be oscillatory.

  For example:

  Circular motion is a periodic motion, but it is not oscillatory. **The motion of the earth around the sun is periodic but not oscillatory**.
- There is no significant difference between oscillations and vibrations. It seems that when the frequency is small, we call it **oscillation** (like the oscillation of a branch of a tree), while when the frequency is high, we call it **vibration** (like the vibration of a string of a musical instrument).
- **Simple harmonic motion (SHM) is the simplest form of oscillatory motion**. This motion arises when the force on the oscillating body is directly proportional to its displacement from the mean position, which is also the equilibrium position.
- In SHM, forces acting on the particle is always directed towards a fixed point known as equilibrium position and the magnitude of force is directly proportional to the displacement of the particle from the equilibrium position and is given by

  $$F = -kx$$

  where k is the force constant, x = displacement of the particle from the fixed point and the negative sign shows that force opposes increase in x.

  The SI unit of force constant k is **N/m** and the magnitude of k depends on elastic properties of the system under consideration.

Characteristics of SHM

- It is also known as restoring force, which takes the particle back towards the equilibrium position, and opposes increase in displacement.
- The period of SHM does not depend on amplitude or energy or the phase constant.

Simple Pendulum

An ideal simple pendulum consists of a heavy point mass (called **bob**) tied to one end of a perfectly inextensible, flexible and weightless string.

Amplitude

It is the maximum displacement of the pendulum from its mean position.

Factors on which T of a pendulum depends

The time period of a simple pendulum is given by the expression $T = 2\pi\sqrt{\frac{L}{g}}$. It follows, from this formula, that

- The time period of a pendulum depends directly upon the square root of its length (L), i.e. $T \propto \sqrt{L}$. The larger the length of a pendulum the more is its time period.
- The time period of a pendulum depends inversely upon the square root of acceleration due to gravity (g), i.e. $T \propto \frac{1}{\sqrt{g}}$. Since g is different at different places, therefore even for the same length, the time period will be different at different places.
- The time period of a pendulum does not depend upon the mass of the bob.
- The time period of a pendulum also does not depend upon its amplitude of vibration so long as it remains small.
- If a pendulum clock is brought inside an artificial satellite, then due to the state of weightlessness inside the satellite (g = 0), the time period of the clock becomes infinite (∞). That's why such clocks don't work inside artificial satellites.
- In summer season, the effective length of the pendulum clock is lengthened (increased length), so its time period is also increased and consequently the clock becomes slow. But in winter season the effective length is reduced, thus the time period is decreased and the clock becomes fast.
- On the moon the value of acceleration due to gravity is **g/6**, where g is acceleration due to gravity on the earth's surface. Thus, the period of oscillation of the pendulum clock is increased on the moon and so it (pendulum clock) is slowed down.

Heat and Thermodynamics

Temperature

Temperature is a relative measure or indication of hotness or coldness of a body.

Concept of Heat

Energy transfer that takes place solely because of a temperature difference is called **heat flow** or **heat transfer,** and the energy transferred in this way is called **heat**.

On the basis of kinetic model of matter, heat energy is the sum of total kinetic and potential energies of all the molecules of a given substance.

In other words, heat is the form of energy transferred between two (or more) systems or a system and its surroundings by virtue of temperature difference. The SI unit of heat energy transferred is expressed in **Joule (J)** while the SI unit of temperature is **Kelvin (K)**, and **°C** is a commonly used unit of temperature.

Calorie: The amount of heat required to raise the temperature of 1 gm water by 1° C is called a calorie.

By Joule's experiment, it was observed that heat is a form of energy by which various works can be performed. Joule also asserted that heat and mechanical work are inter-transferable and the ratio of mechanical work to heat energy by which work is done is a fixed ratio called **mechanical equivalent of heat** and basically it is a conversion unit. If mechanical work W is produced by amount of heat H, then J = W/H or W = JH,

where J = mechanical equivalent of heat

= 4186 Joule/kilo cal. = 4.186 Joule/cal

= 4.186 × 107 erg/cal.

Thermometry

Introduction

A **thermometer** is a device for measuring the temperature of a body, often a sealed glass tube that contains a liquid, such as mercury, that expands and contracts with rise and fall in temperature.

Types of Thermometer

Thermometers are classified in accordance with the type of thermometric substance used and on the type of property which varies with temperature. They are of the following types:

1. **Bimetallic thermometer:** A bimetallic thermometer uses a bimetallic strip made by bonding strips of two different metals together. When the system gets hotter, one metal expands more than the other, so the composite strip bends when the temperature changes. This strip is usually formed into a spiral, with the outer end anchored to the thermometer case and the inner end attached to a pointer. The pointer rotates in responses to temperature changes.
2. **Platinum resistance thermometer:** In a resistance thermometer, the changing electrical resistance of a coil of fine wire, a carbon cylinder, or a germanium crystal is measured. Because resistance can be measured very precisely, resistance thermometers are usually more precise than most other types.
3. **Optical pyrometer:** To measure very high temperatures, an optical pyrometer can be used. It measures the intensity of radiation emitted by a red-hot or white-hot substance. The instrument does not touch the hot substance, so the optical pyrometer can be used at temperatures that would destroy most other thermometers.
4. **Thermoelectric thermometer:** The thermoelectric thermometer works on the principle that the difference in temperature between two junctions produces a current. This current can be measured and the temperature can be estimated.
5. **Mercury-in-glass thermometer:** It uses mercury and is based on the volume expansion of mercury. Mercury is mainly used in thermometers because it does not stick to the glass surface.
6. **Alcohol-in-glass thermometers:** It is based on the expansion of alcohol.
7. **Constant volume gas thermometers:** It is based on the concept of increase in pressure of a gas with rise in temperature.

Temperature Scales

The two most commonly used temperature scales are:

1. Celsius scale and 2. Fahrenheit scale

1. **Celsius Scale (°C):** The Celsius (earlier called centigrade) was put forward by **Anders Celsius** in 1742. Its minimum point (freezing point of pure water at atmospheric pressure or melting point of pure ice) is at **0°C** and its upper end is at **100°C** (boiling point of pure water at atmospheric pressure). It is divided into 100 equal divisions. Each division is called one degree Celsius. A degree on the Celsius scale is 1/100th of the fundamental interval.

2. **Fahrenheit Scale (°F):** It was devised by **Daniel Fahrenheit** in 1717. Its lower point (freezing point of pure water at atmospheric pressure) is at **32 °F** and the upper point (boiling point of pure water at atmospheric pressure) is at **212°F**. It is divided into 180 equal divisions. Each division is called one degree Fahrenheit. A degree on the Fahrenheit scale is 1/180th of the fundamental interval.

Kelvin or Absolute Scale (K): It was devised by Lord Kelvin. Its lower point (freezing point of water at atmospheric pressure) is at 273.15 or **273 K** and the upper point (boiling point of water at atmospheric pressure) is at **373 K**. It has 100 divisions.

Relation between the Celsius and the Fahrenheit scales of temperature

$$\frac{T_C - 0}{100 - 0} = \frac{T_F - 32}{212 - 32} = \frac{T_K - 273}{373 - 273}$$

$$\frac{T_C}{100} = \frac{T_F - 32}{180} = \frac{T_K - 273}{100}$$

Thermal equilibrium

Thermal equilibrium is a situation in which two objects in thermal contact with each other cease (stop) to have any net energy exchange due to a difference in their temperatures.

In other words, **temperature** can also be defined as a quantity which determines the direction of flow of heat when two bodies are placed in contact.

Heat always flows from a higher to a lower temperature. In SI, temperature is measured in kelvin (K) and in CGS system in Celsius (°C). The two scales are related as

$$T\,K = 273 + t°C$$

Absolute zero: Theoretically there is no limit to maximum temperature but there is a limit or restriction on the minimum temperature. The lowermost temperature is –273.15°C and it is called *absolute temperature*.

The temperature on various scales

Temperature	Celsius	Fahrenheit	Kelvin (K)
Freezing of water	0°C	32°F	273 K
Normal temperature of the room	27°C	80.6° F	300 K
Normal temperature of the human body	37°C	98.6°F	310 K
Boiling point of water	100°C	212°F	373K

Thermal expansion

Matter (solids, liquids and gases), in general, expands on heating and contracts on cooling (with the exception of water that contracts from 0°C to 4°C).

The expansion of a solid with change in temperature is called **thermal expansion**. If there is change in the length of a solid due to expansion it is termed as **linear expansion**. If there is a change in the surface area of the solid then the expansion is called **superficial expansion.** When volume undergoes a change in the expansion then it is called **cubical expansion**. With a small change in temperature, there is a large change in the volume of liquids and gases, therefore liquids and gases have **cubical expansion**.

Simple examples of the uses of expansion of solids

1. **Iron tyres of horse-carts:** Many bullock-carts and horse-carts (*tongas*) have large wooden wheels with iron rims. To fit an iron rim tightly on the wheel, it is made with its diameter slightly smaller than the diameter of the wheel. It is then heated until it expands and has its diameter slightly greater than the diameter of the wheel. The hot iron rim is then made to slide over the wheel and left to cool. As iron rim cools, it contracts and fits very tightly. Steel rims are fitted on railway carriage wheels in a similar manner. The rim is heated until it slides easily on to the wheel; when it cools it fits very tightly.
2. **The jam bottle and its metal cap:** A metal screw cap on a glass bottle (or on a jam bottle) is sometimes very difficult to remove. If the metal cap is slightly heated (carefully turning it around to avoid direct heating of the glass), the metal will expand more than the glass and will unscrew very easily.
3. **Riveting:** A rivet is a metal pin or bolt used for fastening metal plates. Riveting is the act of using rivets to secure two overlapping plates very tightly so that the joint becomes leak-proof. Steel plates, such as those used in ship-building or in large boilers, are usually riveted together using red-hot rivets. This provides a good seal against sea water for ship plates and against water and steam in large boilers.
4. **Fixing a metal wire into glass:** Platinum and soda glass have equal expansion coefficients. This is made use of in fixing a platinum wire into soda glass. Changes in temperature will not affect the seal as both materials expand at approximately the same rate.
5. **Railway tracks:** The rails are made of steel, which expands in summer due to rise in atmospheric temperature. Therefore, a little space is left between the two rails to accommodate their expansion on the railway track. If no gap is left the expansion will cause the rails to bend sideways.
6. Similarly, in an iron bridge, one end of the girder (beam) is fixed while the other end is left free and supported by

rollers. In summer, when the iron girder expands, the rollers roll forward, and in winter when the girder contracts, the rollers roll backwards. Thus, there is less pressure on the girders.

7. **Error in metal measuring scales:** Measuring tapes and metal scales are calibrated accurately by the maker at a particular temperature. A rise or fall in temperature causes the tape/scale to expand or contract and introduces error in the measurements made.
8. **Telegraph/Telephone/Electric lines:** The wires used in these lines expand or contract as the weather changes and temperature rises or falls. Therefore, these are kept slightly sagging in summer so that when they contract in winter, these do not break.
9. **Pendulum of a clock:** In summer, the pendulum of a clock, which is made of metal, expands. Therefore, time taken for one oscillation increases and the clock loses time. In winter, the length of the pendulum decreases and the clock gains time, i.e. it becomes fast.

Anomalous Behaviour of water

While most substances expand when heated, a few do not. For instance, if water at 0°C is heated, its volume decreases until the temperature reaches 4°C. Above 4°C water behaves normally, and its volume increases as the temperature increases. Because a given mass of water has a minimum volume at 4°C, the density of water is greatest at 4°C. This behaviour of water is called its anomalous behaviour or its unusual behaviour.

Consequences of anomalous expansion of water

1. **Bursting of water pipe in winter:** When water freezes it expands and exerts a great pressure inside the pipe as a result of which the pipe bursts. So, enough space is left in the pipe for the expansion to take place and prevent bursting.
2. **Other effects:** Expansion on freezing causes weathering of rocks (as water in its crevices freezes) and weathering of soil. Vegetables and plants get damaged in winter as the water inside them, expands on freezing and bursts the cell walls.
2. **Aquatic animals are able to survive in frozen ponds:** The temperature of water falls in lakes, ponds etc. till 4°C, at which its density becomes the maximum. Due to the anomalous expansion of water, its density decreases when the temperature drops to 0°C. At this temperature water changes to ice, which floats on the surface. Water inside the pond does not freeze completely since ice formed on the top is a bad conductor of heat. Thus fishes and other aquatic animals can easily survive in the lower layers of the frozen lakes as the water below stays at 4°C.

Change of State

Matter is found usually in three states: solid, liquid and gas. **Water exists in the solid state as ice, in the liquid state as water, and in the gaseous state as steam**.

A transition from one state (or phase) to another is called a change of state (or a phase change or phase transition). For any given pressure, a phase change takes place at a definite temperature, usually accompanied by absorption or emission of heat and a change in volume and density.

A familiar example of a change of state is the melting of ice. When we slowly heat ice, the temperature of ice does not increase until all the ice is melted. The effect of adding heat to ice is not to raise its temperature but to change its phase from solid to liquid. Thus, the two states of a substance coexist in thermal equilibrium during a phase transition.

A change of state from solid to liquid is called **melting** and from liquid to solid is called **freezing**.

Melting Point: “The temperature at which a solid changes to liquid state without any change in its temperature, is called its melting point”.

- Heat is absorbed from the surroundings in melting.
- Melting point depends on pressure. The melting point at standard atmospheric pressure of 76 cm of mercury is called **normal melting point**.
- Normal melting point of ice is **0°C**.
- The melting point of substances which contract on melting like ice, cast iron, antimony, bismuth, brass etc. decreases with increase in pressure.
- Due to absorption of heat, melting of ice increases the internal energy without change in temperature. Due to removal of heat, the internal energy decreases in freezing.
- The melting point of other substances which expand on melting like wax, glass, gold, silver, copper etc. increases with increase in pressure.
- Melting point decreases on adding impurity.
- At the melting (or freezing) temperature, the liquid and solid phases can coexist in a condition called **phase equilibrium**, hence water at 0°C cannot be converted into ice by adding any amount of ice at 0°C.
- Cooling a liquid below freezing point without turning it into solid is called **supercooling**. Water can be supercooled up to -12°C.

Vaporisation and Condensation

The phase transition from liquid or solid to gas (or vapour) is **vaporisation** and from gas to liquid is called **condensation**. Vaporisation has three types: boiling, evaporation and sublimation.

Boiling Point: It is the transition from liquid phase to gas phase which takes place at or above the boiling temperature and it occurs below the surface.

We have similar concepts (as of melting and melting point) for vaporisation and boiling as well.

1. At a given pressure, the temperature of boiling and condensation are always the same. At this temperature, the liquid and gaseous phases can coexist in phase equilibrium.
2. The boiling point always increases with increase in pressure. Hence, the cooking in a pressure cooker is faster but cooling becomes difficult on hills.
3. Normal boiling point of water is 100°C. It decreases by 1°C for a decrease in pressure by nearly 26.8 mm of mercury, i.e., with an increase in elevation above the earth's surface by 300 metres.
4. Water can be made to boil at 0°C if the surrounding pressure is 4.6 mm of Hg.
5. Impurity increases the boiling point.
6. The internal energy of a body in vapour phase is greater than that in liquid phase.

Sublimation: There are some substances which normally pass from the solid state to the vapour state directly and vice versa. The process of changing from solid state to vapour state without passing through the liquid state is called "sublimation" and the solid is said to sublime.

Evaporation

The phenomenon of change of liquid into vapour at any temperature below its boiling point is called evaporation.

Factors Affecting Evaporation

You must have observed that the rate of evaporation increases with

- **An increase of surface area:** If the surface area is increased, the rate of evaporation increases. For example, while putting clothes for drying up we spread them out.
- **An increase of temperature:** With the increase of temperature, more number of particles get enough kinetic energy to go into the vapour state.
- **A decrease in humidity:** Humidity is the amount of water vapour present in the air. If the amount of water in air is low, the rate of evaporation increases.
- **An increase in wind speed:** It is a common observation that clothes dry faster on a windy day. With the increase in wind speed, the particles of water vapour move away with the wind, decreasing the amount of water vapour in the surrounding.

Latent Heat

Latent heat of a substance is defined as the amount of heat absorbed or given out by a unit mass of it during the change of state while its temperature remains constant. It is of two types:

(i) Latent heat of fusion
(ii) Latent heat of vaporisation

Latent heat of fusion: The latent heat of fusion of a substance is the quantity of heat absorbed by (or removed from) the substance to change a unit mass of it from solid state to liquid state (or from liquid state to solid state), while temperature remains constant. It is also called **heat effusion**.

Latent heat of vaporisation: The latent heat of vaporisation of a substance is the quantity of heat absorbed by (or removed from) the substance to change a unit mass of it from liquid state to gaseous state (or from gaseous state to liquid state), while temperature remains constant. It is also called **heat of vaporisation**.

Specific Latent Heat: The amount of heat required to change the phase of 1 kg of the substance at a constant temperature.

$$l = \frac{Q}{m}$$

Q = latent heat absorbed or released by the substance
m = mass of the substance.

SI unit: J kg^{-1}

Applications of Specific Latent Heat

- Drinks can be cooled by adding in several cubes of ice. When ice melts a large amount of heat is absorbed and this lowers the temperature of the drink.
- The freshness of fish and meat can be maintained by placing them in contact with ice. With its larger latent heat, ice is able to absorb a large quantity of heat from the fish as its melts. Thus, food can be kept at a low temperature for an extended period of time.
- Water has a large specific latent heat of vaporisation. This property enables steam to be used for cooking by the method of steaming. When steam condenses on the food, the latent heat is released directly onto the food and enables the food to be cooked at a faster rate.
- Our bodies feel cool after sweating. This is because latent heat of vaporization is absorbed from the body when sweat evaporates. As a result, the body is cooled by the removal of heat.

Specific Heat Capacity (c): The amount of heat that must be supplied to increase the temperature by 1°C for a mass of 1 kg of a substance is called its Specific Heat Capacity.

$$\text{Specific heat capacity (c)} = \frac{Q}{m\theta}$$

Q = heat absorbed/released, unit J
m = mass of the substance, unit kg
θ = temperature difference, unit °C

SI unit: J kg^{-1} $°C^{-1}$

Note: A substance with a small value of specific heat capacity

1. heats up and cools at a faster rate. For example, metals like iron, steel, copper and aluminium are used for pots and pans because they can be quickly heated up when there is only small heat absorption.

2. is sensitive to temperature changes. A thermometer has low specific heat capacities, so it enables heat to be easily absorbed and released even when small quantities of heat are involved.

Heat Transfer

Heat is energy transfer from one system to another or from one part of a system to another, arising due to temperature difference.

There are three distinct modes of heat transfer:

1. Conduction
2. Convection and
3. Radiation

Conduction

The process by which heat is transferred from the hotter end to the colder end of an object is known as conduction. In other words, conduction is the mechanism of transfer of heat between two adjacent parts of a body because of their temperature difference. In conduction, heat is transferred between neighbouring parts of a body through molecular collisions, without any flow of matter. If one end of a metallic rod is put in a flame, the other end of the rod will soon be so hot that we cannot hold it with our bare hands.

Gases are poor thermal conductors while liquids have conductivities intermediate between solids and gases.

Good Conductor

The materials which allow heat to pass through them easily are good conductors of heat. Metals like aluminum, iron and copper, human body, acidic water are the examples of good conductors.

Bad Conductor

The materials which do not allow heat to pass through them easily are bad conductors of heat. Poor conductors are known as **insulators**. Examples: water, air, wood, fibre, glass, rubber and plastic.

Thermal insulator

The substances through which heat is not transmitted by any means (method) are called **thermal insulators**. In fact bad conductors are sometimes synonymously used as thermal insulators. Examples: Ebonite, asbestos etc.

Houses made of concrete roofs get very hot during summer days, because thermal conductivity of concrete (though much smaller than that of a metal) is still not small enough. Therefore, people usually prefer to give a layer of earth or foam insulation on the ceiling so that heat transfer is obstructed and it keeps the room cooler.

Thermal conductivities of some materials

Materials	Thermal conductivity ($J\ s^{-1}\ m^{-1}\ K^{-1}$)
Metals	
Silver	406
Copper	385
Aluminium	205
Brass	109
Steel	50.2
Lead	34.7
Mercury	8.3
Non-metals	
Insulating brick	0.15
Concrete	0.8
Body fat	0.20
Glass	0.8
Ice	1.6
Wood	0.12
Water	0.8
Gases	
Air	0.024
Argon	0.016
Hydrogen	0.14

Application of conduction

- Drinking tea in a metallic cup is somewhat painful but drinking tea in a ceramic cup is pleasant. The simple reason behind it is that heat from the tea goes into the metallic cup, which becomes hot and one's lips have a painful and bitter experience due to good conduction of heat. But due to bad conduction of heat in ceramic or fibre cup, heat doesn't travel from tea to the cups and does not make the cup hot.
- Refrigerators and ice-boxes have similar double walls to minimise heat gain by conduction.
- Eskimos live in snow huts called igloos. Snow, being a poor conductor, shields them from cold. It prevents the heat they generate from escaping and keeps them warm.

Convection

Convection is a mode of heat transfer by actual motion of matter. It is possible only in fluids (liquids and gas). Convection can be natural or forced.

In forced convection, material is forced to move by a pump or by some other physical means.

Examples of forced convection systems – air heating systems in home, the human circulatory system, and the cooling system of an automobile engine. In the human body, the heart acts as the pump that circulates blood through different parts of the body, transferring heat by forced convection and maintaining it at a uniform temperature.

Natural convection is responsible for many familiar phenomena. During the day, the ground heats up more quickly than large bodies of water do. This occurs both because the water has a greater specific heat and because mixing currents disperse the absorbed heat throughout the great volume of water. The air in contact with the warm ground is heated by conduction. It expands, becoming less dense than the surrounding cooler air. As a result, the warm air rises (air currents) and other air moves (winds) to fill the space, creating a sea breeze near a large body of water. Cooler air descends, and a thermal convection cycle is set up, which transfers heat away from the land. At night, the ground loses its heat more quickly, and the water surface is warmer than the land. As a result, the cycle is reversed.

Another example of natural convection is the steady surface wind on the earth blowing in from north-east towards the equator, the so called **trade wind**.

Heating elements in geysers and water heaters are fitted near the **bottom** so that water can be heated by convection currents. Heating elements in electric ovens are fitted near the bottom to heat the entire enclosed air by convection.

The cooling unit (freezer) in a refrigerator is fitted near the **top** to cool the whole of the interior. The air near the top cools and descends due to increased density. Its place near the top is taken by warm air and in this way convection currents are set up, which cool the entire interior.

To avoid the burning of the filaments of the electric bulbs, which are made of **tungsten** (high atomic weight and high melting point), the bulb is evacuated (creation of vacuum). Also, to avoid the melting of filaments in the bulb, some inert gases like **argon** or **krypton** are filled up and thus thermal radiations generated by filaments form a convectional current inside the bulb and a tremendous quantity of thermal energy produced doesn't melt the filament.

Radiation

The third mechanism for heat transfer needs no medium; it is called **radiation** and the energy so radiated by electromagnetic waves is called **radiant energy**. Electromagnetic waves can travel in vacuum with the same speed as the speed of light, i.e. 3×10^8 ms^{-1}.

Heat transfer by radiation does not need any medium and it is very fast.

Examples of radiation

- The heat is transferred to the earth from the sun through the empty space.
- When we sit in front of a room heater, we get heat by this process.
- A hot utensil kept away from the flame cools down as it transfers heat to the surroundings by radiation.
- Our body, too, gives heat to the surroundings and receives heat from it by radiation.

All bodies emit radiant energy, whether they are solids, liquids or gases. The electromagnetic radiation emitted by a body by virtue of its temperature, like the radiation by a red hot iron or light from a filament lamp, is called thermal radiation.

When this thermal radiation falls on other bodies, it is partly reflected and partly absorbed. The amount of heat that a body can absorb by radiation depends on the colour of the body. **Black bodies absorb and emit radiant energy better than bodies of lighter colours**. Note the following examples:

- We wear white or light-coloured clothes in summer so that they absorb the least heat from the sun. However, during winter, we use dark-coloured clothes, which absorb heat from the sun and keep our body warm.
- The bottoms of the utensils for cooking food are blackened so that they absorb maximum heat from the fire and give it to the vegetables to be cooked.
- The base of an electric iron is highly polished so that it does not lose heat by radiation.
- A cloudy night in winter is warmer than a night with clear sky.
- In a desert, days are too hot and nights too cold.

Note: Convection and conduction are not possible in vacuum while radiation is possible in vaccum.

Newton's Law of Cooling: This law states that the rate at which a hot body loses heat is directly proportional to the difference between its temperature and the surrounding temperature. For example, hot water takes much less time in cooling from 90°C to 80°C than in cooling from 40°C to 30°C.

If hot water and fresh tap water are kept in a refrigerator, the rate of cooling of hot water will be faster than that of tap water. Suppose a person is served hot coffee with added cream (at room temperature), but he wants to drink it after a while. It is then advisable to add cream right in the beginning rather than at the time of taking the coffee because this way the coffee will remain hotter.

Thermodynamics

It is the branch of natural science concerned with heat and its relation to other forms of energy and work. It defines macroscopic variables (such as temperature, internal energy, entropy, and pressure) that describe average properties of material bodies and radiation, and explains how they are related and by what laws they change with time. Thermodynamics does not describe the microscopic constituents of matter, and its laws can be derived from statistical mechanics.

Applications

Thermodynamics can be applied to a wide variety of topics in science and engineering, such as engines, phase transitions, chemical reactions, transport phenomena, and even black holes.

Much of the empirical content of thermodynamics is contained in its four laws:

- The **Zeroth Law of Thermodynamics** is a generalization principle of thermal equilibrium among bodies, or thermodynamic systems, in contact. It states: If two systems are each in thermal equilibrium with the third, they are also in thermal equilibrium with each other.
- The **First Law of Thermodynamics** is simply the law of conservation of energy applied to the thermodynamic system. According to this law, if a substantial amount of thermal energy is supplied to a thermodynamic system, then it is partially utilised in changing its internal energy.
  $\Delta U = Q - W$
  Q = Thermal energy supplied
  ΔU = Change in internal energy
  W = External work done
- The **Second Law of Thermodynamics** concerns a quantity called entropy that expresses limitations, arising from what is known as irreversibility, on the amount of thermodynamic work that can be delivered to an external system by a thermodynamic process. It states: Heat cannot spontaneously flow from a colder location to a hotter location.
- The **Third Law of Thermodynamics** is a statistical law of nature regarding entropy and the impossibility of reaching absolute zero of temperature. This law provides an absolute reference point for the determination of entropy.

Note: 1. Absolute zero is **–273.15 °C** (Degrees Celsius), or –459.67 °F (Degrees Fahrenheit) or 0 K (kelvin).

2. **Entropy** is a thermodynamic property that is the measure of a system's thermal energy per unit temperature that is unavailable for doing useful work.

Several commonly studied thermodynamic processes are:

- **Isobaric process:** It occurs at constant pressure.
- **Isochoric process:** It occurs at constant volume (also called **isometric/isovolumetric**).
- **Isothermal process:** It occurs at a constant temperature.
- **Adiabatic process:** It occurs without loss or gain of energy as heat.

Examples:

When a motor tyre bursts, the sudden expansion of air into the atmosphere is an adiabatic process in which the tyre is cooled down.

To prepare dry ice (solid CO_2), carbon dioxide is suddenly expanded and consequently it converts into ice called dry ice.

On shaking, a thermos containing tea becomes warm, because on shaking the existing viscous forces between various layers of the tea do external work and this work is transformed into thermal energy. So its internal energy increases and consequently the temperature rises.

- **Isentropic process:** A reversible adiabatic process that occurs at a constant entropy, but is a fictional idealisation.
- **Isolated process:** It occurs at constant internal energy and elementary chemical composition.

Elasticity

A **rigid** body generally means a hard solid object having a definite shape and size. But in reality, bodies can be stretched, compressed and bent. Even the appreciably rigid steel bar can be deformed when a sufficiently large external force is applied on it. This means that **solid bodies are not perfectly rigid**. A solid has definite shape and size. In order to change (or deform) the shape or size of a body, a force is required. The property of a body, by virtue of which it tends to regain its original size and shape when the applied force is removed, is known as **elasticity**, and the deformation caused is known as **elastic deformation**. Examples: steel, rubber and quartz.

However, if we apply force to a lump of putty or mud, it has no gross tendency to regain its previous shape, and it gets permanently deformed. Such substances are called **plastic** and this property is called **plasticity.** Examples: putty, clay, mud, wax, lead and chewing gum. Putty and mud are close to ideal plastics.

The elastic behaviour of materials plays an important role in engineering design. For example, while designing a building, knowledge of elastic properties of materials like steel, concrete etc. is essential. The same is true in the design of bridges, automobiles, ropeways etc.

Note: Steel is more elastic than rubber, copper, brass and aluminium. It is for this reason that steel is preferred in heavy-duty machine and in structural designs.

- By the process of hammering or rolling, the elasticity of a body increases.
- By the process of annealing, the elasticity of a body is reduced.

Stress and Strain

When a force is applied on a body, it is deformed to a small or large extent, depending upon the nature of the material of the body and the magnitude of the deforming force.

When a body is subjected to a deforming force, a restoring force is developed in the body. This restoring force is equal in magnitude but opposite in direction to the applied force. **The restoring force per unit area is known as stress**. If F is the force applied and A is the area of cross-section of the body, magnitude of the stress = F/A

The SI unit of stress is Nm^{-2} or **Pascal (Pa)** and its dimensional formula is $[ML^{-1}T^{-2}]$.

Strain

When a body suffers a change in its size or shape under the action of external forces, it is said to be *deformed* and the corresponding fractional change is called *strain*. **The strain is a ratio and it has no unit, no dimension**.

There are three types of strain — longitudinal (linear) strain, volume strain and shearing (shape) strain.

Hooke's Law

For small deformations, stress and strain are proportional to each other. This is known as Hooke's law.

Thus, stress $\propto$ strain

or, stress = $\kappa \times$ strain

where κ is the proportionality constant and is known as modulus of elasticity.

Hooke's law is an empirical law and is found to be valid for most materials.

Elastic Moduli

The ratio of stress to strain, called **modulus of elasticity**, is found to be a characteristic of the material. There are three types of elasticity:

1. Young's Modulus 2. Shear Modulus 3. Bulk Modulus

Young's Modulus

The ratio of longitudinal stress (σ) to longitudinal strain (L) is defined as Young's modulus and is denoted by the symbol Y.

$$Y = (F/A)/(\Delta L/L)$$
$$= (F \times L)/(A \times \Delta L)$$

Since strain is a dimensionless quantity, the unit of Young's modulus is the same as that of stress, i.e. Nm^{-2} or Pascal (Pa).

Shear Modulus

The ratio of shearing stress to the corresponding shearing strain is called the shear modulus of the material and is represented by G. It is also called the *modulus of rigidity.*

The SI unit of shear modulus is $N\ m^{-2}$ or Pa. It can be seen that shear modulus (or modulus of rigidity) is generally less than Young's modulus. For most materials **G = Y/3**.

Bulk Modulus

When a uniform pressure is applied all over the surface of a body, the volume of the body changes. The change in volume per unit volume of the body is called *volume strain* and the applied pressure is called *normal stress.* Thus the ratio of normal stress to volume strain is called *bulk modulus* of the material of the body.

$$B = -p/(\Delta V/V)$$

Where p = normal stress $\frac{\Delta v}{v}$ = volume strain

The negative sign indicates the fact that with an increase in pressure, a decrease in volume occurs. That is, if p is positive, ΔV is negative.

Thus for a system in equilibrium, the value of bulk modulus B is always positive. The SI unit of bulk modulus is the same as that of pressure, i.e. Nm^{-2} or Pa.

The reciprocal of bulk modulus is called compressibility and is denoted by k. **It is defined as the fractional change in volume per unit increase in pressure.**

$$k = (1/B) = -(1/\Delta p) \times (\Delta V/V)$$

Note: 1. The bulk moduli for solids are much larger than for liquids, which are again much larger than the bulk modulus for gases (air). Thus solids are least compressible whereas gases are most compressible. Gases are about a million times more compressible than solids. Gases have large compressibility, which vary with pressure and temperature.

2. The Young's modulus and Shear modulus are relevant only for solids since only solids have lengths and shapes.

Gravitation

Gravitation: It is the force of attraction between any two bodies in the universe.

Gravity: It is the force of attraction between a planet and a body.

Acceleration due to gravity: The acceleration produced in a body due to the force of gravity is called acceleration due to gravity. It is denoted by **g**. It is independent of the mass of the body. It varies with altitude and depth.

The value of acceleration due to gravity is taken as **9.8 ms^{-2}** at 45° latitude at the sea level.

Weight: It is defined as the force with which a body is attracted towards the centre of the earth.

Newton's Law of Gravitation

The law of gravitation states that the force of attraction between any two objects is proportional to the product of their masses and inversely proportional to the square of the distance between them. The law applies to objects anywhere in the universe. Such a law is said to be universal.

Consider two particles of masses m_1 and m_2 separated by a distance r, then by Newton's law of gravitation we have

$$F \propto m_1 m_2 \quad \text{.... (1)}$$

$$F \propto \frac{1}{r^2} \quad \text{.... (2)}$$

Combining equations 1 and 2, we have

$$F \propto \frac{m_1 m_2}{r^2}$$

$$\text{or, } F = \frac{G m_1 m_2}{r^2} \quad \text{... (3)}$$

Here G is a constant called the **universal gravitational constant**. In SI it has a value 6.67×10^{-11} Nm^2 kg^{-2}, which is a small value. The above expression is valued only for bodies having spherical shape. The gravitational unit of force in SI is kilogram weight (kgwt). **1 kgwt = 9.8 N**

Acceleration due to Gravity at the Surface of the Earth

Suppose a body of mass *m* is placed on the surface of the earth. Let the mass of the earth be M and its radius be R. Since the radius of the body is very small, the centre-to-centre distance between the bodies is R. Now, by Newton's gravitational law, the force of attraction between these two bodies is

$$F = \frac{GMm}{R^2} \quad \text{... (1)}$$

Now, the weight of a body is defined as the force with which a body is attracted to the centre of the earth. Therefore, the Weight (W) of the body is given by

$$W = mg \quad \text{... (2)}$$

Therefore, from equations 1 and 2, we have

$$mg = \frac{GMm}{R^2} \text{ or } g = \frac{GM}{R^2}$$

If the body lies at a distance r from the centre of the earth then the acceleration due to gravity is given by the expression $g = \frac{GM}{r^2}$

The acceleration due to gravity on the surface of the earth is given by $g = \frac{GM}{R^2}$.

It should be noted that the acceleration due to gravity
1. decreases with height from the surface of the earth.
2. decreases with depth from the surface of the earth.
3. is a maximum at the surface of the earth.
4. is more at the poles than at the equator.

Difference between mass and weight

Mass	Weight
It is the amount of matter contained in a body.	It is a force equal to the gravitational pull exerted by a planet.
It is a constant quantity and does not change with respect to position or place.	It is a variable quantity and changes with the change in acceleration due to gravity at a place.
Mass of a body can never be zero.	Weight of a body can be zero during free fall.
It is measured by using a physical balance.	It is measured by using a spring balance.
It is measured in kilogram.	It is measured in Newton.

Applications of Newton's Law of Gravitation

Newton's law of gravitation has a large number of applications. Some of these are:

1. It can be used to estimate the mass of the earth by using the expression $g = \frac{GM}{R^2}$.
2. It can also be used to estimate the mass of the moon, the sun and other planets.
3. It is used to study the binary stars — a system of two stars orbiting around their common centre, the centripetal force being provided by the gravitational force of attraction between them. Any distortion in the orbit of a star indicates the presence of a companion such that the system moves as a double star. Newton's law of gravitation can be used to estimate the masses of these stars.
4. The wobbling (irregularity in the motion) of a star can be detected by modern techniques. By using the law of gravitation we can estimate the mass of these stars.

Weight of an Object on the Moon: The weight of an object on the surface of the moon would be the magnitude of mass in kilograms multiplied by 1.67 N.

Escape Velocity

The escape velocity is the minimum required velocity of a body through which it is projected. It goes beyond the gravitational pull and never comes back.

If *m* be the mass of a body projected from the earth's surface of radius R_e and mass M_e, the kinetic energy of the body must be equal to the gravitational potential energy.

Thus; $\frac{1}{2}mv_e^2 = \frac{GM_e m}{R_e}$

or, $v_e = \sqrt{\frac{2GM_e}{R_e}}$ where v_e = escape velocity.

But $g = \frac{Gm_e}{R_e^2}$

v_e = escape velocity = $\sqrt{2gR_e} = 11.2 \text{ km/sec}$

This implies that if a body is thrown from the earth's surface with the velocity of 11.2 km/sec, then the body will never come back to the earth.

Here we observe that escape velocity of a body on the earth's surface is

$$v_e = \sqrt{2gR_e}$$

and the orbital velocity of the body around the earth

$$v_0 = \sqrt{gR_e}$$

$$v_e = \sqrt{2}v_0$$

Thus, if the velocity of an orbiting satellite close to the earth is increased $\sqrt{2}$ times or 41%, then the satellite will leave the orbit and will escape. In other words, if the kinetic energy of an orbiting satellite is doubled immediately, then the satellite will escape. The escape velocity is maximum on the sun and it is 614 km/sec. That's why even lighter gases like hydrogen and helium do not escape. The moon has the least volume of escape velocity, i.e. 2.4 km/sec. So, no gases exist on the moon. That's why the moon has no atmosphere and, from the surface of the moon, the sky appears black. The escape velocity of the gaseous molecules must be more than the root mean square (rms) velocity for the existence of the atmosphere.

Note: An astronaut experiences weightlessness in a space satellite. This is not because the gravitational force is small at that location in space. It is because both the astronauts and the satellites are in "free fall" towards the Earth.

Waves

Waves can occur whenever a system is disturbed from its equilibrium position and when the disturbance can travel or propagate from one region of the system to the other. Sound, light, ocean waves, radio and television transmission, and earthquakes are all wave phenomena.

The waves are mainly of three types: (a) mechanical waves, (b) electromagnetic waves and (c) matter waves.

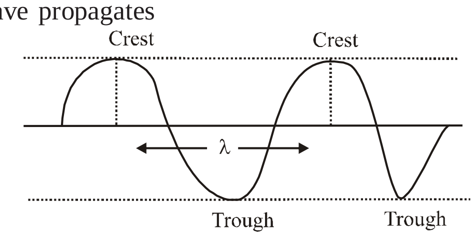
Mechanical wave: Mechanical waves require a material medium for their propagation, i.e. they cannot travel in vacuum. Example: Water waves, sound waves, seismic waves, etc

Types of mechanical wave:

(a) Transverse mechanical wave

(b) Longitudinal mechanical wave

Transverse mechanical wave: If in an elastic medium wave propagates



or (transmits) along the perpendicular direction of the particle's vibration, it is called transverse mechanical wave.

Transverse mechanical waves can be generated in solids and upper surfaces of the liquids. **But it cannot be generated through gases and inside liquids due to lack of rigidity**. The transverse wave propagates in the form of **crest** (max. upward displacement) and **trough** (max. downward displacement). The distance between two adjacent crests or trough is called wavelength and it is represented by λ.

Longitudinal mechanical wave: If, in an elastic medium, a wave propagates (transmits) along the direction of particle's vibration, it is called longitudinal mechanical wave.

Longitudinal waves can be generated (produced) in all mediums — solids, liquids and gases — and such waves transmit through compression and rarefaction. In compression, the pressure and the density of the medium is maximum, while in rarefaction, the pressure and the density of the medium is minimum. Examples — Sound waves in air, earthquake waves, water waves etc. are longitudinal mechanical waves.

Electromagnetic wave

- An electromagnetic wave is a wave generated by the oscillations of electric and magnetic fields oscillating mutually perpendicular to each other. Electromagnetic waves do not require a medium to propagate.
- The orderly distribution of electromagnetic radiations according to their frequency or wavelength is termed as **electromagnetic spectrum**.
- For an electromagnetic wave, the frequency, wavelength and the velocity of the wave are related by the expression; $\mathbf{c = v\lambda}$.

Types of Electromagnetic Waves

The various types of electromagnetic waves (in the order of increasing wavelength) are:

Name	Wavelength		Discoverer Origin
Gamma rays	$1 \times 10^{-13} \rightarrow 1 \times 10^{-10}$	Becquerel and Curie	Nuclei of atoms
X-rays	$1 \times 10^{-10} \rightarrow 3 \times 10^{-8}$	Roentgen	Bombardment of high Z targets
Ultraviolet rays	$3 \times 10^{-8} \rightarrow 4 \times 10^{-7}$	Ritter	Excitation of atoms
Visible light	$4 \times 10^{-7} \rightarrow 8 \times 10^{-7}$	Newton	Excitation of atoms
Infrared rays	$8 \times 10^{-7} \rightarrow 3 \times 10^{-5}$	Herschel	Heating
Microwaves	$1 \times 10^{-3} \rightarrow 3 \times 10^{-1}$	Hertz	Oscillating circuits
Ultra High Frequency (UHF)	$1 \times 10^{-1} \rightarrow 1$	Marconi	Oscillating circuits
Very High Frequency (VHF)	$1 \rightarrow 10$	Marconi	Oscillating circuits
Radio Frequency (RF)	$10 \rightarrow 10^{4}$	Marconi	Oscillating circuits
Power Frequency (PF)	$5 \times 10^{6} \rightarrow 6 \times 10^{6}$	Marconi	Weak radiations from ac circuits

Uses of Electromagnetic Waves

- The study of **gamma rays** provides valuable information about the structure of the atomic nucleus.
- **X-rays** are used as a diagnostic tool in medicine and used in the study of crystal structure.
- **UV radiations** are used for sterilisation, to check the purity of gems, eggs, etc., and to check counterfeit currency.
- **UV radiations** are the cause of sun tanning and skin cancer.
- **Infrared radiations** are used in physical therapy, infrared photography, and vibrational spectroscopy, in warfare, for looking through haze, in greenhouses and in the electronic industry as infrared remote control.
- **Microwaves** are used in communication, navigation, studying atomic and molecular structure, and also in microwave ovens.
- **Radio waves** are used in radio and TV communication.

Properties of Electromagnetic waves

The range of wavelength of the visible part of the spectrum is as below:

Violet/Indigo	400 to 440 nm
Blue	440 to 480 nm
Green	480 to 560 nm
Yellow	560 to 590 nm
Orange	590 to 630 nm
Red	630 to 790 nm

The following properties are common to all electromagnetic waves:

(i) They are produced by accelerated charges.
(ii) They do not require any material medium to travel.
(iii) An electromagnetic wave consists of an electric and a magnetic field which are mutually perpendicular and also perpendicular to the direction of motion.
(iv) Both the electric and magnetic field vectors vary both with respect to time and space.
(v) They are transverse in nature.
(vi) They exhibit the phenomenon of reflection, refraction, polarisation and diffraction.
(vii) They are unaffected by electric and magnetic fields.
(viii) All the components of the electromagnetic spectrum have a velocity of 3×10^{8} ms^{-1} in vacuum. However their velocity decreases in other medium.

Thus all electromagnetic waves travel through vacuum at the same speed c, given by $c = 3 \times 10^{8}$ ms^{-1} (speed of light). Unlike the mechanical waves,the electromagnetic waves do not require any medium for their propagation.

Note: Cathode rays, sound waves, alpha, beta and ultrasonic waves are not electromagnetic waves.

Matter wave: Matter waves are associated with moving electrons, protons, neutrons and other fundamental particles, and even atoms and molecules. Because we commonly think of these as constituting matter, such waves are called **matter waves**. Matter waves are conceptually more abstract than mechanical or electromagnetic waves.

Sound Wave

Sound and its production

Sound is a form of energy which excites in our ears the sensation of hearing. It is a longitudinal wave that is created by a vibrating object, such a guitar string, the human vocal cords, or the diaphragm of a loudspeaker.

Sound needs a medium to travel

Sound is a mechanical wave and needs a material medium like air, water, steel etc. for its propagation. It cannot travel through vacuum.

On the moon, there is vacuum, i.e. there is no air, therefore sound cannot propagate on the moon. Thus the astronauts cannot hear each other.

Terms related to sound wave

Air is the most common medium through which sound travels. When a vibrating object moves forward, it pushes and compresses the air in front of it, creating a region of high pressure. This region is called a **compression (C)**. This compression starts to move away from the vibrating object.

When the vibrating object moves backwards, it creates a region of low pressure called **rarefaction (R)**. As the object moves back and forth rapidly, a series of compressions and rarefactions is created in the air. These create sound wave that propagates through the medium.

Compression is the region of high pressure and rarefaction is the region of low pressure. Pressure is related to the number of particles of a medium in a given volume. More density of the particles in the medium gives more pressure and vice versa. Thus, propagation of sound can be visualised as propagation of density variations or pressure variations in the medium.

Relation between velocity, wavelength and frequency

Frequency (ν): It is defined as the number of waves per second.

Wavelength (λ): It is defined as the distance travelled by a wave when the particles of a medium complete one vibration. It is also defined as the distance between two consecutive crests or troughs or two consecutive compressions or rarefactions. The particle takes time T equal to the time period to complete one vibration. In this time, the wave travels a distance λ. Let v be the velocity of the wave, then

$$V = \frac{\text{Distance travelled by the wave}}{\text{time taken}} = \frac{\lambda}{T} = \nu\lambda$$

$$\left(\because \nu = \frac{1}{T}\right)$$

Thus velocity = frequency × wavelength

The frequency range of a sound wave

Sound is produced by a vibrating body. But not all vibrating bodies produce sound which we can hear.

Audible Range

A sound with a single frequency is called a **pure tone**. A healthy young person hears all sound frequencies in the range from approximately 20 to 20,000 Hz (20 kHz). This range of frequency is called the **audible range**. The ability to hear high frequencies decreases with age, however, and a normal middle-aged adult hears frequencies only up to 12-14 kHz.

Sound waves whose frequency lie above 20 kHz are called **ultrasonic waves** while those with a frequency below 20 Hz are called **infrasonic waves**. Infrasonic waves are produced by a vibrating pendulum, whales, elephants and earthquakes.

It is observed that some animals get disturbed before earthquakes. Earthquakes produce low-frequency infrasound before the main shock waves begin. It is possibly this that alerts the animals. These waves are extensively used for drilling purposes.

Ultrasound is produced by dolphins, bats and porpoises. Rats also play games by producing ultrasound.

Applications of Ultrasound

- Ultrasounds are high-frequency waves. They are able to travel along well-defined paths even in the presence of obstacles. They are used extensively in industries and for medical purposes.
- Ultrasound is generally used to clean parts located in hard-to-reach places; for example, spiral tube, odd-shaped parts, electronic components etc.
- Objects to be cleaned are placed in a cleaning solution and ultrasonic waves are sent into the solution. Due to the high frequency, the particles of dust, grease and dirt get detached and drop out. The objects thus get thoroughly cleaned.
- Ultrasounds can be used to detect cracks and flaws in metal blocks.

- Metallic components are generally used in construction of big structures like buildings, bridges, machines and also scientific equipment. The cracks or holes inside the metal blocks, which are invisible from outside, reduces the strength of the structure.
- Ultrasonic waves are allowed to pass through metal blocks and detectors are used to detect the transmitted waves. If there is even a small defect, the ultrasound gets reflected back, indicating the presence of the flaw or defect.
- Ultrasonic waves are made to reflect from various parts of the heart and form the image of the heart. This technique is called **echocardiography**.
- An **ultrasound scanner** is an instrument which uses ultrasonic waves for getting images of internal organs of the human body. It helps the doctor detect abnormalities such as stones in the gall bladder and kidney, or tumours in different organs. These waves are converted into electrical signals that are used to generate images of the organ. These images are then displayed on a monitor or printed on a film. This technique is called **ultrasonography**.
- Ultrasound may be employed to break small 'stones' formed in the kidneys into fine grains. These grains later get flushed out with urine.

SONAR

The acronym SONAR stands for **Sound Navigation and Ranging**. Sonar is a device that uses ultrasonic waves to measure the distance, direction and speed of underwater objects.

Sonic boom: When the speed of any object exceeds the speed of sound, it is said to be travelling at **supersonic speed**. Bullets, jet aircraft, etc. often travel at supersonic speeds. When a sound-producing source moves with a speed higher than that of sound, it produces shock waves in air. These shock waves carry a large amount of energy. The air pressure variation associated with this type of shock waves produces a very sharp and loud sound called **sonic boom**. The shock waves produced by a supersonic aircraft have enough energy to shatter glass and even damage buildings.

Frequency is an objective property of a sound wave, because frequency can be measured with an electronic frequency counter.

Speed of Sound

The speed of sound in a medium depends upon
1. the elasticity of the medium (E) and
2. the density of the medium (ρ)

According to Newton, the velocity of sound in an elastic medium is given by

$$v = \sqrt{\frac{E}{\rho}}$$

Newton assumed that the propagation of sound waves through air (a gas) takes place at a constant temperature, i.e. it is an isothermal process. For such a process, the elasticity is equal to the pressure (P) of air/gas. Therefore, the speed of sound, according to Newton, is

$$v = \sqrt{\frac{P}{\rho}}$$

This formula gives the value of the speed of sound at 0°C as 280 ms^{-1}, which is much lower than the experimental value.

This discrepancy was overcome by Laplace. According to Laplace, the propagation of sound through air is an **adiabatic process** (no exchange of heat) and not an isothermal process. In this process we have

$$E = \gamma P$$

where γ is the ratio of the specific heat at constant pressure to the specific heat at constant volume of the gas $\left(\gamma = \frac{C_P}{C_V}\right)$.

Hence, according to Laplace, the speed of sound in air is given by

$$v = \sqrt{\frac{\gamma P}{\rho}}$$

For air, $\gamma = 1.4$

Sound travels through gases, liquids and solids at considerably different speeds as revealed. At room temperature, the speed of sound in air is about **343 ms^{-1}** and is markedly greater in liquids and solids. For example, sound travels more than four times faster in water and more than seven times faster in steel than it does in air. In general, sound travels slowest in gases, faster in liquids and fastest in solids.

The speed of sound depends on the nature of the medium. In air, the speed of sound depends upon its temperature, its density and its humidity.

Factors on which the velocity of sound depends

The velocity of sound depends upon the following factors: (i) Pressure (ii) Density (iii) Temperature (iv) Humidity (v) Velocity of wind.

Effect of pressure: Pressure does not affect the velocity of sound because an increase in pressure increases the density and a decrease in pressure decreases the density of air.

Effect of density: Velocity of sound varies inversely as square root of density.

Ex: Velocity of sound is more in H_2 than in O_2 as the density of oxygen is greater than the density of hydrogen.

Effect of temperature: The velocity of sound in air depends upon temperature as $v \propto \sqrt{T}$, where T is the absolute temperature. Therefore, if other factors remain the same, the velocity of sound in air increases with an increase in the temperature of the air.

Effect of humidity: The velocity of sound increases with humidity. This shows that the velocity of sound in moist air is greater than the velocity of sound in dry air. As a result, the velocity of sound is more during the night than during the day. Also, it is more during the rainy season than during the dry season.

Speeds of sound in various media

When sound travels in a denser medium its velocity increases. Therefore, velocity of sound is more in solids than in liquids or gases.

Medium	**Speed of sound in m/s at 0°C**
CO_2	260
Air	332
Vapour (100°)	405
Alcohol	1213
Hydrogen	1269
Mercury	1450
Water	1493
Sea water	1533
Iron	5130
Glass	5640
Aluminium	6420

Echo

An echo is the phenomenon of repetition of sound of a source by reflection from an obstacle reaching ear drum after 0.1s. Let *d* be the minimum distance of a reflector from the source, *v* the velocity of sound in air at room temperature, and *t* the total time taken by sound to reach the listener after reflection.

Now, total distance travelled (2d)
= velocity (v) × total time (t)
Therefore, we have

$$t = \frac{\text{Total distance travelled}}{\text{Speed of sound}} = \frac{2d}{v}$$

For simple sounds, the condition of echo is that the reflecting surface should be at a minium distance of 17m from the source of sound. The sensation of sound persists in our ear for $\frac{1}{10}$th of a second, so to hear an echo, the sound after reflection should fall on the eardrum after $\frac{1}{10}$th of a sound.

For articulate sounds, the condition of echo is that the reflecting surface should be at a minimum distance of 34m from the source of sound.

The phenomenon of echo is utilised by bats and dolphins. The phenomenon of echo is used in fishing boats and in SONAR and RADAR and in **ultrasonography**. Ultrasonography is the technique in which the ultrasonic waves are used for taking the photograph of uterus, gall bladder, liver etc. Using ultrasonic waves, a detailed photograph of human heart can also be taken. This is called **echocardiography**.

Pitch (Shrillness) and Frequency

Pitch is that characteristic of sound by which an acute or shrill note can be distinguished from a flat or grave note. The frequency of note produced by a string in stringed instruments can be changed by changing the place of plucking or by increasing the tension on the string or by using the string of less or more thickness. The pitch of a woman's voice is higher than that of a man.

The pitch of sound depends on (i) frequency and (ii) relative motion between source and listener. Pitch is a sensation only.

Reflection of Sound

Sound bounces off a solid or a liquid like a rubber ball bounces off a wall. Like light, sound gets reflected at the surface of a solid or liquid and follows the same laws of reflection. The directions in which the sound is incident and is reflected make equal angles with the normal to the reflecting surface, and the three are in the same plane. An obstacle of large size which may be polished or rough is needed for the reflection of sound waves. The rolling of thunder is due to the successive reflections of sound from a number of reflecting surfaces, such as the clouds and the land.

Uses of Multiple Reflection of Sound

1. Megaphones or loudhailers, horns, musical instruments such as trumpets and *shehnais*, are all designed to send sound in a particular direction without spreading it in all directions.
2. **Stethoscope** is a medical instrument used for listening to sounds produced within the body, chiefly in the heart or lungs. In stethoscopes the sound of the patient's heartbeat reaches the doctor's ears by multiple reflection of sound.
3. Generally, the ceilings of concert halls, conference halls and cinema halls are curved so that sound reaches all corners of the hall after reflection. Sometimes a curved sound board may be placed behind the stage so that the sound, after reflecting from the sound board, spreads evenly across the width of the hall.

Hearing Aid

People with hearing loss may need a hearing aid. A hearing aid is an electronic, battery-operated device. The hearing aid receives sound through a microphone. The microphone converts the sound waves to electrical signals. These electrical signals are amplified by an amplifier. The amplified electrical signals are given to a speaker of the hearing aid. The speaker converts the amplified electrical signal to sound and sends to the ear for clear hearing.

Reverberation

A sound created in a big hall will persist by repeated reflection from the walls until it is reduced to a value where it is no longer audible. The repeated reflection that results in this persistence of sound is called **reverberation**. In an auditorium or big hall, excessive reverberation is highly undesirable. To reduce reverberation, the roof and walls of the auditorium are generally covered with sound-absorbent materials like compressed fibreboard, rough plaster or draperies. The seat materials are also selected on the basis of their sound-absorbing properties.

Resonance

When the frequency of an externally applied periodic force is either equal to or an integral multiple of the natural frequency of the body, the amplitude of oscillation is increased to a high value. This phenomenon is known as resonance.

The phenomenon of resonance occurs in:

(i) Machine parts
(ii) Radio and TV reception
(iii) Air columns and
(iv) Sound boxes of musical instruments

Applications of Resonance

(i) When the soldiers walk in step, they produce some fixed frequency. If this frequency corresponds to the natural frequency of the bridge, resonance can take place. This will make the bridge vibrate violently, and hence it may collapse. To avoid such a situation, the soldiers are asked not to march in step.

(ii) When the glass rattles, its natural frequency corresponds with the frequency with which the piano is being played. Thus, resonance takes place, which makes the glass to vibrate violently.

(iii) When the frequency of the engine of a motorbike corresponds with the natural frequency of the rear view mirror, resonance takes place. Thus, the rear view mirror vibrates with larger amplitude.

(iv) A tuning fork held close to the ear, disturbs a small amount of air and thence sound heard is faint. When the handle of the vibrating tuning fork is held against a table, it sets up forced vibrations in the table top. As the table top has a larger surface area, large volume of air is set into vibrations, thereby producing a loud sound.

(v) A large sound box contains a large amount of trapped air. When the vibrations of the vibrating string are impressed upon the air, it sets up forced vibrations in the air column. As a large volume of enclosed air vibrates, a loud sound is produced.

Loudness and Intensity

Loundess is the property by virtue of which a loud sound can be distinguished from a faint one, both having the same pitch and quality.

Loudness depends on the following:

(i) It is directly proportional to the square of amplitude.
(ii) It is inversely proportional to the square of distance.
(iii) It is directly proportional to the surface area of vibrating body.
(iv) It is directly proportional to the density of the medium.
(v) The more the resonant bodies nearby, the more will be the loudness.

The unit of loudness is **phon**.
The unit of intensity level is **decibel**.

Intensity is a measurable quantity whereas loudness is a sensation.

L = K log I, where L = Loudness
I = Intensity
K = Constant

Intensity is proportional to (i) square of amplitude, (ii) square of frequency and (iii) density of air.

Source of sound	Intensity (db)
Whisper	15-20
Ordinary conversation	40-60
Loudspeaker	70-80
Hot discussion	70-80
Heavy motor vehicle, motor bike	90-95
Press	100-105
Orchestra	100-110
Rocket	160-170
Missile	180-190
Siren	190-200

Doppler Effect

The Doppler effect is the change in frequency of a wave (sound or light) due to the motion of the source or observer. The frequency (and hence pitch) of a sound appears to be higher when the source approaches the listener and lower when the source recedes from him. It is due to the Doppler effect that **the whistle of a train appears shriller when it approaches a listener than when it moves away from him**.

Speed guns (or radar sets), used by police to measure the speed of vehicles, use Doppler effect. A radar set sends out a radio pulse and waits for the reflection. Then it measures the Doppler shift in the signal and uses the shift to determine the speed.

The Doppler effect is very useful in **astronomy**. It can be used to find out whether a star is approaching towards us or receding away from us. When a star is receding from us the light emitted from the star appears more red (red light is of lower frequency than other colours). Thus, the fact that the light emitted by the stars of distant galaxies suffers a red shift when observed from the earth means that these galaxies are receding from our galaxy. This is the principle evidence in favour of the hypothesis of expanding universe.

Doppler effect can also be used to detect or even measure the rotation of a star, e.g. the sun.

The effect can be used to track a moving object, such as a satellite, from a reference point on the earth. The method is remarkably accurate; changes in the position of a satellite 10m away can be determined to a fraction of a centimetre.

Light

Light is a transverse, electromagnetic wave that can be seen by humans. The wave nature of light was first illustrated through experiments on diffraction and interference. Like all electromagnetic waves, light can travel through a vacuum. The transverse nature of light can be demonstrated through polarisation. The human eye has the sensitivity to detect electromagnetic waves within a small range of the electromagnetic spectrum. **Electromagnetic radiation belonging to this region of the spectrum (wavelength of about 400 nm to 750 nm) is called light**.

The speed of light is finite and measurable. Its presently accepted value in vacuum is $c = 2.99792458 \times 10^8$ m s^{-1}. For many purposes, it suffices to take $c = 3 \times 10^8$ m s^{-1}. **The speed of light in vacuum is the highest speed attainable in nature**.

A light wave can be considered to travel from one point to another, along a straight line joining them. The path is called a **ray** of light, and a bundle of such rays constitutes a **beam** of light.

The scientific study of the behaviour of light is called **optics**.

Dual (Wave-Particle) Nature of Light

The **wave nature** of light shows up the phenomena of interference, diffraction and polarisation. This phenomena shows that light is an electromagnetic wave consisting of electric and magnetic fields with continuous distribution of energy over the region of space over which the wave is extended.

On the other hand, photoelectric effect and Compton effect, which involve energy and momentum transfer and radiation, show the **particle nature** of light. (Particles exist in the form of **photon**.)

For example: In the familiar phenomenon of seeing an object by our eye, both descriptions are important. The gathering and focussing mechanism of light by the eye-lens are well described by the wave phenomena. But the light absorption by the rods and cones (of the retina) requires the photon phenomena of light.

Speed of light

Firstly **Romer** (an astronomer) obtained the value of the speed of light with the help of the motion of the satellite of the planet Jupiter. In different media the speeds of light are different. It depends upon the refractive index of the medium. The medium which has a larger refractive index has a smaller speed of light.

The refractive index or index of refraction (μ)

$$= \frac{\text{speed of light in vacuum}}{\text{speed of light in medium}}$$

The speed of light is maximum in vacuum and it is 3×10^8 metre/sec (1,86,310 miles/sec or 2,99,776 km/sec). In any denser medium the speed of light is always smaller than that of vacuum. In air the value of the speed of light is 0.03% lesser than the value of the speed of vacuum; in water it is smaller than 25% and in glass it is lesser than 35%.

Values of the speeds of light in various media

Medium	**Speed of light (m/s)**
Vacuum	3×10^8
Water	2.25×10^8
Oil of turpentine	2.04×10^8
Glass	2×10^8
Rock salt	1.96×10^8
Nylon	1.96×10^8

Reflection of light

The bouncing back of light when it strikes a smooth or polished surface is called reflection of light.

- The light ray that strikes the surface of the mirror is called **incident ray**.
- The light ray that bounces off from the surface of the mirror is called **reflected ray**.
- The **normal** is a line perpendicular to the mirror surface where the reflection occurs.
- The angle between the incident ray and the normal is called the **angle of incidence (i)**.
- The angle between the reflected ray and the normal is called the **angle of reflection (r)**.

The image formed by reflection in a plane mirror is

1. laterally inverted
2. same size as the object
3. virtual
4. upright
5. as far behind the mirror as the object is in front of it.

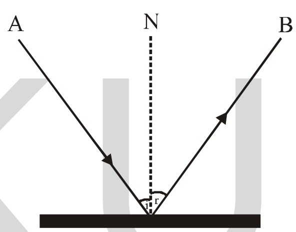
Note: Real image: Image that can be seen on a screen.

Virtual image: Image that cannot be seen on a screen.

Laws of Reflection

The reflecting surfaces obey the following two laws called the laws of reflection:

1. The angle of incidence (i) is equal to the angle of reflection (r).
2. The incident ray, the reflected ray and the normal at the point of incidence all lie in the same plane.



Application of Reflection of Light

The reflection of light is useful in the functioning of modern-day equipment like in the operation of laser printers. In fact, the reflection of laser light is used widely, in applications ranging from measuring the speeds of automobiles to reading price information from bar codes at the supermarket.

Plane Mirror

One surface of the mirror is plane and another surface has a sharp metallic polish, which is pasted. This is done to avoid polish decay. The backside of the mirror with silver or mercury layers (metallic polish) works as reflective surface. The object and image both are located at equal distance. In a plane mirror, the image formed is always imaginary and equal to the size of the object laterally inverted.

Characteristics of image formed by a plane mirror

It is worthwhile to remember the following in case of a plane mirror:

1. The image is as far behind the mirror as the object is in front.
2. The line joining the image to the object is perpendicular to the mirror.
3. The image is of the same size as the object, virtual and erect.
4. The image has right-left reversal.
5. If a plane mirror is rotated in the plane of incidence by an angle θ, then the image rotates by an angle 2θ, the reflected ray rotates by an angle θ, while the incident ray remains fixed.
6. If the object is displaced through a distance x away from the mirror, the image is also displaced by a distance x away from the mirror.
7. If a mirror moves through a distance x towards or away from an object, then its image moves by a distance x towards or away from the mirror.
8. If a person moves with a velocity v towards or away from the mirror, then his image appears to move with a velocity $2v$ towards or away from the mirror to him, but if a stationary observer observes the image then it appears to move with a velocity v.
9. If the mirror moves with a velocity v towards or away from a stationary observer, then the image will appear to move with a velocity $2v$ towards or away from the object.

Note: If an object is placed between two mirrors lying parallel to each other then infinite number of images are formed.

Application of plane mirrors

Plane mirrors have many applications. Some of these are:

1. The most common use is that of a looking mirror in the bathroom or dressing room.
2. It is used in showrooms to increase the effective length of the room.
3. It is used in the optician's room to increase the effective length of the room.
4. Large plane mirrors are mounted at the corners of a blind curve on highways to enable drivers to see the approaching traffic.
5. A plane mirror is used below the pointers of instruments such as voltmeter, ammeter and galvanometer to remove parallax error.
6. It is used in instruments such as periscope, sextant, photocopier, overhead projector, solar cooker and kaleidoscope.

Periscope

A periscope is an optical instrument which enables us to see objects over or round an obstacle. It can be used to view objects from above the head of people in a crowd. Its most common use is in the submarine.

Uses of Periscope

A periscope is used to view objects

(i) from above the head of people in a crowd.
(ii) on the other side of a high wall.
(iii) from a trench in a war.
(iv) from a submarine.

Spherical mirrors

The mirror constructed in a spherical plane is called a **spherical mirror**. One side of the mirror has a layer of mercury or coating of lead oxide.

Spherical mirrors are of two types: If the inside or the concave side of the spherical surface is polished, it is a **concave mirror** or a **converging mirror.** If the outside or the convex surface is polished, it is a **convex mirror or a diverging mirror.**

Both concave and convex mirrors are constructed from the same spherical glass. The centre of the glass sphere is called the **centre of curvature** (C) and the middle point (O) of the spherical mirror is called the **pole**. The line passing through the centre of curvature and the pole is called the **principal axis**. The middle point of the straight line drawn from the pole to the radius of curvature is called **focus** (F).

The focal distance (f) = $\dfrac{\text{radius of curvature}}{2}$

The focal distances (f) for both concave and convex mirrors are evaluated by the following formula

$\dfrac{1}{v}+\dfrac{1}{u}=\dfrac{1}{f}$ where u = Object distance

v = Image distance
f = Focal length of the mirror

Images by a Concave mirror

Position of object	Position of image	Nature of image	Use
At infinity	At the principal focus or in the focal plane	Real, inverted and extremely diminished in size	To collect heat radiations in solar devices
Beyond the centre of curvature	Between the principal focus and centre of curvature	Real, inverted and diminished	————
At the centre of curvature	At the centre of curvature	Real, inverted and equal to the size of the object	Reflecting mirror for projector lamps
Between focus and the centre of curvature	Beyond centre of curvature	Real, inverted and bigger than object	In flood lights
At the principal focus	At infinity	Real, inverted and extremely magnified	In torches, head lights
Between the pole and the principle focus	Behind the mirror	Virtual, erect and magnified	Shaving mirror, dentist

Note: A convex mirror always forms a virtual and erect image no matter at what place in front of the mirror the object is placed. The image is always situated between the pole and the focus, irrespective of the position of the object in front of the mirror.

For a Convex Mirror

Position of object	Position of image	Nature of image	Uses
At infinity	Appears at the principal focus	Virtual, erect and extremely diminished	Used as a rear view mirror and reflectors in street lights
Between infinity and the pole	Appears between the principal focus and the pole	Virtual, erect and diminished	Used as a rear view mirror and reflectors in street lights

Uses of Spherical Mirrors

Concave Mirror

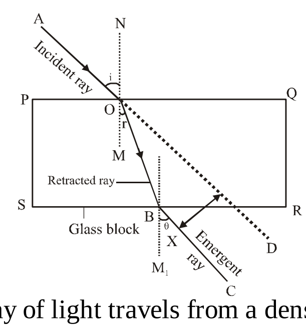
1. **To collect heat radiation in solar devices:** Heat radiation from the sun coming from infinity is brought to focus by the concave mirror in its focal plane or at the focus.
2. **Reflecting mirror for projector lamps:** The object is placed at the centre of curvature to obtain an image of the same size.
3. **In floodlights:** The source of light is placed just beyond the centre of curvature. This illuminates a certain section of the ground.
4. **In torches and headlights:** The source of light is placed at the focus to obtain a parallel beam of light.
5. **Shaving mirror or dentist's mirror:** It produces an erect virtual and highly magnified image of an object placed between its pole and focus.
6. It is used in the **ophthalmoscope** by doctors to concentrate light on a small region which is to be examined.

Convex Mirrors

1. **Rear view mirror:** It is used in automobiles. This is due to the reason that a convex mirror provides a wider field of view than a plane or concave mirror. It produces an erect, diminished and virtual image. It does not give the exact distance of the vehicle coming from behind.
2. **Street light reflector:** It is used as a reflector in street lamps so as to diverge light over a large area.
3. **Security mirror:** It is used as a security mirror in shops and on roads at sharp bends and concealed entrances.

Refraction of light

It is the phenomenon of light in which a ray of light bends from its path when it travels from one medium to another. When a ray of light travels from an optically rarer medium into an optically denser medium, it bends towards the normal i.e., $\angle i > \angle r$.



When a ray of light travels from a denser medium to a rarer medium, it bends away from the normal that is $\angle i > \angle r$.

If the ray is incident normally on the surface separating the two media, it goes undeviated i.e, $\angle i = 0, \angle r = 0$.

Cause of refraction: Light has different speeds in different media.

Laws of Refraction and Refractive Index

Incident ray, the refracted ray and the normal at the point of incidence lie in the same plane. The ratio of the sine of angle of incidence to the sine of angle of refraction is a constant value which is known as **refractive index** for the pair of media. It is also equal to the inverse ratio of the two indices of the two media, i.e.,

$$\frac{\sin i}{\sin r} = \frac{\mu_2}{\mu_1} = {}^1\mu_2$$

where ${}^1\mu_2$ is the refractive index of the 2nd medium with respect to the 1st medium.

This law is also known as **Snell's law**. Refractive index has no unit as it is a **ratio**. It is equal to **unity** for vacuum.

$$\mu = \frac{\text{Speed of light in vacuum}}{\text{Speed of light in medium}}$$

When a ray of light goes from a rarer medium to a denser medium,

$$\mu > 1$$

When a ray of light goes from a denser medium to a rarer medium.

$$\mu < 1$$

The refractive index of a medium depends on

(i) Nature of the two media in contact
(ii) Temperature of the medium
(iii) Wavelength of light

The refractive index of the two media and the wavelength of light in those media are related as:

$$\lambda_1\mu_1 = \lambda_2\mu_2$$

Snell's law and hence laws of refraction fail if $\angle i = \angle r = 0$, i.e. when a ray of light falls normally on the surface.

Critical Angle

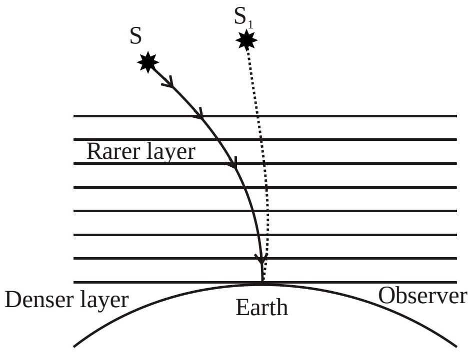
Critical angle is the angle of incidence in the denser medium for which angle of refraction in the rarer medium is 90°, when the ray of light is travelling from the denser to the rarer medium.

Critical Angles of Some Transparent Media

Substance medium	Refractive index	Critical angle
Water	1.33	48.75°
Crown glass	1.52	41.14°
Dense flint glass	1.62	37.31°
Diamond	2.42	24.41°

Applications of Refraction of Light

1. **Twinkling of stars at night:** The light from stars suffers a series of refractions due to atmospheric layers of different densities and different refractive indices.



Due to this reason, a ray of light starting from a star S bends more and more towards the normal before reaching the observer on the earth. But the observer sees the star in the direction of the ray reaching finally in the eye, so star appears to him at S_1 instead of S. On account of change in temperature and density the apparent position of the start changes continuously, which gives the twinkling effect to the star.

2. A harpoon used to kill a fish is aimed at a point below the apparent position of the fish because the fish appears to be raised up due to refraction of light from denser medium (water) to rarer medium (air) at the surface separating the two media.
3. When a coin is kept inside a water container, the phenomenon of refraction takes place and the coin kept in the container seems upwardly uplifted.
4. A fish inside water seems lifted up from its original position.
5. A straight rod partially sunk inside water seems to be bent.
6. When the sun is below the horizon before sunrise and after sunset, the region around the sun appears red due to refraction.
7. Water in a pond appears to be only three-quarters of its actual depth.

Total Internal Reflection

When a ray of light travels from a denser to a rarer medium and the angle of incidence in the denser medium for that pair of media is more than the critical angle, the ray of light, instead of going into the rarer medium, comes back in the denser medium and follows the laws of reflection, i.e., $\angle i = \angle r$. In this case, no ray of light is refracted or absorbed. It is totally reflected and the image formed is very bright. That's why it is known as total internal reflection.

Due to total internal reflection, diamonds sparkle, mirage occurs in hot countries and looming occurs in cold countries.

Applications of total internal reflection

Mirage

On hot summer days, the air near the ground becomes hotter than the air at higher levels. The refractive index of air increases with its density. Hot air is less dense and has smaller refractive index than cool air. If the air currents are small, that is, the air is still, the optical density at different layers of air increases with height. As a result, light from a tall object such as a tree, passes through a medium whose refractive index decreases towards the ground. Thus, a ray of light from such an object successively bends away from the normal and undergoes total internal reflection, if the angle of incidence for the air near the ground exceeds the critical angle. When shown in to a distant observer, the light appears to be coming from somewhere below the ground. The observer naturally assumes that light is being reflected from the ground, say, by a pool of water near the tall object. Such inverted images of distant tall objects cause an optical illusion to the observer. This phenomenon is called mirage.

Mirage is especially common in hot deserts. It is noticed that while moving in a bus or a car during a hot summer day, a distant patch of road, especially on a highway, appears to be wet. But, you do not find any evidence of wetness when you reach that spot. This is also due to mirage.

Diamond

Diamonds are known for their spectacular brilliance. Their brilliance is mainly due to the total internal reflection of light inside them. The critical angle for diamond-air interface (**24.4°**) is very small, therefore once light enters a diamond, it is very likely to undergo total internal reflection inside it. Diamonds found in nature rarely exhibit the brilliance for which they are known. It is the technical skill of a diamond cutter which makes diamonds to sparkle so brilliantly. By cutting the diamond suitably, multiple total internal reflections can be made to occur.

Prism

Prisms designed to bend light by 90º or by 180º make use of total internal reflection. Such a prism is also used to invert images without changing their size.

Optical fibres

Optical fibres too make use of the phenomenon of total internal reflection. They are fabricated with high-quality composite glass/quartz fibres. When a signal in the form of light is directed at one end of the fibre at a suitable angle, it undergoes repeated total internal reflections along the length of the fibre and finally comes out at the other end.

Since light undergoes total internal reflection at each stage, there is no appreciable loss in the intensity of the light signal. Optical fibres are fabricated such that light reflected at one side of inner surface strikes the other at an angle larger than the critical angle. Even if the fibre is bent, light can easily travel along its length. Thus, an optical fibre can be used to act as an optical pipe. A bundle of optical fibres can be put to several uses. Optical fibres are extensively used for transmitting and receiving electrical signals, which are converted to light by suitable transducers. Obviously, optical fibres can also be used for transmission of optical signals. For example, these are used as a 'light pipe' to facilitate visual examination of internal organs like oesophagus, stomach and intestines.

A commonly available decorative lamp has fine plastic fibres with their free ends forming a fountain-like structure. The other end of the fibres is fixed over an electric lamp. When the lamp is switched on, the light travels from the bottom of each fibre and appears at the tip of its free end as a dot of light.

The fibres in such decorative lamps are optical fibres. The main requirement in fabricating optical fibres is that there should be very little absorption of light as it travels for long distances inside them. This has been achieved by purification and special preparation of materials such as quartz. In silica glass fibres, it is possible to transmit more than 95% of the light over a fibre length of 1 km. (Compare with what you expect for a block of ordinary window glass 1 km thick.)

Nowadays optical fibres are extensively used for transmitting audio and video signals through long distances like telephone and other transmitting cables.

Terms related to lens

Optical centre: It is the mid point in a lens and any light ray which passes through it doesn't deviate.

Focus: The point at which the light rays coming parallel to the principal axis meet or appear to meet after refraction is called focus.

Focal length: The distance between the optical centre and the focus is called focal length.

Image formation by convex lens: The nature of image formed, its size and position etc. depend on the distance of the object kept from the focus.

Note: 1. The focal length of a mirror does not depend upon the nature of the medium in which it is placed whereas the total length of a lens depends upon the medium in which it is placed. Thus, there will be no change in the focal length of the concave mirror whereas the focal length of the convex lens will change.

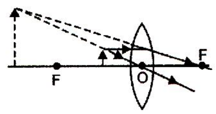
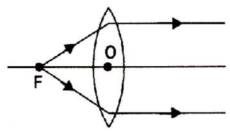
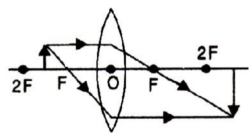
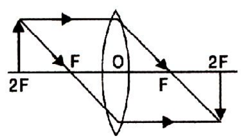
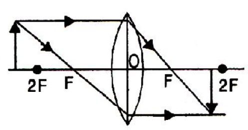
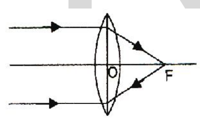
2. The type of lens (converging and diverging lens) changes, if it is placed in a medium having a higher refractive index than that of the material of the lens.

Refraction through a lens

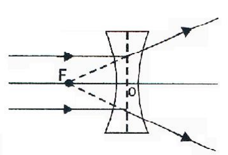
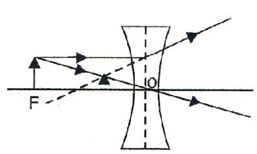
- **Lens** is a portion of a transparent refracting medium bounded by one or two spherical surfaces, i.e. convex lens (converging lens) and concave lens (diverging lens).
- The **power of a lens** is a measure of deviation produced by it in the path of rays refracted through it. Thus, power of a lens in **dioptre (D)** is the reciprocal of its focal length in metre.
- The power of a convex lens is taken as positive, i.e. a person suffering from **long-sightedness (hypermetropia)** uses lens of positive power in his/her spectacles.
- The power of a concave lens is taken as negative, i.e. a person using spectacles for **short-sightedness (myopia)** has negative power of spectacles.
- The **least distance of distinct vision** is the distance of the nearest point up to which the normal human eye can see distinctly without strain.
- The **power of accommodation** is the ability of the eye-lens to focus the objects at different distances by changing its focal length.
- **Persistence of vision** is the time up to which the impression of an image persists upon the retina (1/16 of a second) after the object has been removed.
- **Simple Microscope:** A simple microscope is based on the principle that a convex lens produces an erect, virtual and highly magnified image of the object when it is placed between the principal focus and the optical centre of the lens. It consists of a single converging or convex lens of short focal length.

Formation of images by a convex lens and a concave lens for different positions of the object

In case of convex lenses

S. No.	Position of object	Figure	Position of image	Nature of image	Uses
1.	Between the optical centre and the principal focus		On the same side as that of the object	Virtual, erect and magnified	Magnifying glass, eye-lenses, spectacles for long-sightedness or hypermetropia
2.	At the principal focus		At infinity	Real, inverted and extremely magnified	Spotlights
3.	Between F and 2F		Beyond 2F	Real, inverted and bigger than the object	Projector, microscope
4.	At 2F		At 2F	Real, inverted and equal to the size of the object	Photocopier
5.	Beyond 2F		Between F and 2F	Real, inverted and diminished	In a camera, in eye while reading
6.	At infinity		At the principal axis	Real, inverted and extremely small	Telescope, camera lens, burning glass

In case of concave lenses

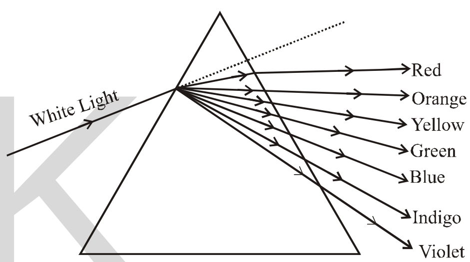
S. No.	Position of object	Figure	Position of image	Nature of image	Uses
1.	At infinity		Appears at the principal focus	Virtual, erect and extremely small	Spectacles for short-sightedness
2.	Between infinity and the optical centre		Appears between the principal focus and the lens	Virtual, erect and diminished	Spectacles for short-sightedness or myopia

Dispersion of light

The process of splitting of white light (polychromatic light) into its constituent colours is known as **dispersion**.

When different colours or wavelengths are present in the incident light, different colours are deviated to different extents in a medium other than air or vacuum. In vacuum, all colours move with the same speed and so appear white, but when they are made to pass through prisms or lenses, the violet colour, whose refractive index is the maximum, is deviated the most, and the red colour, whose refractive index is the least, is deviated to the least extent. The deviations of other colours lie between those of red and violet.

Dispersion of white light through a prism



Violet is deviated the most while red is deviated the least.

Visible Spectrum

A band of colours obtained on the screen when a polychromatic (white) light splits into its constituent colours is called a **spectrum**.

Wavelength is the main characteristic of colour. The light of a certain colour has a fixed wavelength. The portion of the spectrum ranging from 8000Å to 4000 Å is visible to human eye and is called the **visible spectrum**. In the visible spectrum, the wavelength of red colour is the maximum and that of violet the minimum. The frequency of red colour is the minimum and that of violet the maximum. In vacuum, all colours have the same speed, but the velocity of visible colours changes in different mediums. In glass, red colour has higher speed than violet.

Examples of Visible Spectrum

(i) *Rainbow*: The seven-coloured spectrum which is formed opposite the sun after rain.

(ii) *Colour of an object changes on heating*: The colour of iron ball is red at low temperature. When it is further heated its colour changes from red to orange to yellow. At very high temperature it glows with bluish white light, because its colours shift from red to violet side of the spectrum as temperature increases.

Invisible Spectrum

The portion of the spectrum which extends on either side of the visible spectrum is called the **invisible spectrum**. These do not produce any sensation of vision but their presence can be detected with suitable instruments. They are: (a) Infrared spectrum (b) Ultraviolet spectrum.

(a) **Infrared radiations** are long-wavelength radiations having wavelength 8000Å–400,000Å (where 1Å = 10^{-10} m).

They cause heating effect. They do not affect ordinary photographic films.

(b) **Ultraviolet radiations** have short wavelengths ranging from 4000Å–100Å. They strongly affect photographic plates. They produce fluorescence. Their penetration power is large.

Scattering of Light

The deflection of light by fine particles of solid, liquid or gaseous matter from the main direction of beam is called **scattering**. The scattering of light by the earth's atmosphere depends upon the wavelength of light and the size of the particles. For large-sized particles, reflection and refraction are more prominent. For particles whose size is much smaller than the wavelength of light, scattering is more pronounced. According to the **fourth-power law of Rayleigh**, the intensity of scattered radiation is inversely proportional to the fourth power of wavelength. This means that short wavelength will be scattered more $\left(I \propto \frac{1}{\lambda^4}\right)$. Very fine particles scatter blue light while particles of large size scatter red light more. The blue colour of the sky is due to the scattering by air molecules and the sun appears red is because of the removal of blue from the direct beam. Chalk dust particles are whitish because their size is quite large and reflection is more prominent. The scattered light appears to be white. It is for this reason that clouds are white.

Rainbow is an example of dispersion of light. The rainbow is formed due to dispersion of light by water drops hanging in the atmosphere after the rainfall. The sunrays are incident on the raindrops and get dispersed and are then totally reflected internally and transmitted to form a rainbow.

Colour of Objects

We see objects because of the light they reflect. Most of the objects around us reflect only a part of the light that is incident upon them and it is the reflected part which gives the objects their colour.

When a rose is viewed in white light, its petals appear red, and the leaves appear green, because the petals reflect the red part of the white light and the leaves reflect the green part. The remaining colours are absorbed. When the same rose is viewed in green light, the petals will appear black and the leaves green. In blue or yellow light, both the petals and the leaves will appear black.

This page appears white because it reflects all the colours and the print appears black because it absorbs all the colours.

Mixing Coloured Light: White light can be produced by a mixture of red, green and blue lights. In fact all colours can be produced by a suitable mixture of these three colours. Red, green and blue are therefore called **primary colours**. Others, such as yellow, are **secondary colours**.

Thus, Red + Green = Yellow
Red + Blue = Magenta
Green + Blue = Cyan

Also,
Green + Magenta = White
Red + Cyan = White
Blue + Yellow = White

Two colours which give white light when put together are called **complementary colours**. Blue and yellow are complementary colours.

By adding various amounts of red, green and blue, we can produce any colour in the spectrum. For this reason, they are called the **additive primary colours**. Yellow, magenta and cyan, which are obtained by mixing two additive primary colours, are called **subtractive primary colours**. The colours obtained by mixing two subtractive colours are:

Cyan (Peacock Blue) + Yellow = Green
Magenta + Yellow = Red
Cyan + Magenta = Blue

Interference of light

The superposition of two (or more) waves of the same kind that pass the same point in space at the same time is called **interference**.

At some points the intensity is maximum and the interference at these points is called **constructive interference**. At some other points the intensity is minimum (possibly even zero) and the interference at these points is called **destructive interference**.

Interference is the most fundamental characteristic of a wave and there is no loss of energy in it; there is only redistribution of energy from maxima to minima. The phenomenon of interference was firstly demonstrated by Thomas Young in his experiment called **Young's double slit experiment**.

Examples related to interference

(i) The kerosene oil spread on the water surface seems to be coloured due to interference of light.
(ii) The soap bubbles have a brilliant colour in sunlight due to interference of light.

Diffraction of light

Diffraction is a general characteristic exhibited by all types of waves, be it sound waves, light waves, water waves or matter waves. Since the wavelength of light is much smaller than the dimensions of most obstacles, we do not encounter diffraction effects of light in everyday observations. Indeed the colours that we see when a CD is viewed is due to diffraction effects.

When a beam of light passes through a narrow slit or an aperture, it spreads out to a certain extent into the region of geometrical shadow. This is an example of *diffraction,* i.e. of the failure of light to travel in a straight line. If one uses monochromatic light for diffraction, bright and dark bands are observed in the region of geometrical shadow. With white light, coloured bands are observed. Diffraction is a particular case of interference and is due to the wave nature of light.

A **diffraction grating** is a device used to disperse a beam of light for producing its spectrum. Gratings may be prepared by ruling equidistant parallel lines onto a glass (transmission grating) or metal surface (reflection grating).

Note: In interference and diffraction, light energy is redistributed. If it reduces in one region, producing a dark fringe, it increases in another region, producing a bright fringe. There is no gain or loss of energy, which is consistent with the principle of conservation of energy.

Polarisation

Polarisation is a feature of **transverse waves** only. Longitudinal waves can never be polarised. A wave is **plane-polarised** if all the vibrations in the wave are in a **single** plane, which contains the direction of propagation of the wave. Suppose we have a rope and make waves down it, we could make waves in any direction we liked. But if we made waves through a narrow vertical slit, we would find that the waves would only pass through if they were vertical. This would be a **vertically polarised wave**.

Light waves are easily polarised using **polaroid** filters. Light waves, like all electromagnetic waves, consist of an **electric field** component perpendicular to a **magnetic field** component, which are always in phase. We normally consider only the electric field component in polarisation, because the electrical effects are those that dominate.

A light wave that is vibrating in more than one plane is referred to as **unpolarised light**. Light emitted by the sun, by a lamp in the classroom, or by a candle flame is unpolarised light.

It is possible to transform unpolarised light into polarised light. **Polarised light waves** are light waves in which the vibrations occur in a single plane. There are a variety of methods of polarising light. For example,

1. Polarisation by Transmission
2. Polarisation by Reflection
3. Polarisation by Refraction
4. Polarisation by Scattering

Polaroid

Light waves are transverse in nature; i.e., the electric field associated with a propagating light wave is always at right angles to the direction of propagation of the wave. This can be easily demonstrated using a simple polaroid. You must have seen thin plastic-like sheets, which are called polaroids. A polaroid consists of long-chain molecules aligned in a particular direction. The electric vectors (associated with the propagating light wave) along the direction of the aligned molecules get absorbed.

Thus, if an unpolarised light wave is incident on such a polaroid then the light wave will get linearly polarised with the electric vector oscillating along a direction perpendicular to the aligned molecules.

Applications of Polarisation

- Polarisation has a wealth of other applications besides their use in glare-reducing sunglasses.
- In industry, polaroid filters are used to perform stress analysis tests on transparent plastics.
- Polarisation is also used in the entertainment industry to produce and show 3-D movies.
- Polaroids are used in headlights and windscreens of cars to cut off the dazzling light of a car approaching from the opposite side.

Coherence and incoherence

- Coherent radiation originates from a single oscillator, or a group of oscillators in perfect synchronisation (phase-locked), e.g., microwave ovens, radars, lasers, radio towers (i.e., artificial sources).
- Incoherent radiation originates from independent oscillators that are not phase-locked. Natural radiation is incoherent.

Light Amplification by Stimulated Emission of Radiation (LASER)

A laser is an optical device that produces an intense beam of coherent monochromatic light. A laser is not a source of energy. It is simply a converter of energy, taking advantage of stimulating emission to concentrate a certain fraction of energy (commonly 1%) into radiation of a single frequency, moving in a single direction.

1. Eye surgeons use lasers to 'weld' detached retinas back into place without making incision.
2. Laser beams have been used to measure the exact distance between the earth and the moon and to provide information on continental drift.
3. The detection and measuring of pollutants in vehicular exhaust gases is accomplished with lasers.
4. Communications can be carried in a laser beam directed through space, through atmosphere, or through optical fibres that can bend like cables.
5. A laser beam is used as a non-wearing 'optical' needle for video and phonograph records, as a knife to rapidly and accurately cut cloth in garment factories, as a tool for meat inspection, and for fingerprint detection.
6. Police use special guns emitting short bursts of infrared laser lights to measure the speed of vehicles. A laser speed gun measures the round-trip time for light to reach a vehicle and reflect back. If the gun takes a large number (say 1000) of readings per second, it can compare the change in distance between readings and calculate the speed of vehicles.

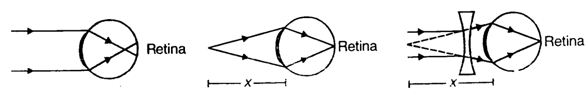
The Eye

Human eye consists of a **natural convex lens** which forms real, inverted and diminished image on the retina. **Ciliary muscles** can change the focal length of the human eye. For a grown-up person, the separation between the retina and the lens is about **2.5 cm**, which is the image distance.

A normal eye can see up to maximum distance of infinity and the minimum distance of clear vision is about **25 cm**. For seeing at maximum distance of infinity, eye muscles are fully relaxed having maximum focal length and for seeing at minimum distance, muscles are strained, having minimum focal length.

Some Common Defects

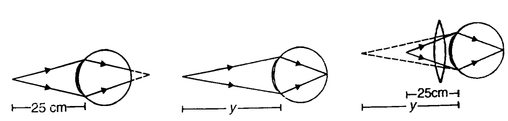
(A) Shortsightedness or Myopia: A person suffering from this defect cannot see a distant object but near objects are clearly seen. In this, f_{max} is less than the distance from the lens to the retina and hence the image of a distant object is formed short of retina (see figure a). For remedy, a **divergent lens** is given to a myopic person (see figure c). This lens forms the image of a distant object at a distance x, which is maximum distance of clear vision.



(a) (b) (c)

(B) Farsightedness or Hypermetropia: A person suffering from this defect cannot see a near object (see figure (a)). For remedy, a convergent lens is used (see figure (c)).

If y is the minimum distance up to which the eye can clearly see, the **converging lens** should form the image of an object at distance y = 25 cm.



(a) (b) (c)

(C) **Presbyopia:** In this defect, both far-off and nearer objects are not clearly seen. This is corrected by using **bi-focal lens**.

(D) **Astigmatism:** Such a person cannot see all directions equally well. This is corrected by using **cylindrical lenses**.

Optical Instruments

Microscope

It is an optical instrument used to see the small objects which cannot be seen with the naked eye.

Simple Microscope: It consists of a single convex lens of small focal length. Hence, a magnifying glass may be called a simple microscope. It forms the final image magnified and erect.

In general, for a microscope or for a telescope, remember that when the final image is formed at infinity (also called normal adjustment) our eyes are most relaxed and magnification is minimum. But if the final image is formed at the least distance of distinct vision (D = 25 cm), our eyes are most strained and magnification is maximum.

Magnifying Power: It is the ratio of the angle subtended by the image at the eye to the angle subtended by the object at the eye when both are placed at the least distance of distinct vision independently.

Compound Microscope: It consists of two convex lenses placed co-axially and the distance between them can be changed. The lens towards the object is called **objective (O)** and that near the eye is called **eyepiece (E)**. The objective has small focal length and small aperture. The eyepiece has large aperture and large focal length compared to the objective.

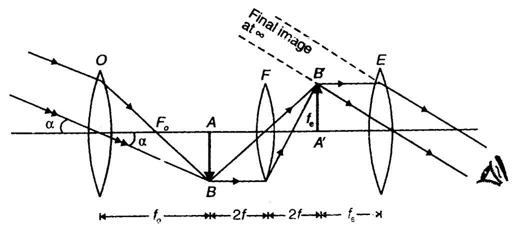
Telescope

Telescope is an optical instrument to observe a distant object clearly. Basically, they are of two types, refracting and reflecting.

Astronomical Telescope: It consists of two converging lenses placed co-axially. The objective has large aperture and large focal length. The eyepiece has smaller aperture and smaller focal length. The separator between the two lenses can be changed.

Magnifying Power (M): It is the ratio of the angle subtended by the image at the eye when it is at the least distance of distinct vision to the angle subtended by the object at the eye.

Terrestrial Telescope: It is used to see the objects on the earth. It forms the final image erect.



It consists of three converging lenses, namely, objective (O), eyepiece (E) and field lens (F). The focal plane of the objective is at a distance of 2*f* from the field lens so that $A'B' = AB$ (see fig above).

Galilean Telescope: It is a terrestrial telescope having very small field of view due to the concave lens used as an eyepiece.

Lens Camera: Basically, a camera consists of lightproof box with a lens system in front and photographic film at the back. The lens system, which converges light onto the film, consists of a number of lenses. The purpose of using more than one lens is to minimise defects or aberrations of the image. Objects at different distances are focused on the film by moving the lens system. Like the pupil in the eye, a camera also has an opening or aperture whose diameter can be varied by the camera iris. There is a shutter placed between the lens system and the film. When a photograph is taken, the shutter opens and closes rapidly. The time for which the shutter remains open can be adjusted.

Static Electricity

The word electricity comes from the Greek word *electron*, which means “amber”.

Amber is petrified tree resin currently used in jewellery and if amber rod is rubbed with a piece of cloth, it attracts small pieces of dry leaves or paper. This is known as **static electricity** or **amber effect**.

The branch of Physics that deals with the interaction between stationary charges is called **Electrostatics**.

Example: We may have felt a shock when we touched a metal door knob after sliding across a car seat.

Charge: Charge is the property associated with matter due to which it produces and experiences electrical and magnetic effects.

There are two types of electric charges termed as positive and negative charge.

Unlike charges attract while like charges repel each other.

Charge is conserved in nature. Charge is neither created nor destroyed; it is merely transferred from one body to other.

Charging by Friction, Conduction and Induction

- **Franklin** is the smallest unit of charge while **Faraday** is the largest.
- Friction causes one object to gain electrons from another object.
- Charging by conduction occurs when excess charges in one object are transferred through contact to another object.
- Charging by induction occurs when a charged object influences the charge distribution in another object.

Note: Benjamin Franklin was the first to assign positive and negative signs of charge.

- The existence of two types of charges was discovered by **Duafog**.

Modern concept or principle of electricity : According to this theory, when two bodies are rubbed, the electrons of the outermost orbit of the atoms of one body transfer to the atoms of another body, and thus, the first body has lesser number of electrons than the second body. Thereby, the first body becomes positively charged and the second body becomes negatively charged. This is the latest concept of electricity.

Electric Field: If an isolated charge is kept anywhere, the region or space around it, up to which if any other charged particle is brought, experiences a force. This region or space is called electric field.

The concept of potential difference

The positive charge flows from a body at a higher potential to a body at a lower potential and the negative charge flows from a body at a lower potential to a body at a higher potential.

The flow of charge continues until the potential between the two bodies becomes equal.

The **electric potential difference** between two conductors is defined as the amount of work done in moving a unit positive charge from one conductor to the other.

Mathematically, suppose the charge is q; then the electric potential difference between the two conductors is given by

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

Since work (W) is measured in joule and charge (q) in coulomb, the electric potential difference is measured in **joule per coulomb (JC^{-1})**. This unit occurs so often in our study of electricity that it has been named as **volt**, in honour of the scientist Alessandro Volta (the inventor of the Voltaic cell). Thus

$$1\,\text{volt} = \frac{1\ \text{joule}}{1\,\text{coulomb}}$$

Potential difference is a scalar quantity.

Current Electricity

Electric Current

Electric current is defined as the amount of charge per unit time that crosses the surface. Current is measured in ampere (A). Charge is measured in coulomb (C).

$$I = \frac{\text{charge}}{\text{time}}$$

1 ampere current flows when 1 coulomb of charge flows for 1 sec. or 6.25×10^{18} electrons flow in 1 second through a conductor.

$\therefore$ Q = n × e (number of electrons × charge present on 1 electron)

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

Current always flows from positive potential towards negative in the circuit.

Electromotive force (emf)

Electromotive force is the work done in establishing the flow of unit charge in the circuit. This requires an arrangement. Such an arrangement is called a source of emf.

Electric cell

The electric cell is an equipment which maintains a potential difference between any two points of the conducting wire so that the flow of electric current is continuously sustained. In electric cells, the chemical energy which is produced by various chemical reactions transforms into electrical energy. There are two metallic rods in every electric cell which are called **electrodes** and which have opposite nature. The metallic rod which is positively charged is called **anode** and the collected ions are called **anions**, while the metallic rod which is negatively charged is called **cathode**, and the collected ions are called **cations**. These metallic rods (electrodes) are kept inside the solvent called **electrolyte**.

Usually electric cells are of two types :

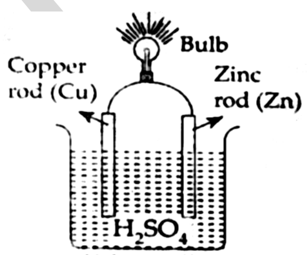
(i) Primary cell

(ii) Secondary cell

(i) Primary cell: In a primary cell, chemical energy is directly converted into electrical energy, and when all the chemical energy is exhausted (used up), the cell becomes dead. The Voltaic cell, Leclanche cell, Dry cell, Daniel's cell etc. are the examples of primary cell.

(ii) Secondary cell: In a secondary cell, first the electrical energy is converted into chemical energy. Then this chemical energy is converted into electrical energy. The entire process is completed by charging, and during its use, it is discharged, then it is again charged, and this is the process (way) of its functioning. That's why all the secondary cells are rechargeable. The process of recharging is done through an external source of electrical energy. **The battery or cell attached in motor vehicle, motor bike, emergency light etc. are the examples of secondary cell.**

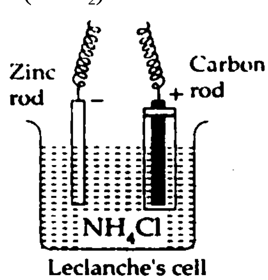
Voltaic cell: The Voltaic cell was invented by Professor **Alessandro Volta** in 1799. In this cell a zinc rod and a copper rod are kept inside the glass container of sulphuric acid (H_2SO_4).



Voltaic cell

In this cell the copper rod acts like an anode and the zinc rod acts like a cathode. The value of emf in this cell is **1.08 volt**.

Leclanche cell: In this cell a saturated solution of NH_4Cl is taken in a glass container, in which the zinc rod acts like a cathode and the carbon rod kept in a mixture of manganese dioxide (MnO_2) acts like an anode.



Leclanche's cell

The value of emf is **1.5 volt**. This type of cell is used where electric current is not regularly available. Such cells are mainly used in **electric alarm, siren, telephone etc.**

Dry cell: In this cell the electrolyte used is not in the form of solution but it remains in the dry form. In it there is a zinc container (vessel) in which manganese dioxide (MnO_2), ammonium chloride (NH_4Cl) and carbon are kept and in the middle of this mixture a carbon rod is kept. Here, the carbon rod acts like an anode while the zinc container acts like a cathode. The dense paste of ammonium chloride is kept inside the mixture of MnO_2 and carbon. The value of emf this cell is also 1.5 volt. Such cells are used frequently in **torch, transistor, radio etc.**

Electromotive force of cells

Cell	EMF
Voltaic cell	1.08 volt
Daniel's cell	1.08 volt
Dry cell	1.50 volt
Leclanche cell	1.50 volt
Lead container cell	2.00 volt
Battery of six cells	12.00 volt

Resistance

It is the obstruction to the flow of electrons. The more the resistance in the circuit, the less will be the current flowing through the circuit. Increase in resistance causes electrical energy to get converted into heat energy.

$$R \propto \text{length } (l)$$

$$R \propto \frac{1}{\text{area of cross-section (a)}}$$

$$\therefore R = \rho \frac{l}{a}$$

A long and thin wire offers more resistance than a short and thick wire. It is measured in ohm (Ω).

The resistance of a conductor is said to be one ohm if under a potential difference of one volt a current of one ampere flows through the conductor.

Materials chosen for making

(1) **Connecting wires:** Materials having a flow value of resistivity, e.g., copper, aluminium.

(2) **Resistance boxes:** Materials having a high value of resistivity but whose resistance does not increase with increase in temperature, e.g., constantan, manganin, German silver.

(3) **Resistors and filaments:** Materials having large value of resistivity, not pure metals but alloys, e.g., nichrome, manganin.

(4) **Fuse wire:** Material having low melting point and high resistivity, e.g., solder, an alloy of lead and tin.

In the electrical case, resistance (R) is defined as the ratio of the voltage V applied across a piece of material to the current I through the material, or R = V/I. When only a small current results from a large voltage, there is a high resistance to the moving charge. For many materials (e.g., metals), the ratio V/I is the same for a given piece of material over a wide range of voltages and currents. In such a case, the resistance is a constant and the relation R = V/I is referred to as **Ohm's law,** after the German physicist George Simon Ohm (1789-1854), who discovered it.

The above relation is an empirical formula which relates the current flowing through a conductor to the potential difference applied across it.

It states that "Physical conditions remaining the same, the electric current flowing through a conductor is directly proportional to the potential difference across the two ends of the conductor."

Mathematically

$$V \propto I \text{ or}$$
$$V = IR$$

where R is a "constant" and is called the resistance of the conductor.

The SI unit of resistance is volt per ampere, which is called **ohm** and is represented by the Greek capital letter omega (Ω).

Internal Resistance

The internal resistance of a cell is defined as the opposition of electrolyte to the flow of current through it. It is always in series in a circuit. If a number of cells are in series, then the internal resistances of all the cells are added according to series combination. But if a number of cells are connected in parallel then internal resistance is also calculated according to reciprocal law of parallel combination.

i.e., $\frac{1}{r_P} = \frac{1}{r_1} + \frac{1}{r_2} + \frac{1}{r_3} + \ldots$

The internal resistance of a secondary cell is always less than that of a primary cell.

Electric current, resistance and potential difference in series and in parallel circuits:

For a series combination of resistors

(i) The current is the same in every part of the series circuit.
(ii) The equivalent resistance is the sum of the individual resistances, including the internal resistance of the cell in the circuit.
(iii) Current in the circuit is independent of the relative positions of the resistors in series.
(iv) The equivalent resistance is greater than any individual resistance in the series combination.
(v) The potential drop across each resistor is proportional to its resistance.
(vi) In series combination of resistors, we have

$$R_S = R_1 + R_2 + R_3 + \ldots$$

In parallel combination of resistors

(i) Total current through the combination is the sum of the individual currents through the various branches.
(ii) The potential difference across all resistors is the same.
(iii) The current through each branch is inversely proportional to the resistance of that branch.
(iv) The reciprocal of the equivalent resistance equals the sum of the reciprocals of the individual resistances.
(v) If two resistors R_1 and R_2 are in parallel, then the current I_1 and I_2 in them will be distributed as:

$$I_1 = \frac{R_2 I}{R_1 + R_2} \quad \text{and} \quad I_2 = \frac{R_1 I}{R_1 R_2}$$

or

$$I_1 = \frac{V}{R_1} \quad \text{and} \quad I_2 = \frac{V}{R_2}$$

Where I is the total current in the circuit.

(vi) $\frac{1}{R_P} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \ldots$

About combination of resistors, we have:

(i) Using n conductors of equal resistances, the number of combinations one can have at a time is 2^{n-1}.
(ii) If resistances are different, then the number of combinations is 2^n.
(iii) For n equal resistances, $\frac{R_S}{R_P} = n^2$

Resistivity

- The resistivity of a material is the resistance of a conductor of this material of unit length and unit cross-sectional area.
- Resistivity is independent of the length and cross-sectional area of the conductor and depends upon the nature of the material and the temperature.
- The connecting wires are usually made of a material having a low value of resistivity, e.g., copper, aluminium.
- Resistors are made of wires having a large value of resistivity. Usually, they are made of alloys, e.g., nichrome, manganin and constantan.
- The resistance and resistivity of a conductor is directly proportional to its absolute temperature.
- With rise in temperature, the resistance and resistivity of
  (i) Conductors increase
  (ii) Alloys increase
  (iii) Semiconductors decrease
  (iv) Electrolytes decrease
- Resistance of certain alloys does not increase much or remains almost the same with rise in temperature, e.g.,

manganin, constantan, German sub silver etc. That's why they are used for making resistance boxes.

Factors affecting the resistance of a conductor

The electrical resistance of a conductor depends upon the following factors:

- **Effect of length of conductor:** On increasing the length of a wire, its resistance increases, and on decreasing the length of a wire, the resistance will reduce. Actually, the resistance of a wire is directly proportional to its length.
- **Effect of area of cross-section of conductor:** It has been found that the resistance of a conductor is inversely proportional to the area of the cross-section of the conductor which is used in the circuit.
- **Effect of nature of material of conductor:** The electrical resistance of a conductor depends on the nature of the material of which it is made.
- **Effect of temperature:** The resistance of conductors of pure metals increases on increasing the temperature and decreases on decreasing the temperature.

Domestic electric circuits series or parallel: When designing an electric circuit, we should consider whether a series or parallel circuit is better for the intended use. For example, if we want to connect a large number of electric bulbs for decorating buildings and trees as during festivals such as Diwali or marriage functions, then the series circuit is better because all bulbs connected in series can be controlled with just one switch. A series circuit is also safer because the flow of current in it smaller. But there is a problem with this circuit. This is because if one bulb gets fused, then the circuit breaks and all the bulbs are turned off. An electrician has to spend a lot of time in locating the fused bulb form among hundreds of bulbs, so as to replace it and restore the lighting.

The parallel electric circuit is better for connecting bulbs in house because then we can have separate switches for each bulb and hence operate it separately. In addition to having ease of operation, parallel domestic circuits have many other advantages over the series circuits.

Electric power: We know that the rate of doing work is known as power. So electric power is the electrical work done per unit. That is

Power = Work done/time taken

Or $P = W/t$

Unit of power: The SI unit of electric power is **watt**, denoted by the letter W. The power of 1 watt is the rate of working of 1 joule per second. That is

1 Watt = 1 joule/1 second

Heating effect of current: When an electric current is passed through a high-resistance wire like nichrome wire, the resistance wire becomes hot and produces heat. This is known as the heating effect of current. The role of resistances in circuits is the same as that of friction in machines.

Since a conductor, say a resistance wire, offers resistance to the flow of the current, work must be done by a current continuously to keep itself flowing. We will calculate the work done by a current I when it is passing through a resistance R for time *t*. Now when an electric charge Q moves against a potential difference V, the amount of work done is given by

$$W = Q \times V$$

From the definition of current, we have

$$I = Q/t \text{ or } Q = I\,t$$

And from Ohm's law, we have $V/I = R$

or potential difference , $V = I \times R$

Now putting $Q = I \times t$ and $V = I \times R$,

we have $W = I^2 \times R \times t$

or Heat produced, $H = I^2 \times R \times t$ joules

It is clear that the heat produced in a wire is directly proportional to

- Square of current
- Resistance of wire
- Time for which current is passed

Applications of the heating effect of current

The important applications of the heating effect of electric current are the following:

- The heating effect of current is utilised in the working of electrical heating appliances such as electric iron, kettle, toaster, oven, room heater and water geyser.
- The heating effect of current is utilised in electric bulb for producing light.
- The heating effect of current is utilised in electric fuse for protecting household wiring and appliances.

Electrical Instruments

1. **Electric Bulb:** It is based on the principle that when a current is passed through the resistor filament, it gets very hot and emits light. To retain such a high temperature, the filament must be made of a metal of high remelting point. Generally, a filament is made of a thin wire of tungsten enclosed in a glass bulb containing some inert gases like nitrogen and argon. Tungsten has a high melting point of nearly 3380 °C. The inert gases prolong the life of the filament. Due to high resistance of the filament, a large amount of heat is produced which raises the temperature and hence it begins to emit light at high temperature much below its melting point. For every watt of electrical power consumed, the luminous intensity of bulb is nearly 1 **candela**.
2. **Electric Fuse:** It is a protective device which prevents excessive current. It is always connected in series with an electric circuit or an electric appliance. It consists of a piece of wire generally made of lead-tin alloy having very low melting point and high resistance. If a current

larger than the specified value flows, the fuse wire melts and breaks the circuit and hence the electric appliance is saved from damage. The melting point and the resistance of fuse wires are different for different electric appliances.

When an electric heater of 2kW is operated at 220V, a current of $\frac{2000}{220}\text{A} = 9.1\text{A}$ will be obtained in the circuit. So, a fuse wire of 10A should be used.

3. **Tube light:** Basically it is a long tube of glass and the inside wall of the tube is coated with a thin layer of fluorescent material. The tube glass has mercury along with some inert gas like argon inside it. The two ends of the tube have two terminals on which a thin layer of barium oxide is coated. Whenever these two terminals of the tube are activated to pass an electric current, the electrons are emitted, which are directly respondent to ionise the gas present inside the tube. Consequently, through ionisation of the gas, ions generate a flow of current inside the tube. The mercury confined inside the tube gets sufficient thermal energy and it (mercury) starts to vaporise and finally, due to the electron emission, UV rays are emitted. When these UV rays are incident on the inside wall of the tube on which fluorescent material is coated, they are absorbed by the wall and visible rays, or light of lower frequency, seem to appear.

   The fluorescent material coated is used in such a way that light produced from the tube light appears similar to a white visible sunlight. In the tube light internal energy is produced in smaller amount, so 60% to 70% electrical energy transforms into light energy. That's why the power of tube light is sharper than that of an ordinary bulb. A 40-watt tube light provides 6 to 8 times more light than an ordinary bulb of 40 watts.

Measurement of Voltage, Current and Resistance

Galvanometer: It is a very sensitive instrument to detect very small current, as small as 10^{-3} μA. The deflection in the instrument is directly proportional to the current passing through it.

Ammeter: It measures current and hence is always connected in series to the element through which the current has to be measured so that the total current of the element goes into the ammeter. Ideally the resistance of an ammeter will be zero so that it doesn't introduce any resistance into the main circuit and the main circuit is not affected. (An ideal ammeter has been impossible so far.) In practice, the resistance of an ammeter is approximately 1 Ω, so the current measured is always slightly less than what is flowing into the main circuit.

Voltmeter: It's a device to measure potential difference across a circuit element and hence is always connected in parallel to that element. Ideally the resistance of a voltmeter is infinite so that it doesn't draw any main-circuit current and the potential difference across the circuit element remains to its true value. (The ideal voltmeter has alternatively been realised in practice in the form of potentiometer.)

Types of current

There are two types of electric current: Direct Current (DC) and Alternating Current (AC).

a) If the magnitude and direction of current does not vary with time, it is known as **direct current (DC)**.
b) If a current is periodic, i.e. its magnitude varies periodically and its polarity reverses after each half cycle, it is known as **alternating current (AC)**.

Alternating current

An alternating current is the one which has the following characteristics:

- Its magnitude is not constant but is constantly varying.
- Its direction also reverses after every half a cycle.
- In one cycle of A.C. the current rises from zero to maximum and then decreases to zero and again rises to maximum in the opposite direction before again becoming zero.
- The frequency of an A.C. is the number of cycles of the A.C. produced in one second. In our houses, we use 50 cycles of A.C. in 1 second.
- Alternating current and alternating emf are those whose magnitude and direction vary periodically with time.
- The simplest types of alternating current and alternating emf have a sinusoidal variation, given respectively by $i = i_0 \sin\omega t$ and $\varepsilon = \varepsilon_0 \sin\omega t$
  where i_0 and ε_0 are called peak values of current and voltage respectively and ω is the angular frequency.
- The time taken by an alternating current to go through one cycle of change is called its **period (T)** and $\mathbf{T = 2\pi/\omega}$.
- The number of cycles per second of an alternating current is called its **frequency**, $n = 1/T = \omega/2\pi$.
- The phase of an alternating current at any instant represents the fraction of the time period that has elapsed since the current last passed through the zero position of reference. Phase can also be expressed in terms of angle in radians.
- An alternating current or emf varies periodically from a maximum in one direction through zero to a maximum in the opposite direction, and so on. The maximum value of the current or emf in either direction is called the **peak value**.

Comparison between AC and DC

(a) The generation of AC is more economical than that of DC.
(b) AC voltages can be easily stepped up or stepped down using transformers.
(c) AC can be transmitted to longer distances with less loss of energy.
(d) AC can be easily converted into DC by using rectifiers.
(e) The phenomenon of electrolysis cannot be performed through an AC, so for the extraction of metals in metallurgy and other works in the industrial workshops, only DC, and not AC, can be used.
(f) In electroplating, AC is not used; it can be done by using DC only.
(g) Unlike DC, AC cannot be stored in an accumulator cell.
(h) Electromagnets can only be prepared through DC.

In India, the AC changes direction after every 1/100 second, that is, the frequency of AC is 50 Hz.

Disadvantages of AC

(a) AC is more fatal and dangerous than DC.
(b) AC always flows on the outer layer of the conductor (skin effect) and hence requires stranded wires.
(c) AC cannot be used in electrolysis, e.g. electroplating etc.

Closed and Open Circuits

Open circuit: A circuit is said to be open if no current passes through the circuit. The resistance of such a circuit is infinite. This happens if the key is not plugged.

Closed circuit: A circuit is said to be closed if current passes through the circuit. The resistance of such a circuit is finite. This happens if the key is plugged.

Domestic Electric Circuits

In our homes, we receive supply of electric power through a **main supply** (also called **mains**), either supported through overhead electric poles or by underground cables. One of the wires in this supply, usually with red insulation cover, is called **live wire** (or **positive**). Another wire, with black insulation, is called **neutral wire** (or **negative**). In our country, the potential difference between the two is **220 V**.

At the metre-board in the house, these wires pass into an electricity meter through a main fuse. Through the main switch they are connected to the line wires in the house. These wires supply electricity to separate circuits within the house. Often, two separate circuits are used, one of **15 A** current rating for appliances with higher power ratings such as geysers, air coolers, etc. The other circuit is of **5 A** current rating for bulbs, fans, etc. The earth wire, which has insulation of green colour, is usually connected to a metal plate deep in the earth near the house. This is used as a safety measure, especially for those appliances that have a metallic body, for example, electric press, toaster, table fan, refrigerator, etc. The metallic body is connected to the earth wire, which provides a low-resistance conducting path for the current. Thus, it ensures that any leakage of current to the metallic body of the appliance keeps its potential to that of the earth, and the user may not get a severe electric shock.

In each separate circuit, different appliances can be connected across the live and neutral wires. Each appliance has a separate switch to 'ON'/'OFF' the flow of current through it. In order that each appliance has equal potential difference, they are connected parallel to each other. Electric fuse is an important component of all domestic circuits.

A fuse in a circuit prevents damage to the appliances and the circuit due to overloading. Overloading can occur when the live wire and the neutral wire come into direct contact. (This occurs when the insulation of wires is damaged or there is a fault in the appliance.) In such a situation, the current in the circuit abruptly increases. This is called **short-circuiting**. The use of an electric fuse prevents the electric circuit and the appliance from a possible damage by stopping the flow of unduly high electric current. The Joule heating that takes place in the fuse melts it to break the electric circuit.

Overloading can also occur due to an accidental hike in the supply voltage. Sometimes overloading is caused by connecting too many appliances to a single socket.

Based up on electrical properties, crystalline solids are classified as (i) conductors, (ii) semi-conductors and (iii) insulators.

Insulators and Conductors

1. **Conductors:** These are the substances which easily allow the passage of electricity through them. These materials have a large number of free electrons (-10^{28} m^{-3}) and very small resistivity ($-10^{-8}\ \Omega$ m).
   The resistivity of an ideal conductor is zero and it increases with the rise in temperature in metals (copper, aluminium, silver, gold etc) and decreases in non-metals (graphite). In case of alloys of metals such as nichrome, manganin or constantan, resistivity is more than that of metals but varies slowly with temperature.
2. **Insulators:** These are the substances which have practically no free electrons and have very high resistivity ($-10^{16}\ \Omega$m). The resistivity of an ideal insulator is infinity and decreases with the rise in temperature. Mica, rubber, glass and porcelain are some examples of insulators.

Semiconductor

A semiconductor is a material that has a resistivity value in between that of a conductor and an insulator.

The conductivity of a semiconductor material can be varied under an external electric field. Devices made from semiconductor materials are the foundation of modern electronics, including radio, computer, telephone, and many other devices. Semiconductor devices include transistor, many kinds of diodes including the light-emitting diode, silicon-controlled rectifier, and digital and analog integrated circuits. Solar photovoltaic panels are large semiconductor devices that directly convert light energy into electrical energy.

In a metallic conductor, current is carried by the flow of electrons. In semiconductors, current can be carried either by the flow of electrons or by the flow of positively charged holes in the electron structure of the material. **Silicon** is used to create most semiconductors commercially. So many other materials are used, including germanium and gallium arsenide. In semiconductor production, **doping** intentionally introduces impurities into an extremely pure (intrinsic) semiconductor for the purpose of modulating its electrical properties. The impurities are dependent upon the type of semiconductor.

Intrinsic semiconductors are those in which impurities are not present and are therefore called pure semiconductors.

Extrinsic semiconductors are those in which impurities are present in large quantities.

Based on the impurities present in the extrinsic semiconductors, they are classified into two categories:

1. n-type semiconductors and
2. p-type semiconductors

n-type semiconductors

When a pentavalent substance (Group V elements) like Phosphorus, Arsenic or Antimony is added in sufficient quantities to the pure form of Si or Ge crystal, it is said to be **n-type**.

- In n-type semiconductor, electrons are majority carriers and holes are minority carriers ($n_e > n_h$).

p-type semiconductors

When a trivalent substance (Group III elements) like Boron, Aluminium, Gallium or Indium is added in sufficient quantities (1 in 10 or less) to the pure form of Si or Ge crystal, it is said to be **p-type**.

- In p-type semiconductor, holes are majority carriers and electrons are minority carriers ($n_h > n_e$).

p-n junction: When a semiconducting material such as silicon or germanium is doped with impurity in such a way that one side has a large number of acceptor impurities and the other side has a large number of donor impurities, the resulting semiconductor is called **p-n junction**.

Forward biased: In a p-n junction diode, if p-region is connected to +ve terminal (relatively higher potential) of the battery and n-region is connected to –ve terminal (relatively lower potential) of the battery then it is said to be **forward biased**.

Reverse biased: In a p-n junction diode, if p-region is connected to –ve terminal (relatively low potential) of the battery and n-region is connected to the +ve terminal (relatively high potential) of the battery then it is said to be **reverse biased**.

Semiconductor devices

Semiconductor devices are electronic components that exploit the electronic properties of semiconductor materials, principally silicon, germanium, and gallium arsenide, as well as organic semiconductors. Semiconductor devices have replaced thermionic devices (vacuum tubes) in most applications.

Semiconductor devices are small in size, consume low power, operate at low voltages and have long life and high reliability.

The Cathode Ray Tube (CRT) used in television and computer monitor that works on the principle of vaccum tube is being replaced by LCD (Liquid Crystal Display) monitors with supporting solid-state electronics.

The best examples of the semiconductor devices are: Diode and Transistor.

Diode

Diodes are made from a single piece of semiconductor material which has a positive P-region at one end and a negative N-region at the other, and has a resistivity somewhere between that of a conductor and an insulator.

Application of Diode as a device

- PN diode as a rectifier
- Zener diode as a voltage regulator
- Photodiodes used for detecting optical signals (photo detectors)
- Light emitting diodes (LED) which convert electrical energy into light
- Photovoltaic devices which convert optical radiation into electricity (solar cells)
- Laser Diode
- GUNN Diode as a sensor and measuring instrument

Light Emitting Diodes: Light emitting diodes or LEDs are among the most widely used of all the types of diodes available. They are the most visible type of diode that emits a fairly narrow bandwidth of visible coloured light, invisible infrared or laser type light when a forward current is passed through them. A light emitting diode or LED, as it is more commonly called, is basically just a specialized type of P-N junction diode made from a very thin layer of fairly heavily doped semiconductor material.

Unlike normal diodes, which are made for direction or power rectification and which are generally made either from Germanium or Silicon semiconductor material, light-emitting diodes are made from compound-type semiconductor materials such as Gallium Arsenide (GaAs), Gallium Phosphide (GaP), Gallium Arsenide Phosphide (GaAsP), Silicon Carbide

(SiC) or Gallium Indium Nitride (GaInN).

LEDs have the following advantages over conventional incandescent low-power lamps:

(i) Low operational voltage and less power
(ii) Fast action and no warm-up time required
(iii) The bandwidth of emitted light is 100 Å to 500 Å or in other words it is nearly (but not exactly) monochromatic.
(iv) Long life and ruggedness
(v) Fast on-off switching capability

Liquid Crystal Display

An LCD or Liquid Crystal Display is a flat, thin display device consisting of any number of pixels aligned in front of a reflector or source of light. The LCD has been widely hailed as a prized invention as it is relatively cheap and it consumes less power to function than competing technologies, making it almost indispensable in battery-powered electron devices.

Types of LCD

LCDs are broadly classified as either transmissive or reflective, depending upon the position of their source of light. A **transmissive LCD** is illuminated by a light source from the base and is viewed from the front.

Such LCDs are used in applications where high luminal levels are required, such as computer displays, personal digital assistance televisions, and mobile phones.

On the other hand, **reflective LCDs**, usually found in digital displays of watches and calculators, are illuminated by an external light, which in turn is reflected back by a diffusing reflector located behind the display. As the light has to pass twice through the liquid crystal layer, it is attenuated twice and hence reflective LCDs produce darker blacks than their transmissive counterparts. But, since the same attenuating phenomenon, to an extent, happens in the translucent part of the liquid crystal layer as well, the contrast of the display image will be less than a transmissive LCD.

In terms of power consumption, reflective LCDs, due to the absence of an artificial light source, are more power-efficient than their transmissive counterparts.

There are now LCDs, which combine the basic features of both transmissive and reflective LCDs. They are called transflective LCDs and they operate transmissively or reflectively depending upon the ambient light conditions.

Transistor

A transistor is formed by sandwiching a thin layer of a p-type semiconductor between two layers of n-type semiconductors or by sandwiching a thin layer of an n-type semiconductor between two layers of p-type semiconductors.

Transistor means "transfer of resistance" and is invented by John Bardeen, WH Brattain and William Shockley in 1948. Transistors are of two types:

i) n-p-n; ii) p-n-p

A transistor mainly consists of three sections:

i) emitter, ii) base, iii) collector.

A transistor has three doped regions forming two p-n junctions between them. There are two types of transistors:

(i) **n-p-n transistor:** Here two segments of n-type semiconductor (emitter and collector) are separated by a segment of p-type semiconductor (base).

(ii) **p-n-p transistor:** Here two segments of p-type semiconductor (termed as emitter and collector) are separated by a segment of n-type semiconductor (termed as base).

Uses:

1. Transistor acts as an amplifier.
   An electronic device which can raise the magnitude of current or of voltage input signals is called as amplifier.
2. Transistors are used in electronic circuits called 'oscillators'.
3. Transistors are also used in stabilized power supplies.
4. Transistors form important components of micro electronic systems called ICs (Integrated Circuits) or 'Chips'.

Magnetism

Magnetic phenomena are universal in nature. Vast, distant galaxies, tiny invisible atoms, men and beasts all are permeated through and through with a host of magnetic fields from a variety of sources. The earth's magnetism pre-dates human evolution. The word *magnet* is derived from the name of an island in Greece called Magnesia, where magnetic-ore deposits were found as early as 600 BC.

The directional property of magnets was known since ancient times. A thin long piece of a magnet, when suspended freely, pointed in the north-south direction. The name *lodestone* (or *loadstone*) is given to a naturally occurring ore of iron **magnetite**. The technological exploitation of this property is generally credited to the Chinese texts dating 400 BC that mention the use of magnetic needles for navigation on ships.

Magnet

A substance which attracts substances like iron, nickel, cobalt, etc. is called a **magnet**.

Properties

- When a magnet is freely suspended or pivoted, it comes to rest, showing north and south directions.
- Like poles repel and unlike poles attract each other .
- A magnet attracts substances like iron, nickel, cobalt and steel.
- A magnet imparts its properties to other magnetic substances.

Magnets are of two types. They are:

(i) Natural magnets

(ii) Artificial magnets

Natural magnets

- Magnets which are available in nature are called **natural magnets**.
- Magnetite is a natural magnet.
- It is also called lodestone.
- It is the magnetic oxide of iron.
- Its formula is $\mathbf{Fe_3O_4}$.

Natural magnets have no regular shape. They have less magnetic power.

Artificial magnets

Magnets which are made by artificial methods are called **artificial magnets**; e.g. bar magnets, cylindrical magnets, horseshoe magnets, Robinson magnets, pot-shaped magnets, etc.

- Artificial magnets have regular shape. Their magnetic power is more.
- Horseshoe magnets are used in cycle dynamos.
- Pot-shaped magnets are used in loud speakers.
- Magnets are also used in magneto-therapy to cure some diseases.

Bar magnet

- The two poles of the magnet are generally of equal strength and lie just below the ends.
- The straight line joining the two poles of a magnet is called **axial line**.
- The line passing through the midpoint and normal to the axial line is called **equatorial line**.
- The straight line joining the poles of the magnet is known as **magnetic length**.
- Magnetic length is about 5/6 times or 83.3% of the geometric length.

Magnetic lines of force: A line of force in a magnetic field is the path or curve along which a free unit North Pole travels.

Magnetic Field and Magnetic Field Lines

Magnetic field: The region or space around a magnet through which any other magnetic material experiences a force of attraction or repulsion is called magnetic field.

Characteristics of magnetic lines of force

- Magnetic lines of force start from North Pole and ends on the South Pole outside the magnet.
- Inside the magnet, magnetic lines of force run from South Pole to North Pole.
- They are closed loops.
- No two magnetic lines of force intersect each other.
- They have a tendency to repel each other laterally (they have lateral elongation).
- They contract longitudinally.
- The tangent drawn to the magnetic line of force at any point gives the direction of magnetic field at that point.
- In a uniform magnetic field, lines of force will be straight and parallel lines.
- The number of lines of force at a region represents the intensity of magnetic field at that region, i.e., if the field is strong, the lines of force are crowded, whereas in weak fields they are spaced apart.

Magnetic flux: The number of lines of force passing through any area in a magnetic field is known as magnetic flux.

Magnetic field induction

- The number of magnetic lines of induction passing through unit area normal to the surface is called **magnetic flux density** or **magnetic field induction (B)**.
- The unit of B is **tesla (T)**.

Magnetic susceptibility

- The ratio of magnitude of intensity of magnetization (I) in a material to that of magnetizing field (H) is called magnetic susceptibility of that material.

$$\chi = \frac{I}{H}$$

- The intensity of magnetization inducted in a material by unit magnetizing field is known as magnetic susceptibility.
- χ has no units and no dimensions.

Note: The intensity of the magnetic field or magnetising field strength (H): 'H' is an auxiliary field which is measured as the ratio of magnetic induction to the permeability of the medium at the given point.

Absolute magnetic permeability (m)

- The ratio of magnitude of magnetic induction to magnetising field is defined as magnetic permeability.

$$\mu = \frac{B}{H}$$

- Magnetic permeability of a medium is the extent to which magnetic lines of force can enter a medium. It is the characteristic property of the magnetic material.
- Magnetic permeability represents the amplification of magnetising field in that material.
- μ is always positive and is different for different materials.
- The value of μ depends on magnetising field.

The Earth's Magnetism

Our earth behaves as if it were a powerful magnet. Within it the south pole is towards the earth's north pole and the north pole is towards the earth's south pole. It is supported by the following facts:

(i) A freely suspended magnetic needle stays in north-south direction. If a magnetic needle is suspended so that it is free to move in the horizontal plane, then its north pole rests pointing north and the south pole pointing south.

(ii) On drawing the lines of force of a magnet, we get neutral points, where the magnetic field due to the magnet is exactly neutralised by the earth's magnetic field. Had there been no earth's magnetic field, neutral points would not have been available.

(iii) An iron piece buried in earth becomes a magnet. If we bury an iron rod in the earth in the direction in which a freely-suspended magnetic needle stays, then after some time the rod becomes a magnet.

Magnetism in medicine

An electric current always produces a magnetic field. Even weak ion currents that travel along the nerve cells in our body produce magnetic fields. When we touch something, our nerves carry an electric impulse to the muscles we need to use. This impulse produces a temporary magnetic field. These fields are very weak and are about one-billionth of the earth's magnetic field. **Two main organs in the human body where the magnetic field produced is significant, are the heart and the brain**. The magnetic field inside the body forms the basis of obtaining the images of different body parts. This is done using a technique called **Magnetic Resonance Imaging (MRI)**. The analysis of these images helps in medical diagnosis. Magnetism has, thus, got important uses in medicine.

Magnetic Classification of Substances

On the basis of magnetic behaviour of different materials, they are divided into categories:

(1) diamagnetic substances,
(2) paramagnetic substances and
(3) ferromagnetic substances

Diamagnetic Substance

Diamagnetic substances are those which have tendency to move from stronger to the weaker part of the external magnetic field. In other words, unlike the way a magnet attracts metals like iron, it would repel a diamagnetic substance.

Some diamagnetic materials are bismuth, copper, lead, silicon, gold, zinc, air, hydrogen, nitrogen (at STP), water and sodium chloride. Diamagnetism is present in all the substances. However, the effect is so weak in most cases that it gets shifted by other effects like paramagnetism, ferromagnetism, etc.

The most exotic diamagnetic materials are *superconductors*. These are metals cooled to very low temperatures which exhibit both *perfect conductivity* and *perfect diamagnetism*. Superconducting magnets can be gainfully exploited in a variety of situations, for example, for running magnetically levitated superfast trains.

Note: Diamagnetism is universal. It is present in all materials. But it is weak and hard to detect if the substance is para- or ferromagnetic.

Paramagnetic Substance

Paramagnetic substances are those which get weakly magnetised when placed in an external magnetic field. They have tendency to move from a region of weak magnetic field to strong magnetic field, i.e., they get weakly attracted to a magnet. The individual atoms (or ions or molecules) of a paramagnetic material possess a permanent magnetic dipole moment of their own.

Some paramagnetic materials are aluminium, sodium, calcium, oxygen (at STP) and copper chloride. Experimentally, one finds that the magnetisation of a paramagnetic material is inversely proportional to the absolute temperature T.

Ferromagnetic Substance

Ferromagnetic substances are those which get strongly magnetised when placed in an external magnetic field. They have a strong tendency to move from a region of weak magnetic field to strong magnetic field, i.e., they get strongly attracted to a magnet. The individual atoms (or ions or molecules) in a ferromagnetic material possess a dipole moment as in a paramagnetic material. However, they interact with one another in such a way that they spontaneously align themselves in a common direction over a macroscopic volume called **domain**.

Alnico, an alloy of iron, aluminium, nickel, cobalt and copper, is one such material There are a number of elements, which are ferromagnetic: iron, cobalt, nickel, gadolinium, etc.

The ferromagnetic property depends on temperature. At high enough temperature, a ferromagnet becomes a paramagnet.

The temperature of transition from ferromagnetism to paramagnetism is called the **Curie temperature (T_C).**

Electromagnetism

1. The phenomenon of production of a magnetic field around a current-carrying conductor is called **magnetic effect of currents**. The direction of magnetic field is found by **Snow rule** or **Ampere's swimming rule**.
2. When the current flows through a straight conductor, the conductor behaves like a magnet.
3. If the direction of current flowing through coil is anti-clockwise, then north polarity is created, and vice versa.

Solenoid

A coil of many circular turns of insulted copper wire wrapped closely in the shape of a cylinder is called a **solenoid**.

The intensity of the magnetic field of a solenoid can be increased

(i) by increasing the number of turns on the solenoid,

(ii) by increasing the strength of current flowing through the solenoid, and

(iii) by placing soft iron core along the axis of the solenoid.

Electromagnet: A coil wound over a soft iron piece is usually called an electromagnet. The advantage of such a magnet is that when the current is switched off, the soft iron core loses most of its magnetism.

Electromagnets are used in electrical applicances such as **electric bell, electric fan,** etc. They are used for magnetic separation and for lifting heavy iron loads. A permanent magnet is made from steel. Once magnetised, it cannot lose its magnetism easily.

Electric motor: An electric motor is a device which converts **electrical energy into mechanical energy.** It is based on the principle that when a current-carrying conductor capable of moving freely is placed in a magnetic field, it experiences a force and begins to move in a direction given by Fleming's left hand rule.

It does not work on the principle of electromagnetic induction.

Electric motor is used as an important component in electric fans, refrigerators, mixers, washing machines, computers, MP3 players, etc.

The speed of rotation of an electric motor can be increased by (i) increasing the number of turns in the coil, (ii) increasing the area of cross-section of the coil, (iii) increasing the current flowing into the coil, (iv) increasing the strength of the radial magnetic field and (v) using soft iron core.

Electromagnetic induction

- The phenomenon of electromagnetic induction is the production of induced current in a coil placed in a region where the magnetic field changes with time. The magnetic field may change due to a relative motion between the coil and a magnet placed near to the coil. If the coil is placed near a current-carrying conductor, the magnetic field may change either due to a change in the current through the conductor or due to the relative motion between the coil and the conductor. The direction of the induced current is given by **Fleming's right-hand rule**.
- In the phenomenon of electromagnetic induction, mechanical and magnetic energy are converted into electrical energy.

Faraday's laws of electromagnetic induction are:

(i) Whenever there is a change in magnetic flux within a conductor, an induced emf is set up in it which gives rise to induced current. The direction of induced current is always opposite to the cause which produces it. (**Lenz's law**)

(ii) The magnitude of the emf induced is directly proportional to the rate of change of magnetic field, the number of turns in the coil and the area of cross-section of the coil.

The direction of induced emf is given by Fleming's right hand rule. **Fleming's right hand rule** states that if the thumb, the middle finger and the forefinger of the right hand are stretched mutually perpendicular to each other and if the forefinger indicates the direction of the magnetic field and the thumb indicates the direction of motion of conductor then the middle finger will indicate the direction of induced current.

Transformer: A transformer is a device used to change the AC voltage. It converts a low voltage at a high current to a high voltage at a low current, and vice versa.

A transformer is of two types:

(i) Step-up and (ii) Step-down

A step-up transformer increases the emf whereas the step-down transformer decreases the emf. **Transformer works on the principle of mutual induction,** i.e., whenever the magnetic flux linked with a coil changes, an induced emf is produced in the neighbouring coil.

The energy loss in a transformer takes place in the following ways:

(i) Increasing the current through it

(ii) Heating in the coils

(iii) Eddy currents in the core

(iv) Hysteresis loss in the core

Eddy currents are induced circular currents in the soft iron core itself, tending to oppose the change in the magnetic flux through it. Eddy currents produce a heating effect and lower the efficiency of the transformer.

The ratio of the turns $\frac{N_S}{N_P}$ is called the transformation ratio where N_S is the number of turns on output or secondary winding and N_P is the number of turns on the input or primary winding. For a step-up transformer, $\frac{N_S}{N_P} > 1$ and for a step-down transformer, $\frac{N_S}{N_P} < 1$.

In a step-up transformer, the primary coil consists of smaller number of turns of thin wire. In a step-down transformer, the primary coil consists of a large number of turns of thin wire and the secondary coil consists of a smaller number of turns of thick wire.

Transformer is used in a) power station, b) television, c) telephone, d) telegraph and e) radio.

Electric generator

Based on the phenomenon of electromagnetic induction, the experiments studied above generate induced current, which is usually very small. This principle is also employed to produce large currents for use in homes and industry. In an electric generator, mechanical energy is used to rotate a conductor in a magnetic field to produce electricity.

A generator of dynamo is a device which converts mechanical energy into electrical energy. It is based on the principle of electromagnetic induction.

Modern Physics

Emission of electrons

There are four types of emission of electrons:

(i) Thermionic emission
(ii) Photoelectric emission
(iii) Field emission and
(iv) Secondary emission

The emission of electrons from a metal surface when heat is supplied to it is called **thermionic emission**.

The phenomenon due to which the surface of a metal ejects free electrons by absorbing some kind of energy is called **photoelectric emission**.

Work function

The minimum energy required to emit electron from the metal surface is called **work function** or **threshold energy**.

The number of electrons emitted per second depends on: (i) Material of the surface, (ii) Temperature of the surface, (iii) Its surface area.

Thermionic emitters should have the following properties: (i) High melting point, (ii) Low work function, (iii) Mechanically rugged, (iv) Low vapour pressure.

Some practical thermionic emitters are: (i) Pure tungsten, (ii) Thoriated tungsten, (iii) Alkali metal oxide coated tungsten.

Work function is measured in electron volt (eV).

$1 eV = 1.6 \times 10^{-19} C \times 1V$ or $1 eV = 1.6 \times 10^{-19} J$.

The work function of tungsten = 4.52 eV and that of thoriated tungsten = 2.6 eV.

The minimum frequency at which a given metal can emit photoelectrons is called **threshold frequency**.

Photoelectric effect

Photoelectric effect is the phenomenon of emission of electrons by metals when illuminated by light of suitable frequency.

The minimum energy needed by an electron to come out from a metal surface is called the work function of the metal. Energy greater than the work function (f) required for electron emission from the metal surface can be supplied by suitably heating or applying strong electric field or irradiating it with light of suitable frequency.

Certain metals respond to ultraviolet light while others are sensitive even to the visible light. Photoelectric effect involves conversion of light energy into electrical energy. It follows the law of conservation of energy. The photoelectric emission is an instantaneous process and possesses certain special features.

Photoelectric current depends on (i) the intensity of incident light, (ii) the potential difference applied between the two electrodes, and (iii) the nature of the emitting material.

Photoelectric Cell

The device which converts light energy into electric energy is called photoelectric cell.

A photoelectric cell uses the photoelectric effect. It converts light energy into electric energy. A photocell consists of a cathode coated with an alkali metal. Opposite to it a collector is placed. These are arranged in an evacuated bulb.

When light falls on alkali metal photoelectrons are liberated. They are attracted by the collector due to the positive potential on it and current flows through the circuit. The changes in current are according to the changes in the light falling on alkali metal.

Uses of photocells:

- In automatic switching on and off of street lights
- In photometry, they are used to compare the illuminating powers of two sources.
- They are used in fire alarms and burglar's alarms.
- In meteorology, they are used to record the intensity of day light.
- The photocells inserted in the street light electric circuit are used to switch on and off the street lighting system automatically at dusk and dawn.
- Photocells are used in the control of a counting device, which records every interruption of the light beam. So photocells help count the persons entering a temple or auditorium.
- They are used to reproduce sound in cinematograph and in the television camera for scanning and telecasting scenes.
- They are also used in automatic opening and closure of doors.
- They are used in solar arrays to generate electricity.
- They are used in controlling the temperature of furnaces.
- They are used in industries for detecting minor flaws of holes in metal sheets.
- They are used for detection of traffic law defaulters.
- The temperature of celestial bodies is measured and their spectra are studied by photocells.

Radioactivity

Natural radioactivity is defined as the spontaneous disintegration of a nucleus with the emission of certain particles and radiations.

Radioactivity is unaltered by: (i) Strongest chemical or physical treatments, (ii) Excessive heating or cooling, (iii) Strong electric or magnetic fields.

In radioactivity, α, β and γ rays are emitted.

In radioactivity, the nucleus which breaks is called the **parent nucleus** and the one which is formed as a result of decay is called the **daughter nucleus**.

α and β are positively and negatively charged particles respectively but γ-rays is an electro-magnetic wave (uncharged radiations).

During α and β particles emissions, the emitting nucleus undergoes a change in its atomic number and mass number, but during γ-emission no such change takes place.

Alpha and beta particles are deflected by electric and magnetic fields.

Radioactivity is used to cure diseases like leukemia and cancer by radiation therapy. The radio isotopes are used as fertilisers for plants. They are used to study wear and tear of piston rings and gears in engine. They are used to provide electric power.

The isotope of carbon-14 has been used for carbon dating to estimate the age of rocks and trees.

Properties of α, β, γ radiations: Some properties of a, β and γ are as shown in the table below:

S.No.	Property	Alpha Particles	Beta Particles	Gamma Rays
1.	Nature	These are helium nuclei	These are fast moving electrons	These are electromagnetic radiations
2.	Charge	$+3.2 \times 10^{-19}$ C (+2e)	-1.6×10^{-19} C (e)	Zero
3.	Rest mass	6.6×10^{-27} kg ($4m_\rho$)	9.1×10^{-31} kg	Zero
4.	Penetrating power	Minimum, can hardly penetrate	100 times that of alpha, can travel 10 cm through matter	100 times that of beta, can penetrate through several cm of lead
5.	Ionising power	100 times that of beta	100 times that of gamma	Minimum
6.	Effect of electric and magnetic fields	Are deflected by electric and magnetic fields	Are deflected by electric and magnetic fields	Undeflected by electric and magnetic fields
7.	Photographic effect	Can blacken a photographic plate	Can blacken a photographic plate	Can blacken a photographic plate
8.	Fluorescence	Can cause fluorescence	Can cause fluorescence	Can cause fluorescence
9.	Burning effect	Causes burning effect	Harmful to mankind	Very harmful
10.	Speed	Speed of 15,000 km per second	About 33% to 99% of the velocity of light	Travel with the velocity of light

Nuclear Energy

Fission is the splitting up of the nucleus of a heavy atom into two roughly equal fragments, accompanied by the release of energy. For example, uranium-235 splits up when it captures a slow neutron according to the fission reaction

$$^{235}_{92}U + ^{1}_{0}n \rightarrow ^{141}_{56}Ba + ^{92}_{36}Kr + 3^{1}_{0}n$$

In this reaction, the total mass on the left-hand side is more than the total mass on the right-hand side. This excess mass is converted into energy in accordance with Einstein's mass-energy relation, **$E = mc^2$**. The energy released in the fission of one nucleus of uranium-235 is nearly 200 million electron volts (1 electron volt = 1.6×10^{-19} joules). This is an enormous amount of energy. The energy produced on complete fission of just one gram of uranium-235 is equivalent to that from an electric power plant operating at one megawatt for nearly one day.

If the neutrons produced in the fission reaction are slowed down, they may produce further fission and, thus, start a chain reaction. However, if the uranium-235 lump is small, many neutrons escape from its surface without producing fission and, therefore, a chain reaction does not develop. The size of the material that sustains a chain reaction is called the critical size, the mass of which is called **critical mass**. If the mass of fissile material is greater than the critical mass, the chain reaction takes place so fast that an explosion occurs.

Atomic Bomb: In an atomic bomb, two subcritical masses of uranium-235 (or plutonium 239) are brought together in less than a microsecond. Since the combined mass exceeds the critical mass, a violent explosion takes place. In such explosions, temperatures as high as 107° C or even more are produced. Tremendous air blasts and intense radioactivity cause destruction. It is interesting to note that uranium-235 used in the Hiroshima blast was only of the size of a cricket ball.

Enriched Uranium: For an atomic bomb, fissile uranium-235 is needed. Natural uranium contains only 0.7% of uranium-235. The rest of it is uranium-238, which is not fissile. Therefore, uranium-235 has to be separated from natural uranium as far as possible. Uranium with an abundance of the uranium-235 isotope is known as enriched uranium.

For nuclear reactors, enriched uranium having nearly 6% U-235 is required. However, for nuclear bombs, highly enriched uranium (HEU) containing nearly 90% U-235 is used.

Nuclear Reactor: A nuclear reactor is a device in which fission occurs at a controlled rate. Common features of a nuclear reactor are:

(i) Nuclear fuel, generally uranium, that has been somewhat enriched in uranium-235 isotope

(ii) A moderator to slow down fast neutrons. Usually, graphite or heavy water is used as moderator.

(iii) A control device to control the flow of neutrons by absorbing some of them. Generally, boron or cadmium rods, that can be moved in or out of the reactor, are used for this purpose.

When proper adjustments are made in a reactor such that every fission reaction leads to, on an average, one further reaction, the reactor is said to have become '**critical**' and is ready to produce controlled energy.

In several countries, including India, nuclear reactors are being used to produce electricity. Besides, reactors are used to produce radioisotopes. Reactors are also used to convert uranium-238 into plutonium-239, which is fissile and used for atomic bombs.

Breeder Reactor: A reactor that produces more fissionable material than it burns is called a breeder reactor. These reactors fuelled initially with $^{238}U \rightarrow ^{239}Pu$ or $^{232}Th \rightarrow ^{233}U$ operate subsequently with the addition of ^{235}U or ^{232}Th, which are much more abundant than the only naturally occurring fissionable material, ^{235}U.

Nuclear Fusion: The combining of the nuclei of light atoms to form heavier nuclei with the release of energy is termed nuclear fusion. Nuclear fusion takes place in the sun and other stars and is one of the important sources of stellar energy. A typical fusion reaction is

$$^{2}_{1}H + ^{3}_{1}H \rightarrow ^{4}_{2}He + ^{1}_{0}n + \text{energy}$$

As in a fusion reaction, here also, the surplus mass is converted into energy. An extremely high temperature, such as that in the sun, is required for fusion to take place. On the earth, fusion reaction occurs during the explosion of a hydrogen bomb, which requires an atomic bomb for its detonation.

Research is currently going on to evolve the technique of controlled fusion. Efforts are being made to achieve fusion of the hydrogen isotope using laser beams.

Uncontrolled fusion reactions

Hydrogen bomb: It is based on the phenomenon of nuclear fusion and was made in 1952 by American scientists. The central core of a hydrogen bomb is a uranium (or plutonium) fission bomb which is surrounded by a compound of heavy hydrogen, like lithium hydride (LiH_2). When the fission bomb is exploded, it produces such a high temperature and pressure that the heavy hydrogen nuclei come extremely close and fuse together, liberating huge energy.

$$_1H^3 + {}_1H^2 \rightarrow {}_2He^4 + {}_0n^1 + 17.6 \text{ MeV}$$

Solar Energy

The sun has continuously been emitting light and heat at a very high rate for crores of years. The emission of such high energy by chemical reactions is impossible. The reason is that even if the sun was made entirely of carbon, its complete combustion would have supplied energy at such a high rate only for a few thousand years.