T.Vediyappan.M.Sc.,B.Ed.,M.Phil.,

UNIT 1 ELECTROSTATICS

Electricity is really just organized lightning

– George Carlin

Note 1

Note that the strength of the force between the two charges in water is reduced by 80 times compared to the force between the same two charges in vacuum. When common salt (NaCl) is taken in water, the electrostatic force between Na and Cl ions is reduced due to the high relative permittivity of water ($\varepsilon_r = 80$). This is the reason water acts as a good solvent.

Note 2

Without the superposition principle, Coulomb's law will be incomplete when applied to more than two charges. Both the superposition principle and Coulomb's law form fundamental principles of electrostatics and explain all the phenomena in electrostatics. But they are not derivable from each other.

Do you know

Microwave oven works on the principle of torque acting on an electric dipole. The food we consume has water molecules which are permanent electric dipoles. Oven produces microwaves that are oscillating electromagnetic fields and produce torque on the water molecules. Due to this torque on each water molecule, the molecules rotate very fast and produce thermal energy. Thus, heat generated is used to heat the food.

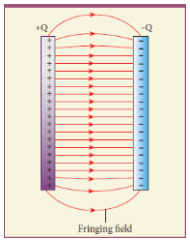
Note

Gauss law is a powerful technique whenever a given charge configuration possesses spherical, cylindrical or planer symmetry, then the electric field due to such a charge configuration can be easily found. If there is no such symmetry, the direct method (Coulomb's law and calculus) can be used. For example, it is difficult to use Gauss law to find the electric field for a dipole since it has no spherical, cylindrical or planar symmetry.

Substance	Dielectric strength (Vm^{-1})
Mica	100×10^6
Teflon	60×10^6
Paper	16×10^6
Air	3×10^6
Pyrex glass	14×10^6

Note

While deriving an expression for capacitance of the parallel plate capacitor, the expression of the electric field for infinite plates is used. But for finite sized plates, the electric field is not strictly uniform between the plates.



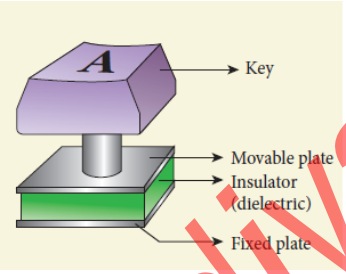
At both edges, the electric field is bent outwards as shown in the Figure. This is called “fringing field”. However under the condition (d2 << A), this effect can be ignored.

Do you know

Sometimes we notice that the ceiling fan does not start rotating as soon as it is switched on. But when we rotate the blades, it starts to rotate as usual. Why it is so? We know that to rotate any object, there must be a torque applied on the object. For the ceiling fan, the initial torque is given by the capacitor widely known as a condenser. If the condenser is faulty, it will not give sufficient initial torque to rotate the blades when the fan is switched on.

Do you know

Computer keyboard keys are constructed using capacitors with a dielectric as shown in the figure.



When the key is pressed, the separation between the plates decreases leading to an increase in the capacitance. This in turn triggers the electronic circuits in the computer to identify which key is pressed.

Table 1.2

S. No	Dielectric is inserted	Charge Q	Voltage V	Electric field E	Capacitance C	Energy U
1	When the battery is disconnected	Constant	decreases	Decreases	Increases	Decreases
2	When the battery is connected	Increases	Constant	Constant	Increases	Increases

UNIT 2 CURRENT ELECTRICITY

We will make electricity so cheap that only the rich will burn candles
– Thomas A. Edison

Do you know

Electric current is not only produced by batteries. In nature, lightning bolt produces enormous electric current in a short time. During lightning, very high potential difference is created between the clouds and ground so charges flow between the clouds and ground.

Ions

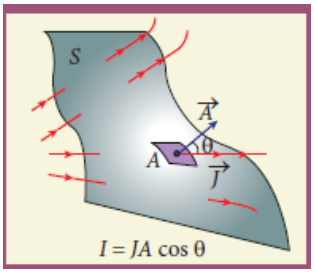
Any material is made up of neutral atoms with equal number of electrons and protons. If the outermost electrons leave the atoms, they become free electrons and are responsible for electric current. The atoms after losing their outer most electrons will have more positive charges and hence are called positive ions. These ions will not move freely within the material like the free electrons. Hence the positive ions will not give rise to current.

Note

The typical drift velocity of electrons in the wire is 10^{-4} m s^{-1}. If an electron drifts with this speed, then the electrons leaving the battery will take hours to reach the light bulb. Then how electric bulbs glow as soon as we switch on the battery? When battery is switched on, the electrons begin to move away from the negative terminal of the battery and this electron exerts force on the nearby electrons. This process creates a propagating influence (electric field) that travels through the wire at the speed of light. In other words, the energy is transported from the battery to light bulb at the speed of light through propagating influence (electric field). Due to this reason, the light bulb glows as soon as the battery is switched on.

Note

Why current density is a vector but current is a scalar? In general, the current I is defined as the scalar product of the current density and area vector in which the charges cross.



$\mathbf{I} = \vec{J}.\vec{A}$

The current I can be positive or negative depending on the choice of the unit vector normal to the surface area A.

Do you know

The human body contains a large amount of water which has low resistance of around 200 Ω and the dry skin has high resistance of around 500 k Ω. But when the skin is wet, the resistance is reduced to around1000 Ω. This is the reason, repairing the electrical connection with the wet skin is always dangerous.

Do you know

While reading the colour code, hold the resistor with colour bands to your left . Resistors never start with a metallic band on the left.

Do you know

A multimeter is a very useful electronic instrument used to measure voltage, current, resistance and capacitance. In fact, it can also measure AC voltage and AC current. The circular slider has to be kept in appropriate position to measure each electrical quantity.

Do you know

The resistance of certain materials become zero below certain temperature T_c. This temperature is known as critical temperature or transition temperature. The materials which exhibit this property are known as superconductors. This phenomenon was first observed by Kammerlingh Onnes in 1911. He found that mercury exhibits superconductor behaviour at 4.2 K. Since R = 0, current once induced in a superconductor persists without any potential difference.

Do you know

The electrical power produced (dissipated) by a resistor is I^2R. It depends on the square of the current. Hence, if current is doubled, the power will increase by four times. Similar explanation holds true for voltage also.

Do you know

The Tamilnadu Electricity Board is charging for the amount of energy you use and not for the power. A current of 1A flowing through a potential difference of 1V produces a power of 1W.

Do you know

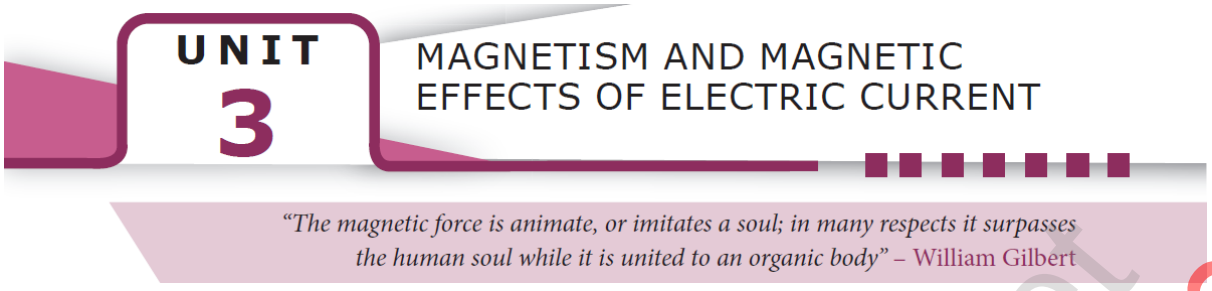
If we connect copper and zinc rod in a lemon, it acts as an electric cell. The citric acid in the lemon acts as an electrolyte. The potential can be measured using a multimeter.

Do you know

When the car engine is started with headlights turned on, they sometimes become dim. This is due to the internal resistance of the car battery.

Do you know

A galvanometer is an instrument used for detecting and measuring even very small electric currents. It is extensively useful to compare the potential difference between various parts of the circuit.



Note

Many birds and animals have magnetic sense in their eyes using Earth's magnetic field for navigation. Magnetic sensing in eyes - for Zebrafinches bird, due to protein cryptochromes Cry4 present in retina, it uses Earth magnetic field for navigation

Do you know

Aurora Borealis and Aurora Australis People living at high latitude regions (near Arctic or Antarctic) might experience dazzling coloured natural lights across the night sky. This ethereal display on the sky is known as aurora borealis (northern lights) or aurora australis (southern lights). These lights are often called as polar lights. The lights are seen above the magnetic poles of the northern and southern hemispheres. They are called as "Aurora borealis" in the north and "Aurora australis" in the south. This occurs as a result of interaction between the gaseous particles in the Earth's atmosphere with highly charged particles released from the Sun's atmosphere through solar wind. These particles emit light due to collision and variations in colour are due to the type of the gas particles that take part in the collisions. A pale yellowish – green colour is produced when the ionized oxygen takes part in the collision and a blue or purplish – red aurora is produced due to ionized nitrogen molecules.

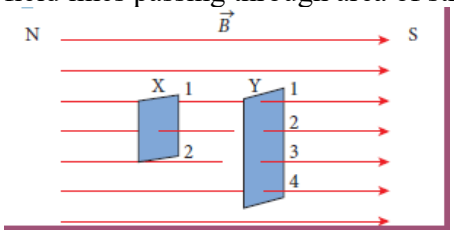
Do you know

(i) Pole strength is a scalar quantity with dimension $[M^0LT^0A]$. Its SI unit is N T^{-1} (newton per tesla) or A m (ampere-metre). (ii) Like positive and negative charges in electrostatics, north pole of a magnet experiences a force in the direction of magnetic field while south pole of a magnet experiences force opposite to the magnetic field. (iii) Pole strength depends on the nature of materials of the magnet, area of cross- section and the state of magnetization. (iv) If a magnet is cut into two equal halves along the length then pole strength is reduced to half. (v) If a magnet is cut into two equal halves perpendicular to the length, then pole strength remains same. (vi) If a magnet is cut into two pieces, we will not get separate north and south poles. Instead, we get two magnets. In other words, isolated monopole does not exist in nature.

Do you know

Here the integral is taken over area. Let X and Y be two planar strips whose orientation is such that the direction of area vector of planar strips is parallel to the direction of the magnetic field as shown in figure. The number of magnetic field lines passing through area of the strip X is

two. Therefore, the flux passing through area X is $\Phi_B = 2$ Wb. Similarly, the number of magnetic field lines passing through area of strip Y is $\Phi_B = 4$ Wb.



Do you know

(a) Why a freely suspended bar magnet in your laboratory experiences only torque (rotational motion) but not any translatory motion even though Earth has non-uniform magnetic field? It is because Earth's magnetic field is locally (physics laboratory)uniform.

(b) Suppose we keep a freely suspended bar magnet in a non-uniform magnetic field. What will happen? It will undergo translatory motion (net force) and rotational motion (torque).

Do you know

1. The current in circuit can be calculated from I = K tan θ, where K is called reduction factor of tangent Galvanometer, where

$$K = \frac{2RB_H}{\mu_0 N}$$

2. Sensitivity measures the change in the deflection produced by a unit current, mathematically

$$\frac{d\theta}{dI} = \frac{1}{K\left(1+\frac{I^2}{K^2}\right)}$$

3. The tangent Galvanometer is most sensitive at a deflection of 45°. Generally the deflection is taken between 30° and 60°.

Physical quantity	Component	Direction
Scalar	1 Component	No direction (no unit vector)
Vector	Each Component	1 direction (one unit vector)
Tensor	Each Component	More than one direction (more than one unit vectors)

Physical quantity	Component	Rank
Scalar	1 Component with zero direction	Zero
Vector	Each Component has one direction	One
Tensor of rank two	Each Component associated with two directions	Two
Tensor of rank three	Each Component associated with three directions	Three
Tensor of rank n	Each Component associated with n directions	n

Note

Superconductors are perfect diamagnetic materials. The expulsion of magnetic flux from a superconductor during its transition to the superconducting state is known as Meissner effect.

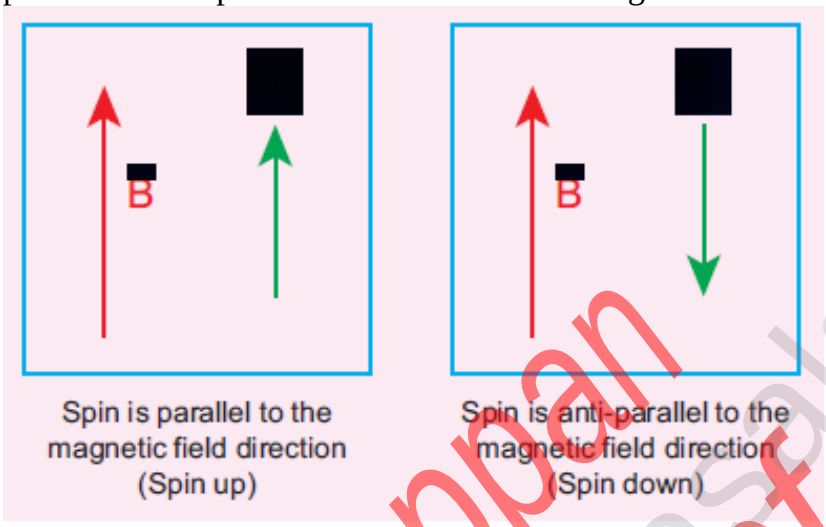
Do you know

Magnetic levitated train

Magnetic levitated train is also called as Maglev train. This train floats above few centimetre from the guideway because of electromagnet used. Maglev train does not need wheels and also achieve greater speed. The basic mechanism of working of Maglev train involves two sets of magnets. One set is used to repel which makes train to float above the track and another set is used to move the floating train ahead at very great speed. These trains are quieter, smoother and environmental friendly compared conventional trains and have potential for moving with much higher speeds with technology in future.

Spin

Like mass and charge for particles, spin is also another important attribute for an elementary particle. Spin is a quantum mechanical phenomenon (this is discussed in Volume 2) which is responsible for magnetic properties of the material. Spin in quantum mechanics is entirely different from spin we encounter in classical mechanics. Spin in quantum mechanics does not mean rotation; it is intrinsic angular momentum which does not have classical analogue. For historical reason, the name spin is retained. Spin of a particle takes only positive values but the orientation of the spin vector takes plus or minus values in an external magnetic field. For an example, electron has spin $s = 1/2$. In the presence of magnetic field, the spin will orient either parallel or anti-parallel to the direction of magnetic field.



This implies that the magnetic spin m_s takes two values for an electron, such as $m_s = 1/2$ (spin up) and $m_s = -1/2$ (spin down). Spin for proton and neutron is $s = 1/2$. For a photon is spin s = 1.

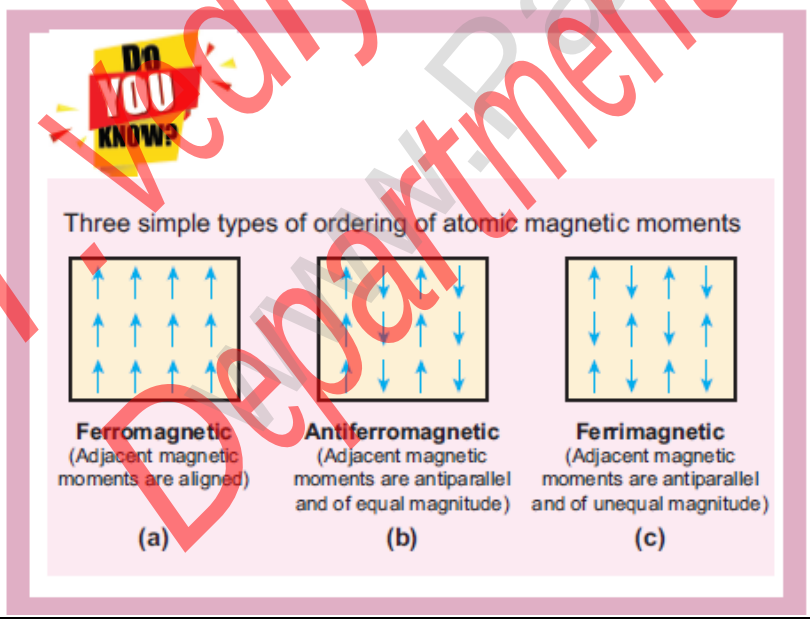


Table 3.2 Difference between soft and hard ferromagnetic materials

S.No.	Properties	Soft ferromagnetic materials	Hard ferromagnetic materials
1	When external field is removed	Magnetisation disappears	Magnetisation persists
2	Area of the loop	Small	Large
3	Retentivity	Low	High
4	Coercivity	Low	High
5	Susceptibility and magnetic permeability	High	Low
6	Hysteresis loss	Less	More
7	Uses	Solenoid core, transformer core and electromagnets	Permanent magnets
8	Examples	Soft iron, Mumetal, Stalloy etc.	Steel, Alnico, Lodestone etc.

Do you know

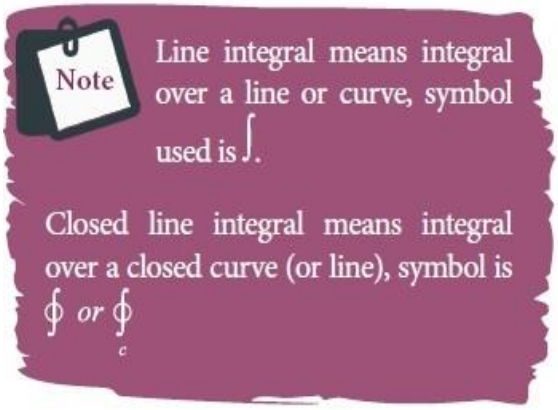
Mnemonic means that it is a special word or a collection of words used to help a person to remember something.

Note

Electric current is not a vector quantity. It is a scalar quantity. But electric current in a conductor has direction of flow. Therefore, the electric current flowing in a small elemental conductor can be taken as vector quantity i.e. $I\vec{dl}$

Table 3.3 End rule – polarity with direction of current in circular loop

Current in circular loop	Polarity	Picture
Anti-clockwise current	North Pole	 Anti-clockwise current Polarity: North Pole
Clockwise current	South Pole	 Clockwise current Polarity: South Pole



Note

Solenoid can be used as electromagnets. It produces strong magnetic field that can be turned ON or OFF. This is not possible in case of permanent magnet. Further the strength of the magnetic field can be increased by keeping iron bar inside the solenoid. This is because the magnetic field of the solenoid magnetizes the iron bar

and hence the net magnetic field is the sum of magnetic field of the solenoid and magnetic field of magnetised iron. Because of these properties, solenoids are useful in designing variety of electrical appliances.

Table 3.4 Deflection based on the velocity – velocity selector

S.No.	Velocity	Deflection
1	$v > v_o$	Charged particle deflects in the direction of Lorentz force
2	$v < v_o$	Charged particle deflects in the direction of Coulomb force
3	$v = v_o$	No deflection and particle moves straight

Note

Deutrons (bundles of one proton and one neutron) can be accelerated because it has same charge as that of proton. But neutron (electrically neutral particle) cannot be accelerated by the cyclotron. When a deutron is bombarded with a beryllium target, a beam of high energy neutrons are produced. These high-energy neutrons are sent into the patient's cancerous region to break the bonds in the DNA of the cancer cells (killing the cells). This is used in treatment of fast-neutron cancer therapy.

UNIT 4
ELECTROMAGNETIC INDUCTION AND ALTERNATING CURRENT

"Nature is our kindest friend and best critic in experimental science if we only allow her intimations to fall unbiased on our minds" — Michael Faraday

An anecdote!

Michael Faraday was enormously popular for his lectures as well. In one of his lectures, he demonstrated his experiments which led to the discovery of electromagnetic induction.

At the end of the lecture, one member of the audience approached Faraday and said, "Mr. Faraday, the behaviour of the magnet and the coil of wire was interesting, but what is the use of it?" Faraday answered politely, "Sir, what is the use of a newborn baby?"

Note:

We will soon see the greatness of 'that little child' who has now grown as an adult to cater to the energy needs.

Importance of Electromagnetic Induction! The application of the phenomenon of Electromagnetic Induction is almost everywhere in the present day life. Right from home appliances to huge factory machineries, from cellphone to computers and internet, from electric guitar to satellite communication, all need electricity for their operation. There is an ever growing demand for electric power. All these are met with the help of electric generators and transformers which function on electromagnetic induction. The modern, sophisticated human life would not be possible without the discovery of electromagnetic induction.

Note

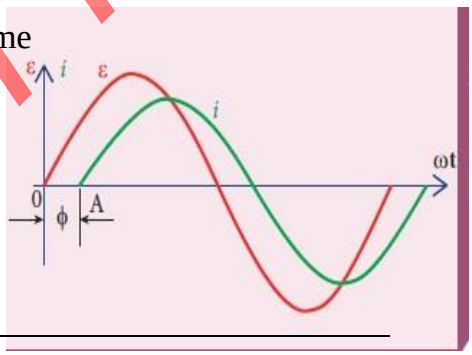
Emf can be induced by changing relative orientation between the coil and the magnetic field. This can be achieved either by rotating a coil in a magnetic field or by rotating a magnetic field within a stationary coil. Here rotating coil type is considered.

Note

Alternating emf is generated by rotating a coil in a magnetic field or by rotating a magnetic field within a stationary coil. The first method is used for small AC generators while the second method is employed for large AC generators. The rotating-field method is the one which is mostly used in power stations.

Note

Phase difference If two alternating quantities of same frequency do not pass through a particular point, say zero point, in the same direction at the same instant, they are said to have a phase difference. The angle between zero points is the angle of phase difference. For the graph shown above, the phase difference between ε and *i* is given by OA = ϕ.



Note

Interestingly, sine waves are very common in nature. The periodic motions like waves in water, swinging of pendulum are associated with sine waves. Thus sine wave seems to be nature's standard. Also refer unit 11 of XI physics text book.

Note

For example, if we consider n currents in a half-cycle of AC, namely $i_1, i_2, \ldots i_n$, then average value is given by

$$I_{av} = \frac{\text{Sum of all currents over half-cycle}}{\text{Number of currents}}$$

$$I_{av} = \frac{i_1 + i_2 + \ldots + i_n}{n}$$

Note

For example, if we consider n currents in one cycle of AC, namely $i_1, i_2, \ldots i_n$, then RMS value is given by

$$I_{RMS} = \sqrt{\frac{\text{Sum of squares of all currents over one cycle}}{\text{Number of currents}}}$$

$$I_{RMS} = \sqrt{\frac{i_1^2 + i_2^2 + \ldots + i_n^2}{n}}$$

Note

RMS value of alternating current is also called effective value and is represented as I_{eff}. It is used to compare RMS current of AC to an equivalent steady current. **RMS value is also defined as that value of the steady current which when flowing through a given circuit for a given time produces the same amount of heat as produced by the alternating current when flowing through the same circuit for the same time.** The effective value of an alternating voltage is represented by V_{eff}.

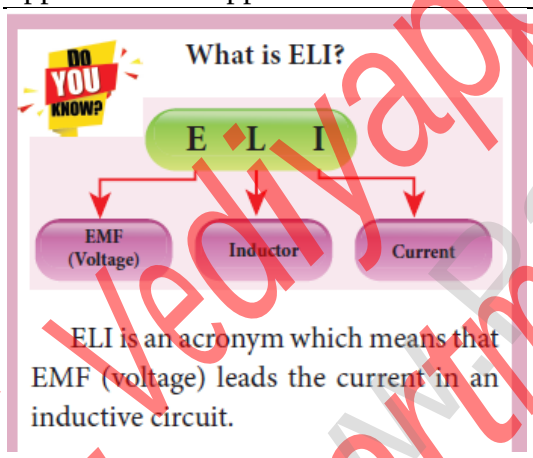
Do you know

For common household appliances, the voltage rating and current rating are generally specified in terms of their RMS value. The domestic AC supply is 230V, 50 Hz. It is the RMS or effective value. Its peak value will be $V_m = \sqrt{2}\ V_{rms} = \sqrt{2} \times 230 = 325V.$

An inductor blocks AC but it allows DC. Why? and How?

An inductor L is a closely wound helical coil. The steady DC current flowing through L produces uniform magnetic field around it and the magnetic flux linked remains constant. Therefore there is no self-induction and self-induced emf (back emf). Since inductor behaves like a resistor, DC flows through an inductor.

The AC flowing through L produces time-varying magnetic field which in turn induces self-induced emf (back emf). This back emf, according to Lenz's law, opposes any change in the current. Since AC varies both in magnitude and direction, its flow is opposed in L. For an ideal inductor of zero ohmic resistance, the back emf is equal and opposite to the applied emf. Therefore L blocks AC.



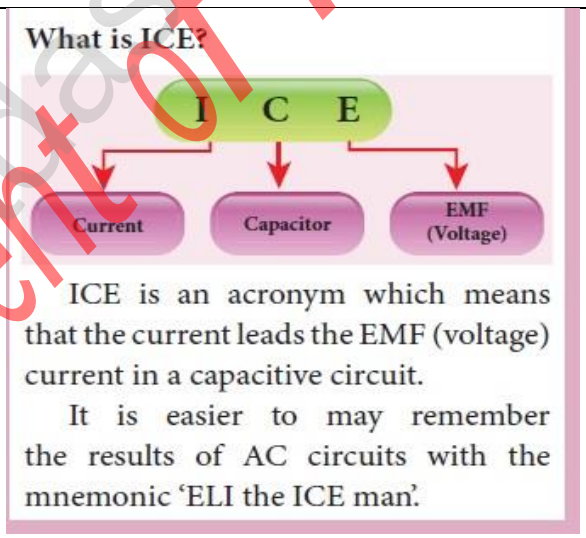


Table 4.1 Summary of results of AC circuits

Type of Impedance	Value of Impedance	Phase angle of current with voltage	Power factor
Resistance	R	0°	1
Inductance	$X_L = \omega L$	90° lag	0
Capacitance	$X_C = 1/\omega C$	90° lead	0
R- L - C	$\sqrt{R^2 + \left(\omega L - 1/\omega C\right)^2}$	Between 0° and 90° lag or lead	Between 0 and 1

Note

The phenomenon of electrical resonance is possible when the circuit contains both *L* and *C*. Only then the voltage across *L* and *C* cancel one another when V_L and V_C are 180° out of phase and the circuit becomes purely resistive. This implies that resonance will not occur in a *RL* and *RC* circuits.

Note

But in practice, the Joule heating and radiation of electromagnetic waves from the circuit decrease the energy of the system. Therefore, the oscillations become damped oscillations.

Table 4.3 Energy in two oscillatory systems

LC oscillator		Spring-mass system	
Element	Energy	Element	Energy
Capacitor	Electrical Energy $= \frac{1}{2}\left(\frac{1}{C}\right)q^2$	Spring	Potential energy $= \frac{1}{2}k\,x^2$
Inductor	Magnetic energy $= \frac{1}{2}Li^2$ $i = \frac{dq}{dt}$	Mass	Kinetic energy $= \frac{1}{2}mv^2$ $v = \frac{dx}{dt}$

Table 4.4 Analogies between electrical and mechanical quantities

Electrical system	Mechanical system
Charge q	Displacement x
Current $i = \frac{dq}{dt}$	Velocity $v = \frac{dx}{dt}$
Inductance L	Mass m
Reciprocal of capacitance $\frac{1}{C}$	Force constant k
Electrical energy $= \frac{1}{2}\left(\frac{1}{C}\right)q^2$	Potential energy $= \frac{1}{2}kx^2$
Magnetic energy $= \frac{1}{2}Li^2$	Kinetic energy $= \frac{1}{2}mv^2$
Electromagnetic energy $U = \frac{1}{2}\left(\frac{1}{C}\right)q^2 + \frac{1}{2}Li^2$	Mechanical energy $E = \frac{1}{2}kx^2 + \frac{1}{2}mv^2$

UNIT 5 ELECTROMAGNETIC WAVES

"One scientific epoch ended and another began with James Clerk Maxwell"
– Albert Einstein

Note

Displacement current The name stuck because Maxwell named it. The word displacement is poorly chosen because nothing is being displaced here.

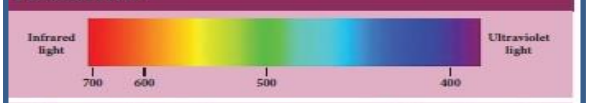
Note

For a point source, $I = \frac{P}{4\pi r^2} \Rightarrow I \propto \frac{1}{r^2}$

For a line source, $I \propto \frac{1}{r}$

For a plane source, I is independent of r

Table 5.1 visible region, frequency and wavelength of different types of radiation



Type of Radiation	Frequency Range (Hz)	Wavelength Range
gamma-rays	10^{20}-10^{24}	$<10^{-12}$m
x-rays	10^{17}-10^{20}	1 nm - 1pm
ultraviolet	10^{15}-10^{17}	400 nm - 1nm
visible	$4 - 7.5 \times 10^{14}$	750 nm - 400nm
near-infrared	1×10^{14}-4×10^{14}	2.5 μm - 750nm
infrared	10^{13}-10^{14}	25 μm - 2.5μm
microwaves	3×10^{11}-10^{13}	1 mm - 25 μm
radio waves	$< 3 \times 10^{11}$	> 1 mm

UNIT 6 OPTICS

An age is called dark, not because the light fails to shine, but because people refuse to see.
— James Albert Michener

Table 6.1 Conditions for nature of objects and images

Nature of object/image	Condition
Real Image	Rays actually converge at the image
Virtual Image	Rays appear to diverge from the image
Real Object	Rays actually diverge from the object
Virtual Object	Rays appear to converge at the object

Table 6.2 Refractive index of different media

Media	Refractive index
Vacuum	1.00
Air	1.0003
Carbon dioxide gass	1.0005
Ice	1.31
Pure water	1.33
Ethyl alcohol	1.36
Quartz	1.46
Vegetable oil	1.47
Olive oil	1.48
Acrylic	1.49
Table salt	1.51
Glass	1.52
Sapphire	1.77
Zircon	1.92
Qubic zirconia	2.16
Diamond	2.42
Gallium phosphide	3.50

Note

It is generally known that a plane mirror can only form a virtual image. But, now we have understood that a plane mirror can form a real image when converging rays fall on it.

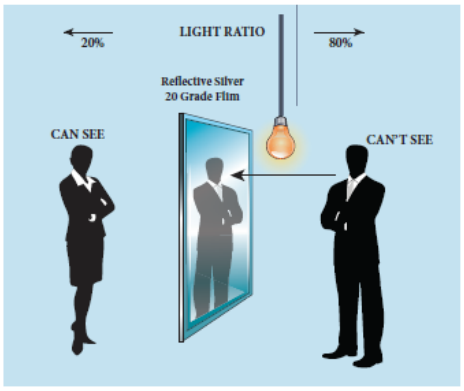
Note

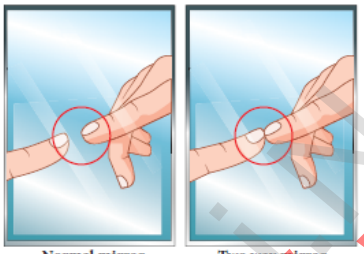
The students are advised to refresh themselves with the image tracing for the concave and convex mirrors for various predetermined positions of the object and the position of image, nature of image etc. studied in 9_{th} standard (Science, Unit 6. Light).

Note

After the disappearance of light for the first time while increasing the speed of rotation of the toothed-wheel from zero to ω, on further increase of speed of rotation of the wheel to 2ω, the light would appear again due to the passing of reflected light through the next slot. So, for every odd value of ω, light will disappear (stopped by tooth) and for every even value of ω light will appear (allowed by slot).

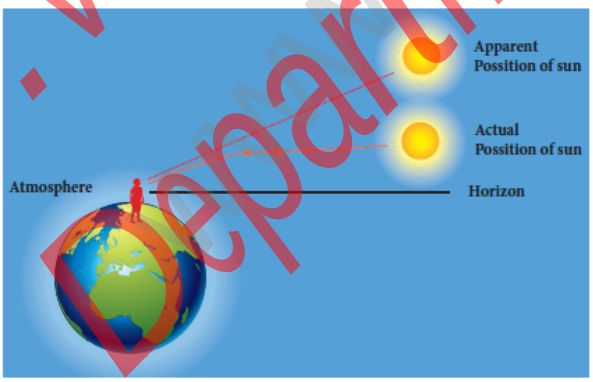
Production of optical surfaces capable of refracting as well as reflecting is possible by properly coating the surfaces with suitable materials. Thus, a glass can be made partially see through and partially reflecting by varying the amount of coating on its surface. It is commercially called as two way mirror, half-silverd or semi-silvered mirror etc. This gives a perception of regular mirror if the other side is made dark. But, still hidden cameras can be kept behind such mirrors. We need to be cautious when we stand in front of mirrors kept in unknown places. There is a method to test the two way mirror. Place the finger nail against the mirror surface. If there is a gap between nail and its image, then it is a regular mirror. If the fingernail directly touches its image, then it is a two way mirror.




Normal mirror Two way mirror

Atmospheric refraction: Due to refraction of light through different layers of atmosphere which vary in refractive index, the path of light deviates continuously when it passes through atmosphere. For example, the Sun is visible a little before the actual sunrise and also until a little after the actual sunset due to refraction of light through the atmosphere. By actual sunrise what we mean is the actual crossing of the sun at the horizon. Figure shows the actual and apparent positions of the sun with respect to the horizon. The figure is highly exaggerated to show the effect. The apparent shift in the direction of the sun is around half a degree and the corresponding time difference between actual and apparent positions is about 2 minutes. Sun appears flattened (oval shaped) during sun rise and sunset due to the same phenomenon.

The same is also applicable for the positions of stars as shown in Figure. The stars actually do not twinkle. They appear twinkling because of the movement of the atmospheric layers with varying refractive indices which is clearly seen in the night sky.



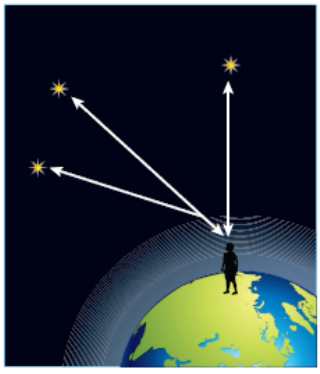


Table 6.3 Refractive index and critical angle of different media

Material	Refractive index	Critical Angle
Ice	1.310	49.8°
Water	1.333	48.6°
Fused Quartz (SiO_2)	1.458	43.3°
Crown Glass	1.541	40.5°
Flint Glass	1.890	31.9°
Calcite ($CaCO_3$)	1.658	37.0°
Diamond	2.417	24.4°
Strontium Titanate ($SrTiO_3$)	2.417	24.4°
Rutile	2.621	22.4°

Do you know

An endoscope is an instrument used by doctors which has a bundle of optical fibres that are used to see inside a patient's body. Endoscopes work on the phenomenon of total internal reflection. The optical fibres are inserted in to the body through mouth, nose or a special hole made in the body. Even operations could be carried out with the endoscope cable which has the necessary instruments attached at their ends.

$$PP_2 = EG = \frac{h_1 - h_2}{\tan\delta} = \frac{h_1 - h_2}{\delta}$$

From equations (6.89) and (6.91)

$$h_2 - h_1 = d\frac{h_1}{f_1} \quad \text{and} \quad \delta = \frac{h_1}{f}$$

$$PP_2 = \left(d\frac{h_1}{f_1}\right) \times \left(\frac{f}{h_1}\right)$$

$$PP_2 = \left(d\frac{f}{f_1}\right) \tag{6.93}$$

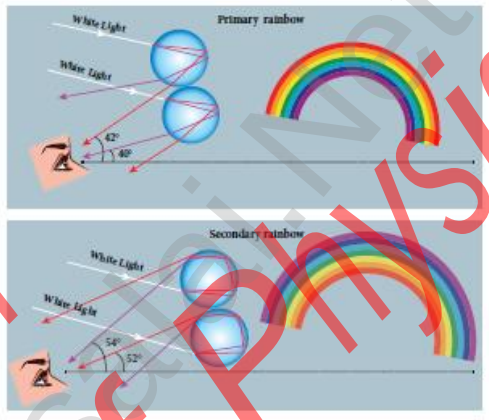
$$PP_1 = d\left(1 - \frac{f}{f_1}\right) \tag{6.94}$$

Note

The Equation (6.92), (6.93) and (6.94) hold good only for the special case of parallel incident rays or object at infinity. We cannot use these equations if the object is at a finite distance. For finite distance of the object, the image positions must be calculated separately using the lens equation for the two lenses.

POINTS TO PONDER

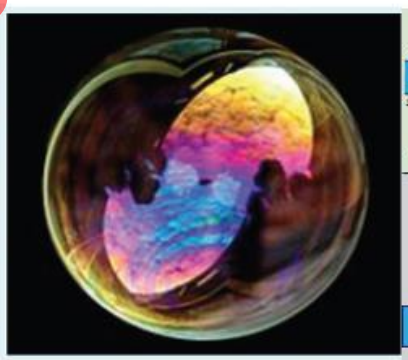
Rainbow is an example of dispersion of sunlight through droplets of water during rainy days. Rainbow is observed during a rainfall or after the rainfall or when we look at a water fountain provided the sun is at the back of the observer. When sunlight falls on the water drop suspended in air, it splits (or dispersed) into its constituent seven colours. Thus, water drop suspended in air behaves as a glass prism. Primary rain bow is formed when light entering the drop undergoes one total internal reflection inside the drop before coming out from the drop as shown in figure. The angle of view for violet to red in primary rainbow is 40° to 42°. A secondary rainbow appears outside of a primary rainbow and develops when light entering a raindrop undergoes two internal reflections. The angle of view for red to violet in a secondary rainbow is, 52° to 54°.

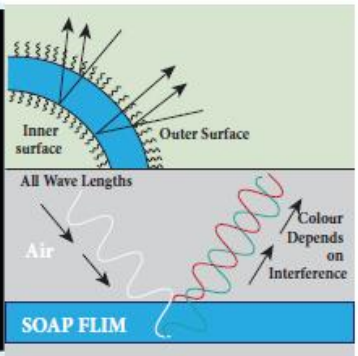


Note

If light of a particular frequency travels through different media, then, its frequency remains unchanged in all the media. Only the wavelength changes according to speed of light in that medium.

Dazzling colours are exhibited by thin films of oil spread on the surface of water and also by soap bubbles as shown in the figure. These colours are due to interference of white light undergoing multiple reflections from the top and the bottom surfaces of thin films. The colour depends upon the thickness of the film, refractive index of the film and also the angle of incidence of the light.





Note

If the incidence is not nearly normal, but at an angle of incidence *i* which has an angle of refraction *r*, then the expression for path difference $2\mu d$ on the left hand side of the above equations are to be replaced with the expression, $2\mu d \cos r$.

Note

Here, sinθ gives the angular spread of the diffraction. The position of the minimum or maximum in terms of y may be expressed by replacing sinθ approximated by tanθ, as θ is small, $\sin\theta = \tan\theta \frac{y}{D}$ Where, y is the position of the minimum from the center of the screen and D is the distance between single slit and the screen.

Note

The students should remember that in a single slit experiment the formula, $a \sin\theta = n\lambda$ is condition for minimum with n as order of minimum. But, the formula in diffraction grating, $\sin\theta = Nm\lambda$ is condition for maxima with *m* as the order of diffraction.

Do you know

You would have noticed the colourful appearance of the compact disc. On the read/writable side which is polished, there are many narrow circular tracks with widths comparable to the wavelength of visible light. Hence, the diffraction takes place after reflection for incident white light to give colourful appearance. The tracks act as reflecting grating.

Note

The SI unit of energy is joule. But electron volt is a commonly used unit of energy in atomic and nuclear physics. One electron volt is defined as the kinetic energy gained by an electron when accelerated by a potential difference of 1 *V*.

1 *eV* = KE gained by the electron
= Work done by the electric field
= q *V*
= 1.602×10^{-19} C × 1 *V*
= 1.602×10^{-19} *J*

Table 7.1 Work function of some materials

Metal	Symbol	Work function (*eV*)	Metal	Symbol	Work function (*eV*)
Cesium	Cs	2.14	Aluminium	Al	4.28
Potassium	K	2.30	Copper	Cu	4.65
Sodium	Na	2.75	Silver	Ag	4.70
Calcium	Ca	3.20	Platinum	Pt	5.65

Do you know

It is interesting to note that the experiment of Hertz confirmed that light is an electromagnetic wave. But the same experiment also produced the first evidence for particle nature of light.

Note

Here, intensity of light means brightness. A bright light has more intensity than a dim light.

Note

According to quantum concept, intensity of light of given wavelength is defined as the number of energy quanta or photons incident per unit area per unit time, with each photon having same energy. The unit is Wm^{-2}.

Do you know

A reader may find it difficult to understand how light can be both a wave and a stream of particle. This is the case even for great scientist like Albert Einstein.

Einstein once wrote a letter to his friend Michel Besso in 1954 expressing his frustration:

"All these fifty years of conscious brooding have brought me no closer to answer the question, 'What are light quanta?' Of course today everyone thinks he knows the answer, but he is deluding himself".

Note

It is to be noted that electrons are not the only particles with which wave nature can be demonstrated. The particles like neutrons and alpha particle are also associated with waves. They undergo diffraction when they are scattered by suitable crystals. Neutron diffraction studies are highly useful for investigating crystal structures.

Note

Diffraction is one of the properties of waves. Whenever waves are incident on an obstacle, they bend around the edges of the obstacle. This bending of waves is called diffraction. The amount of bending depends on the wavelength of the waves. We have learnt in unit 6 that as the wavelength of light is very small, diffraction effects of light are very small. In order to study diffraction of light, diffraction gratings are used. Since X-rays and de Broglie waves of electrons have wavelengths (in the order of 10–10m) much shorter than that of the light wave, diffraction grating cannot be used for their diffraction. In a crystal, the spacing between atomic planes is comparable to the wavelength of x-rays and de Broglie

waves of electrons. Hence, for their diffraction, the crystals are used which serve as three-dimensional grating.

UNIT 8 ATOMIC AND NUCLEAR PHYSICS

All of physics is either impossible or trivial. It is impossible until you understand it, and then it becomes trivial
– Ernest Rutherford

Note

The specific charge is independent of
(a) gas used
(b) nature of the electrodes

Note

In 1931, H.C. Urey and co- workers noticed that in the shorter wavelength region of the hydrogen spectrum lines, faint companion lines are observed. From the isotope displacement effect (isotope shift), the isotope of the same element will have slightly different spectral lines. The presence of these faint lines confirmed the existence of isotopes of hydrogen atom (which is named as Deuterium). On calculating wavelength or wave number difference between the faint and bright spectral lines, atomic mass of deuterium is measured to be twice that of atomic mass of hydrogen atom. Bohr atom model could not explain this isotopic shift. Thus by considering nuclear motion (although the movement of the nucleus is much smaller, it is observed) into account in the Bohr atom model, the wave number or wavelength difference between hydrogen atom and deuterium is theoretically calculated which perfectly agreed with the spectroscopic measured values. The difference between hydrogen atom and deuterium is in the number of neutron. Hydrogen atom contains an electron and a proton, whereas deuterium has an electron, a proton and a neutron.

Table 8.1

Physical quantity	Ground state	First excited state	Second excited state
Radius ($r_n \propto n^2$)	0.529 Å	2.116 Å	4.761 Å
Velocity ($v_n \propto n^{-1}$)	2.19×10^6 m s^{-1}	1.095×10^6 m s^{-1}	0.73×10^6 m s^{-1}
Total Energy ($E_n \propto n^{-2}$)	–13.6 *eV*	–3.4 *eV*	–1.51 *eV*

Do you know

A single teaspoon of nuclear matter would weigh about trillion tons.

Note

During early days of nuclear physics research, the term ‘radiation’ was used to denote the emanations from radioactive nuclei. Now we know that α rays are in fact ${}_2^4He$ nuclei and β rays are electrons or positrons. Certainly, they are not electromagnetic radiation. The γ ray alone is electromagnetic radiation.

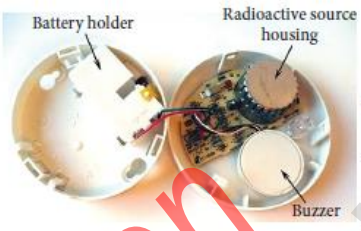
Note: Using Einstein's mass-energy equivalence, the energy equivalent of one atomic mass unit $1u = 1.66 \times 10^{-27} \times (3 \times 10^8)^2 = 14.94 \times 10^{-11} J \approx 931 MeV$

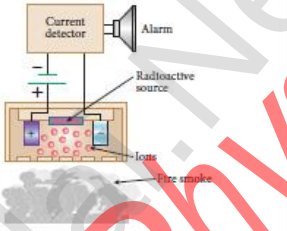
Note

In alpha decay, why does the unstable nucleus emit ${}_2He^4$ nucleus? Why it does not emit four separate nucleons? After all ${}_2He^4$ consists of two protons and two neutrons. For example, if ${}_{92}U^{238}$ nucleus decays into ${}_{90}Th^{234}$ by emitting four separate nucleons (two protons and two neutrons), then the disintegration energy Q for this process turns out to be negative. It implies that the total mass of products is greater than that of parent (${}_{92}U^{238}$) nucleus. This kind of process cannot occur in nature because it would violate conservation of energy. In any decay process, the conservation of energy, conservation of linear momentum and conservation of angular momentum must be obeyed.

DO YOU KNOW?

A very interesting application of alpha decay is in smoke detectors which prevent us from any hazardous fire.





The smoke detector uses around 0.2 *mg* of man-made weak radioactive isotope called americium (${}^{241}_{95}Am$). This radioactive source is placed between two oppositely charged metal plates and α radiations from ${}^{241}_{95}Am$ continuously ionize the nitrogen, oxygen molecules in the air space between the plates. As a result, there will be a continuous flow of small steady current in the circuit. If smoke enters, the radiation is being absorbed by the smoke particles rather than air molecules. As a result, the ionization and along with it the current is reduced. This drop in current is detected by the circuit and alarm starts.

The radiation dosage emitted by americium is very much less than safe level, so it can be considered harmless.

Note

Initially one curie was defined as number of decays per second in 1 g of radium and it is equal to 3.7×10^{10} decays/s.

Note

One should not think that shorter half-life material is safer than longer half- life material because it will not last long. The shorter half-life sample will have higher activity and it is more 'radioactive' which is more harmful.

Note

India has 22 nuclear reactors in operation. Nuclear reactors are constructed in two places in Tamilnadu, Kalpakkam and Kudankulam. Even though nuclear reactors are aimed to cater to our energy need, in practice nuclear reactors now are able to provide only 2% of energy requirement of India.

UNIT 9 SEMICONDUCTOR ELECTRONICS

Electronics is clearly the winner of the day
– John Ford.

Do you know

The world's first computer 'ENIAC' was invented by J. Presper Eckert and John Mauchly at the University of Pennsylvania. The construction work started in 1943 and got over in 1946. It occupied an area of around 1800 square feet. It had 18,000 vacuum tubes and it weighed around 50 tons.

Note

Passive Components: components that cannot generate power in a circuit. Active components: components that can generate power in a circuit.

Note

The energy levels of the orbiting electrons are measured in electron volts, (eV).

Note

In semiconductors, electrons in the valence band are bound electrons which cannot move. Hence, they cannot contribute for conduction.

Note

Definition of a hole: When an electron is excited, covalent bond is broken. Now octet rule will not be satisfied. Thus each excited electron leaves a vacancy to complete bonding. This 'deficiency' of electron is termed as a 'hole'

Note

The n-type and p-type semiconductor are neutral as we are topping neutral atoms to the intrinsic semiconductors.

Note

The reverse saturation current of a silicon diode doubles for every 10 °C rise in temperature.

Note

Ideal diode: It acts like a conductor when it is forward biased. When it is reverse biased, it acts like an insulator. The barrier potential is assumed to be zero and hence it behaves like a resistor.

Note

If the direction of the diode is reversed, the negative half of the ac signal is passed through and the positive half is blocked.

Note

If the direction of the diode is reversed, the negative half of the ac signal is passed through and the positive half is blocked.

Note

For a reverse voltage of,
(i) less than 4V → Zener effect predominates
(ii) greater than 6V → Avalanche effect predominates
(iii) between 4 and 6V → both effects are present.

Note

The maximum reverse bias that can be applied before entering into the Zener region is called the Peak inverse voltage. Commercially referred as PIV rating.

Note

In a PNP transistor, base and collector will be negative with respect to emitter indicated by the middle letter N whereas base and collector will be positive in an NPN transistor [indicated by the middle letter P]

Do you know

Because of the differing size and the amount of dopping, the emitter cannot be replaced by the collector and vice versa.

Note

As the output is taken from the emitter in common collector configuration, it is called an emitter follower.

Note

1. The conventional flow of current is based on the direction of the motion of holes
2. In NPN transistor, current enters from the base into the emitter.
3. In a PNP transistor, current enters from the emitter into the base.
4. The emitter-base junction has low resistance and the collector-base junction has high resistance.

Note

The collector current is independent of the collector- emitter voltage in the active region.

Note

The concept of high (1) and low (0) is not a new one. In fact, it was applied in telephone switching circuits by Shannon in 1938.

UNIT 10

COMMUNICATION SYSTEMS

Good communication is the bridge between confusion and clarity

– Nat Turner

Note

Carrier signal does not have information.

Note

Comparison between FM and PM PM wave is similar to FM wave. PM generally uses a smaller bandwidth than FM. In other words, in PM, more information can be sent in a given bandwidth. Hence, phase modulation provides high transmission speed on a given bandwidth.

Note

If a square wave is used as the baseband signal, then phase reversal takes place in the modulated signal. FM and PM waves are completely different for square wave modulating signal.

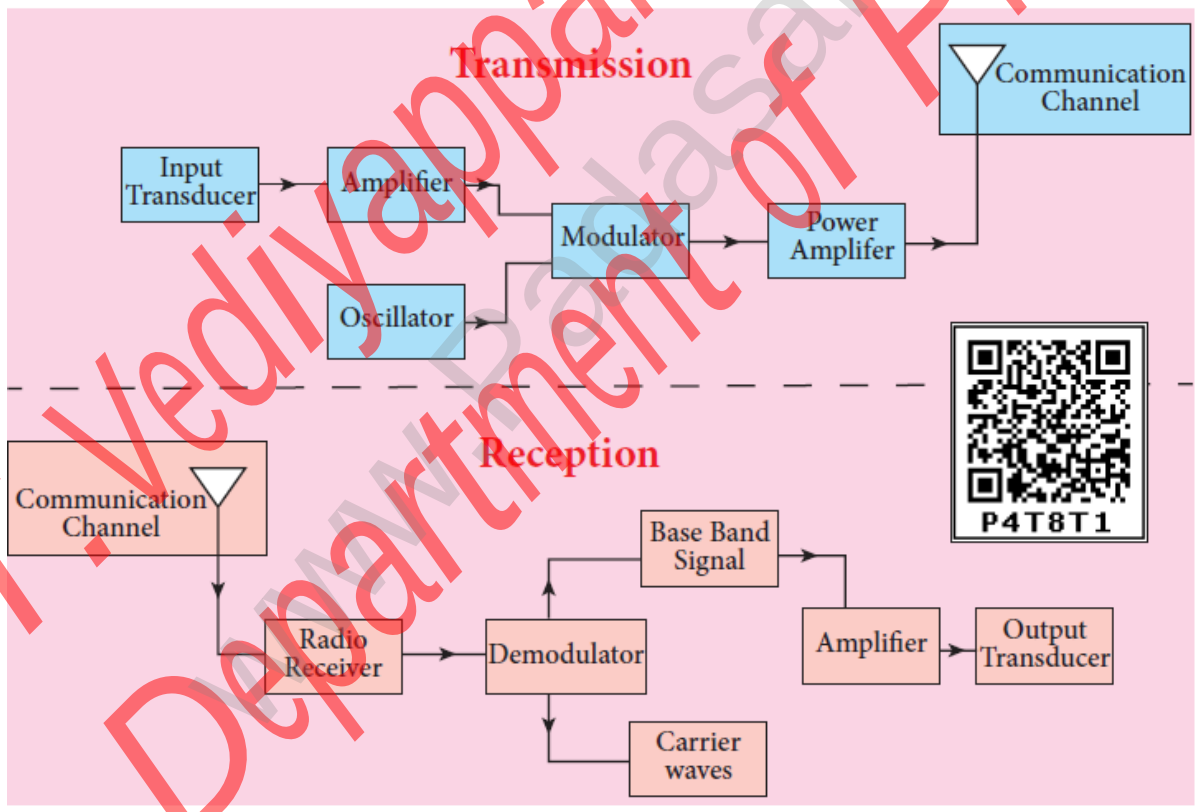


Figure 10.4 Block diagram of transmission and reception of voice signals

Note

The higher the frequency, higher is the skip distance and for a frequency less than the critical frequency, skip distance is zero.

Note

Most transatlantic telecommunication cables between the United States of America and Europe are fiber optic.

Do you know

Fiber optic cables provide the fastest transmission rate compared to any other form of transmission. It can provide data speed of 1 Gbps for homes and business. Multimode fibers operate at the speed of 10 Mbps. Recent developments in optical communication provide the data speed at the rate of 25 Gb km/s

Do you know

Recently, the mobile communication technology has evolved through various stages like 2G, 3G, 4G, 5G, WiMAX, Wibro, EDGE, GPRS and many others. This helps to increase the speed of communication and the range of coverage. The connectivity issues have decreased with reliable and secure connections. The GPS (Global Positioning System) and GSM (Global System for Mobile communication) technology play an important role in mobile communication. This increases the utilization of bandwidth of the network, sharing of the networks, error detections, etc. Many methods like digital switching, TDMA, CDMA have been used to ease the communication process.

Do you know

To store all the information available on the internet, you would need over 1 billion DVDs or 200 million Blu-ray discs.

Common Types of Industrial Robots:

Articulated –

- This robot design features rotary joints and can range from simple two joint structures to 10 or more joints.
- The arm is connected to the base with a twisting joint.
- The links in the arm are connected by rotary joints.
- Each joint is called an axis and provides an additional degree of freedom, or range of motion.
- Industrial robots commonly have four or six axes.

Cartesian –

- These are also called rectilinear or gantry robots.
- Cartesian robots have three linear joints that use the Cartesian coordinate system (X, Y, and Z).
- They also may have an attached wrist to allow for rotational movement.
- The three prismatic joints deliver a linear motion along the axis.

Cylindrical –

- The robot has at least one rotary joint at the base and at least one prismatic joint to connect the links.
- The rotary joint uses a rotational motion along the joint axis, while the prismatic joint moves in a linear motion.
- Cylindrical robots operate within a cylindrical-shaped work envelope.

Polar –

- Also called spherical robots, in this configuration the arm is connected to the base with a twisting joint and a combination of two rotary joints and one linear joint.
- The axes form a polar coordinate system and create a spherical-shaped work envelope.

SCARA –

- Commonly used in assembly applications, this selectively compliant arm for robotic assembly is primarily cylindrical in design.
- It features two parallel joints that provide compliance in one selected plane.

Delta –

- These spider-like robots are built from jointed parallelograms connected to a common base.
- The parallelograms move a single EOAT in a dome-shaped work area.
- Heavily used in the food, pharmaceutical, and electronic industries, this robot configuration is capable of delicate, precise movement.

❖ **Examples** are

- ✓ the **robot** dog Aibo,
- ✓ the Roomba vacuum,
- ✓ AI- powered **robot** assistants, and
- ✓ a growing variety of **robotic** toys and kits.