CBSE Examination Paper, 2018

Time Allowed: 3 Hours | **Maximum Marks: 70**

General Instructions:

(*i*) **All** questions are **compulsory**. There are **26** questions in all.

(*ii*) This question paper has **five** sections: Section **A**, Section **B**, Section **C**, Section **D** and Section **E**.

(*iii*) Section **A** contains **five** questions of **one** mark each, Section **B** contains **five** questions of **two** marks each, Section **C** contains **twelve** questions of **three** marks each, Section **D** contains **one** value based question of **four** marks and Section **E** contains **three** questions of **five** marks each.

(*iv*) There is no overall choice. However, an internal choice has been provided in **one** question of **two** marks, **one** question of **three** marks and all **three** questions of **five** marks weightage. You have to attempt only **one** of the choices in such questions.

(*v*) You may use the following values of physical constants wherever necessary:

$$c = 3 \times 10^{8} \text{ m/s}$$

$$h = 6.63 \times 10^{-34} \text{ Js}$$

$$e = 1.6 \times 10^{-19} \text{ C}$$

$$\mu_0 = 4\pi \times 10^{-7} \text{ T m A}^{-1}$$

$$\varepsilon_0 = 8.854 \times 10^{-12} \text{ C}^2\text{N}^{-1}\text{m}^{-2}$$

$$\frac{1}{4\pi\varepsilon_0} = 9 \times 10^{9} \text{ N m}^2 \text{ C}^{-2}$$

Mass of electron $= 9.1 \times 10^{-31}$ kg

Mass of neutron $= 1.675 \times 10^{-27}$ kg

Mass of proton $= 1.673 \times 10^{-27}$ kg

Avogadro's number $= 6.023 \times 10^{23}$ per gram mole

Boltzmann constant $= 1.38 \times 10^{-23}$ JK^{-1}

NOTE: In Set 2 and Set 3, only the order of questions is different.

Physics—12

SECTION A

1. A proton and an electron travelling along parallel paths enter a region of uniform magnetic field, acting perpendicular to their paths. Which of them will move in a circular path with higher frequency? 1

Ans. Electron

Reason: $\because$ Frequency $\nu = \dfrac{Bq}{2\pi m}$ as $\nu \propto \dfrac{1}{m}$ and $m_e << m_p$

$\therefore$ $$\nu_e >> \nu_p$$

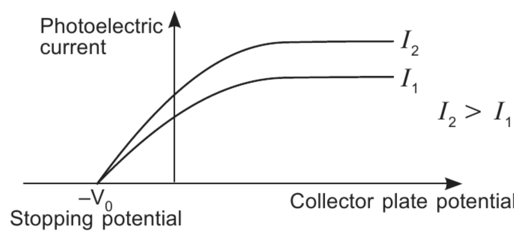
Thus electron will move in circular path with higher frequency.

2. Name the electromagnetic radiations used for (*a*) water purification, and (*b*) eye surgery. 1

Ans. UV rays in both the cases.

3. Draw graphs showing variation of photoelectric current with applied voltage for two incident radiations of equal frequency and different intensities. Mark the graph for the radiation of higher intensity. 1

Ans.



4. Four nuclei of an element undergo fusion to form a heavier nucleus, with release of energy. Which of the two — the parent or the daughter nucleus — would have higher binding energy per nucleon? 1

Ans. Daughter nucleus will have higher B.E./nucleon.

5. Which mode of propagation is used by short wave broadcast services? 1

Ans. Sky wave propagation.

SECTION B

6. Two electric bulbs *P* and *Q* have their resistances in the ratio of 1 : 2. They are connected in series across a battery. Find the ratio of the power dissipation in these bulbs. 2

Ans. Electric bulbs P and Q are connected in series, therefore current flowing through them is same.

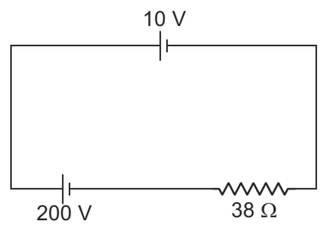
$\because$ Power $P = I^2R$

$\therefore$ Power for bulb P is $P_1 = I^2R_1$

Power for bulb Q is $P_2 = I^2R_2$

$\therefore$ $\frac{P_1}{P_2} = \frac{R_1}{R_2} = \frac{1}{2}$ $\left[\because \frac{R_1}{R_2} = \frac{1}{2} \text{ is given}\right]$

7. A 10 V cell of negligible internal resistance is connected in parallel across a battery of emf 200 V and internal resistance 38 Ω as shown in the figure. Find the value of current in the circuit. **2**



Or

In a potentiometer arrangement for determining the emf of a cell, the balance point of the cell in open circuit is 350 cm. When a resistance of 9 Ω is used in the external circuit of the cell, the balance point shifts to 300 cm. Determine the internal resistance of the cell. **2**

Ans. Equivalent emf = $\varepsilon = 200 - 10 = 190$ V

Internal resistance $r = 38\ \Omega$

$\therefore$ Current in the given circuit $I = \frac{\varepsilon}{r} = \frac{190}{38} = 5$ A

Or

Given: $l_1 = 350$ cm (open circuit), $l_2 = 300$ cm, $R = 9\ \Omega$

$\because$ Internal resistance of a cell $= r = R\left(\frac{l_1}{l_2} - 1\right)$

$$r = 9\left(\frac{350}{300} - 1\right) = 1.5\ \Omega$$

8. (*a*) Why are infrared waves often called heat waves? Explain.

(*b*) What do you understand by the statement, "Electromagnetic waves transport momentum"? **2**

Ans. (*a*) Infrared waves are produced by the vibration of atoms and molecules. Infrared waves are referred as the heat waves because the water molecules present in most materials readily absorb infrared waves. Thus, their thermal motion increases. They heat up and heat their surroundings. Infrared waves are used in earth's satellites and electronic devices.

(*b*) Electromagnetic waves carry both the energy and the momentum, therefore, they exert pressure on the surface they fall.

9. If light of wavelength 412.5 nm is incident on each of the metals given below, which ones will show photoelectric emission and why? 2

Metal	Work function (eV)
Na	1.92
K	2.15
Ca	3.20
Mo	4.17

Ans. Na and K

$\because$ $\lambda = 412.5$ nm $= 412.5 \times 10^{-9}$ m; $h = 6.63 \times 10^{-34}$ J.s.; $c = 3 \times 10^8$ m/s

Energy of incident radiation $= E = \dfrac{hc}{\lambda}$

$$E = \frac{6.63 \times 10^{-34} \times 3 \times 10^{8}}{412.5 \times 10^{-9} \times 1.6 \times 10^{-19}} \text{ eV}$$

$$= 3.01 \text{ eV}$$

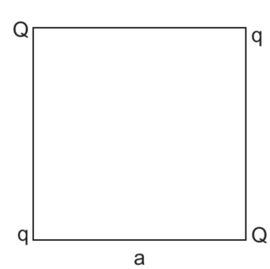
10. A carrier wave of peak voltage 15 V is used to transmit a message signal. Find the peak voltage of the modulating signal in order to have a modulation index of 60%. 2

Ans. Modulation index $\mu = \dfrac{A_m}{A_c}$, when $A_c = 15$ V, $A_m = ?$, $\mu = 60\% = \dfrac{60}{100} = 0.6$

$\therefore$ $0.6 = \dfrac{A_m}{15} = 9.0$ V

SECTION C

11. Four point charges *Q*, *q*, *Q* and *q* are placed at the corners of a square of side '*a*' as shown in the figure.



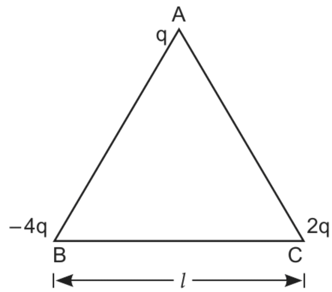
Find the

(*a*) resultant electric force on a charge Q, and

(*b*) potential energy of this system. **3**

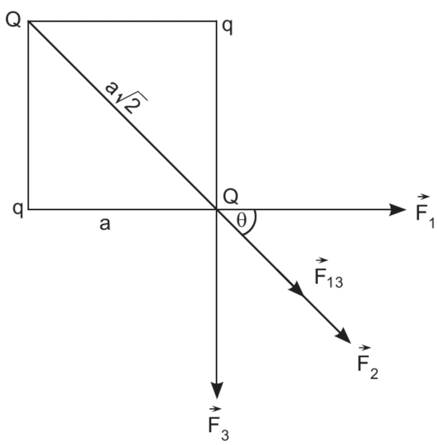
Or

(*a*) Three point charges q, $-4q$ and $2q$ are placed at the vertices of an equilateral triangle ABC of side 'l' as shown in the figure. Obtain the expression for the magnitude of the resultant electric force acting on the charge q.



(*b*) Find out the amount of the work done to separate the charges at infinite distance. **3**

Ans. (*a*)



$\vec{F_1}, \vec{F_2}$ and $\vec{F_3}$ are three forces exerted by charges q, Q and q respectively on electric charge Q.

$$\because \qquad \vec{F_1} \perp \vec{F_3}$$

$$\therefore \quad \text{Resultant of } \vec{F_1} \text{ and } \vec{F_3} = F_{13} = \sqrt{F_1^2 + F_3^2}$$

$$F_{13} = \sqrt{\left(\frac{kqQ}{a^2}\right)^2 + \left(\frac{kqQ}{a^2}\right)^2}$$

$$F_{13} = \frac{kqQ}{a^2} . \sqrt{2} \qquad ...(i)$$

Direction of $\overrightarrow{F_{13}}$ is given by $\tan\theta = \dfrac{F_3}{F_1} = 1 = \tan 45°,\ \theta = 45°$

$$\therefore \quad \overrightarrow{F_{13}} \ || \ \overrightarrow{F_2}$$

$$\therefore \quad \text{Resultant force on } Q = F_{13} + F_2$$

$$= \frac{kqQ}{a^2}.\sqrt{2} + \frac{kQ^2}{(a\sqrt{2})^2}$$

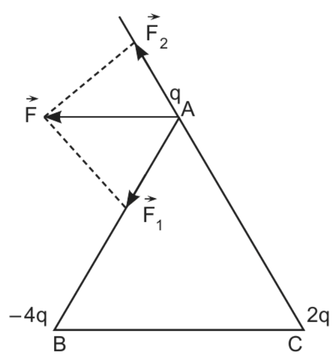
$$\therefore \quad F = \frac{kQ}{a^2}\left[\sqrt{2}\,q + \frac{Q}{2}\right], \text{ along diagonal}$$

(*b*)
$$\text{P.E.} = U = k\left[\frac{qQ}{a} + \frac{qQ}{a} + \frac{qQ}{a} + \frac{qQ}{a} + \frac{q^2}{a\sqrt{2}} + \frac{Q^2}{a\sqrt{2}}\right]$$

$$\therefore \quad U = k\left[\frac{4qQ}{a} + \frac{q^2}{a\sqrt{2}} + \frac{Q^2}{a\sqrt{2}}\right]$$

Or

(*a*) Using Coulomb's law



$$\overrightarrow{F_1} = \text{Force on } q \text{ due to } -4q$$

$$= \frac{k\,|\,q.(-4q)\,|}{l^2}\hat{AB}$$

$$\overrightarrow{F_2} = \text{Force acting on } q \text{ due to } 2q \text{ charge}$$

$$\overrightarrow{F_2} = \frac{k\,|\,q.2q\,|}{l^2}\hat{CA}$$

Angle between $\overrightarrow{F_1}$ and $\overrightarrow{F_2}$ is 120°

∴ Magnitude of Resultant force,

$$F = \sqrt{F_1^2 + F_2^2 + 2F_1F_2\cos 120°}$$

$$= \sqrt{\left(\frac{k.4q^2}{l^2}\right)^2 + \left(\frac{k.2q^2}{l^2}\right)^2 + 2\left(\frac{k.4q^2}{l^2}\right)\left(\frac{k\,2q^2}{l^2}\right)\cos 120°}$$

$$= \frac{kq^2}{l^2}\sqrt{4^2+2^2-\left(2\times4\times2\times\frac{1}{2}\right)}$$

$$= \frac{1}{4\pi\varepsilon_0}\cdot\frac{q^2}{l^2}\sqrt{12} \qquad \left[\because\ k=\frac{1}{4\pi\varepsilon_0}\right]$$

(*b*) Work done $= U_\infty - U_i$

$$= 0 - \left[\frac{kq(-4q)}{l}+\frac{k(-4q)(2q)}{l}+\frac{kq\,.\,2q}{l}\right]$$

$$W = -\left[\frac{-10kq^2}{l}\right] = \frac{1}{4\pi\varepsilon_0}\cdot\frac{10q^2}{l}$$

12. (*a*) Define the term 'conductivity' of a metallic wire. Write its SI unit.

(*b*) Using the concept of free electrons in a conductor, derive the expression for the conductivity of a wire in terms of number density and relaxation time. Hence obtain the relation between current density and the applied electric field *E*. **3**

Ans. (*a*) **Conductivity:** It is the reciprocal of resistivity.

$$\sigma = \frac{1}{\rho}$$

S.I. unit: $(\Omega\text{ m})^{-1}$ or mho. m^{-1} or S m^{-1}

(*b*) The acceleration $\vec{a} = \frac{-e\vec{E}}{m}$

The average drift velocity $\vec{v_d}$ is given by

$$|\vec{v_d}| = \left|\frac{-e\vec{E}}{m}\tau\right| = \frac{eE\tau}{m}$$

(τ = Average relaxation time)

$$\text{If } n = \frac{\text{Number of free electrons}}{\text{Volume}}$$

Then current I is given by

$$I = neA\,|\vec{v_d}| = neAv_d$$

$\therefore$ Current density $= j = \frac{I}{A} = nev_d = ne\left(\frac{eE}{m}\tau\right)$

$$j = \frac{ne^2E\tau}{m}$$

$\because$ Conductivity $= \sigma = \frac{ne^2\tau}{m}$

$\therefore$ Current density $= j = \sigma E$ or $\vec{j} = \sigma\vec{E}$

13. A bar magnet of magnetic moment 6 J/T is aligned at 60° with a uniform external magnetic field of 0.44 T. Calculate (*a*) the work done in turning the magnet to align its magnetic moment (*i*) normal to the magnetic field, (*ii*) opposite to the magnetic field, and (*b*) the torque on the magnet in the final orientation in case (*ii*). **3**

Ans. Magnetic moment = M = 6 JT^{-1}, $\theta_1 = 60°$, $B = 0.44$ T

(*a*) (*i*) $W = ?;\ \theta_2 = 90°$

$$W = -MB[\cos 90° - \cos 60°] = MB \cos 60°$$

$$= 6 \times 0.44 \times \frac{1}{2} = 1.32 \text{ J}$$

(*ii*) $\theta_2 = 180°, \cos 180° = -1$

$\therefore$ $$W = -MB[\cos 180° - \cos 60°]$$

$$= MB + MB \times \frac{1}{2} = \frac{3}{2} \times MB = 3.96 \text{ J}$$

(*b*) Torque $\tau = MB \sin 180° = 0$

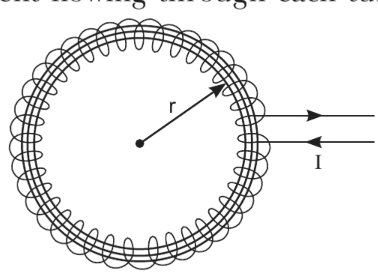
14. (*a*) An iron ring of relative permeability μ_r has windings of insulated copper wire of *n* turns per metre. When the current in the windings is *I*, find the expression for the magnetic field in the ring.

(*b*) The susceptibility of a magnetic material is 0.9853. Identify the type of magnetic material. Draw the modification of the field pattern on keeping a piece of this material in a uniform magnetic field. **3**

Ans. (*a*) Given: μ_r = Relative permeability of iron ring

n = Number of turns of copper wire wound over $\frac{\text{ring}}{\text{meter}} = \frac{N}{2\pi r}$

I = Current flowing through each turn



Using Ampere's circuital law

$$\oint \vec{B} \cdot \vec{dl} = \mu_0 \mu_r I_{enclosed} \qquad ...(i)$$

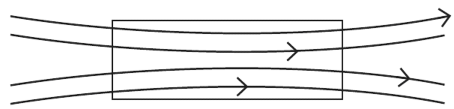
$$\oint B dl \cos 0° = \mu_0 \mu_r (2\pi r n) I$$

(Here $I_{enclosed} = NI = 2\pi r n I$ and r – radius of the ring)

$\therefore$ $$B \oint dl = \mu_0 \mu_r\ 2\pi r n I$$

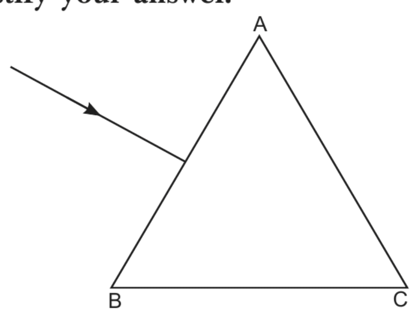
$$B \cdot 2\pi r = \mu_0 \mu_r \cdot 2\pi r n I$$
$$B = \mu_0 \mu_r nI$$

(*b*) Paramagnetic

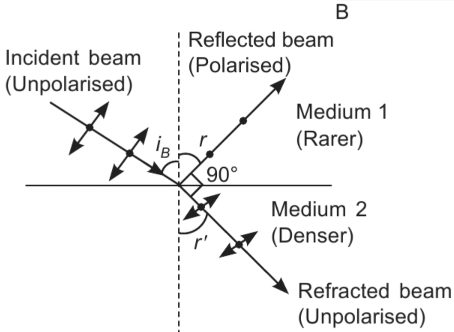


15. (*a*) Show using a proper diagram how unpolarised light can be linearly polarised by reflection from a transparent glass surface.

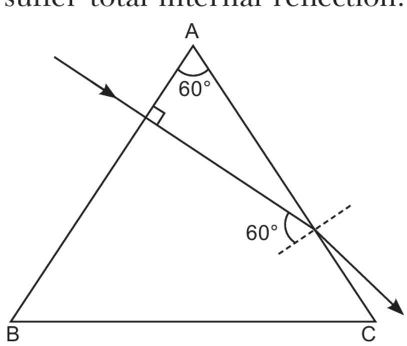
(*b*) The figure shows a ray of light falling normally on the face AB of an equilateral glass prism having refractive index $\frac{3}{2}$, placed in water of refractive index $\frac{4}{3}$. Will this ray suffer total internal reflection on striking the face AC? Justify your answer. **3**



Ans. (*a*)



(*b*) No, Ray will not suffer total internal reflection.



Reason:

$\because$ Condition for Total Internal Reflection is that the incident angle must be greater than critical angle for pair of media, i.e. $i > i_c$, as prism is placed in water, therefore

$$\frac{\eta_g}{\eta_w} = \frac{1}{\sin i_c}$$

$$\Rightarrow \quad \sin i_c = \frac{\eta_w}{\eta_g} = \frac{4}{3} \times \frac{2}{3}$$

$$\therefore \quad \sin i_c = \frac{8}{9} = 0.889 \qquad \left[\because \; \eta_w = \frac{4}{3}, \eta_g = \frac{3}{2}\right]$$

and $\sin i = \sin 60° = \frac{\sqrt{3}}{2} = 0.867$

$\therefore$ $\sin i < \sin i_c \Rightarrow i < i_c$, Thus, total internal reflection do not occur.

16. (*a*) If one of two identical slits producing interference in Young's experiment is covered with glass, so that the light intensity passing through it is reduced to 50%, find the ratio of the maximum and minimum intensity of the fringe in the interference pattern.

(*b*) What kind of fringes do you expect to observe if white light is used instead of monochromatic light? **3**

Ans. (*a*) For maximum intensity $\phi = 0$, $I_{max} = (\sqrt{I_1} + \sqrt{I_2})^2$

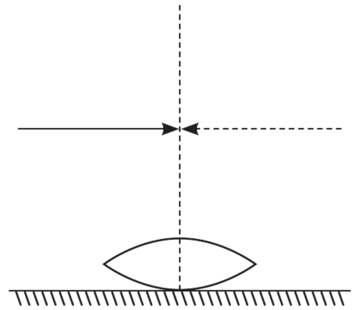
For minimum intensity $\phi = 180°$, $I_{min} = (\sqrt{I_1} - \sqrt{I_2})^2$

$$\because \quad I_1 = I_0 \text{ and } I_2 = \frac{I_0}{2} \qquad [50\% \text{ of } I_0]$$

$$\therefore \quad \frac{I_{max}}{I_{min}} = \frac{\left[\sqrt{I_0} + \sqrt{\frac{I_0}{2}}\right]^2}{\left[\sqrt{I_0} - \sqrt{\frac{I_0}{2}}\right]^2} = \frac{(\sqrt{2}+1)^2}{(\sqrt{2}-1)^2}$$

(*b*) Central maximum will be white, because all the colours will interfere there in phase. But, other fringes will be coloured of different width with fading intensity.

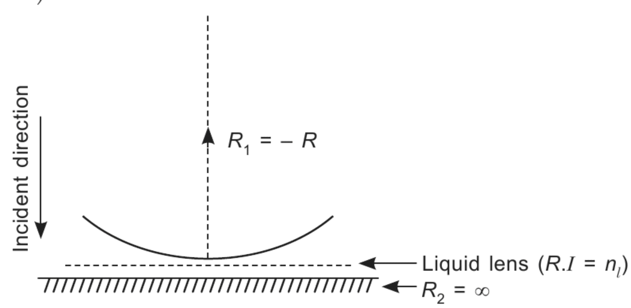
17. A symmetric biconvex lens of radius of curvature *R* and made of glass of refractive index 1.5, is placed on a layer of liquid placed on top of a plane mirror as shown in the figure. An optical needle with its tip on the principal axis of the lens is moved along the axis until its real, inverted image coincides with the needle itself. The distance of the needle from the lens is measured to be *x*. On removing the liquid layer and repeating the experiment, the distance is found to be *y*. Obtain the expression for the refractive index of the liquid in terms of *x* and *y*. **3**



Ans. Focal length of a convex lens $= f_i = y$ cm

Let focal length of a liquid lens (Concave plane lens) $= f_2$

Given, focal length of a system consisting of convex lens and liquid lens $= f = x$ (given)



$$\because \qquad \frac{1}{f} = \frac{1}{f_1} + \frac{1}{f_2}$$

$$\Rightarrow \qquad \frac{1}{x} = \frac{1}{y} + \frac{1}{f_2}$$

$$\therefore \qquad f_2 = \frac{xy}{y-x} \qquad ...(i)$$

R.I. of material of convex lens (glass) = 1.5

If R be the radius of curvature of each surface of lens, then

Using lens Maker's formula for convex lens

$$\frac{1}{y} = (1.5-1)\left[\frac{1}{R} - \left(\frac{1}{-R}\right)\right] \quad [\therefore \quad R_1 = R, R_2 = -R]$$

$$\frac{1}{y} = 0.5 \times \frac{2}{R} \quad \Rightarrow \quad R = y$$

If n_l = R.I. of liquid then, $R_1 = -R$, $R_2 = \infty$

Focal length of plane concave liquid lens is by obtained

$$\frac{1}{f_2} = (n_l - 1)\left[\frac{1}{-R} - \frac{1}{\infty}\right]$$

$$\frac{1}{f_2} = (n_l - 1)\frac{1}{-y} = \frac{(1-n_l)}{y}$$

$$\Rightarrow \quad f_2 = \frac{y}{1-n_l} \qquad \text{...}(ii)$$

Equating equations (*i*) and (*ii*), we get

$$\frac{xy}{y-x} = \frac{y}{1-n_l}$$

$$x(1 - n_l) = y - x$$

$$x - x\,n_l = y - x$$

$$2x - y = x\,n_l$$

$$\Rightarrow \quad n_l = \frac{2x-y}{x}$$

18. (*a*) State Bohr's postulate to define stable orbits in hydrogen atom. How does de Broglie's hypothesis explain the stability of these orbits?

(*b*) A hydrogen atom initially in the ground state absorbs a photon which excites it to the $n = 4$ level. Estimate the frequency of the photon. 3

Ans. (*a*) **Bohr's Second Postulate:** Electrons revolve around the nucleus only in those orbits for which the angular momentum of electrons is an integral multiple of $\frac{h}{2\pi}$.

i.e. $$mvr = \frac{nh}{2\pi},\ n = 1, 2, \ldots$$

As per de Broglie's hypothesis

$$\lambda = \frac{h}{mv} \qquad \text{...}(i)$$

For stable orbit, we must have circumference of the orbit equal to an integral multiple of λ

$$2\pi r = n\lambda \qquad \text{...}(ii)$$

From (*i*) and (*ii*) $$mvr = \frac{nh}{2\pi}$$

Thus, de Broglie showed that formation of stationary pattern for integral value of n gives rise to stability of the atom.

(*b*) $\because\ E_n = \frac{-13.6}{n^2}$ eV, In ground state $n = 1$, $E_1 = -13.6$ eV

When $n = 4$, $E_4 = \frac{-13.6}{4^2}$ eV

$\therefore$ Frequency of emitted photon will be calculated as follow:

$$h\nu = E_4 - E_1$$

$$= \frac{-13.6}{16} - (-13.6)$$

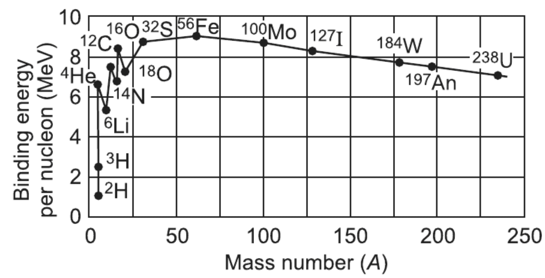
$$= 13.6\left[1-\frac{1}{16}\right] = \frac{15}{16}\times 13.6 \text{ eV}$$

$$\therefore \qquad \nu = \frac{15}{16}\times\frac{13.6\times 1.6\times 10^{-19}}{6.63\times 10^{-34}}\text{ Hz} = 3.1\times 10^{15}\text{ Hz}$$

19. (*a*) Explain the processes of nuclear fission and nuclear fusion by using the plot of binding energy per nucleon (BE/A) versus the mass number A.

(*b*) A radioactive isotope has half-life of 10 years. How long will it take for the activity to reduce to 3.125%? 3

Ans. (*a*)



The binding energy per nucleon of as a function of the mass number

From the plot, we see that

(*i*) During nuclear fission, a heavy nucleus (for A > 170) breaks into two middle level nuclei, resulting in increase in B.E./nucleon, with release of tremendous amount of energy.

(*ii*) During nuclear fission light nuclei (for A < 30) fuse together to form a bigger nucleus having higher B.E./nucleon. Hence, energy gets released.

(*b*) Activity $= R = 3.125\% = \frac{3.125}{100} = \left(\frac{1}{2}\right)^5$

Half life $= T_{1/2} = 10$ years

$$\because \qquad \frac{R}{R_0} = \left(\frac{1}{2}\right)^n = \left(\frac{1}{2}\right)^5,$$

Where n = Numbers of half life

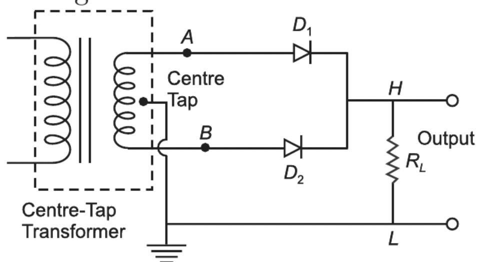
$$\therefore \qquad n = 5 = \frac{\text{Total time } (t)}{\text{Half life } (T_{1/2})}$$

$$\therefore \qquad t = 5\times 10 = 50 \text{ years}$$

20. (*a*) A student wants to use two *p-n* junction diodes to convert alternating current into direct current. Draw the labelled circuit diagram she would use and explain how it works.

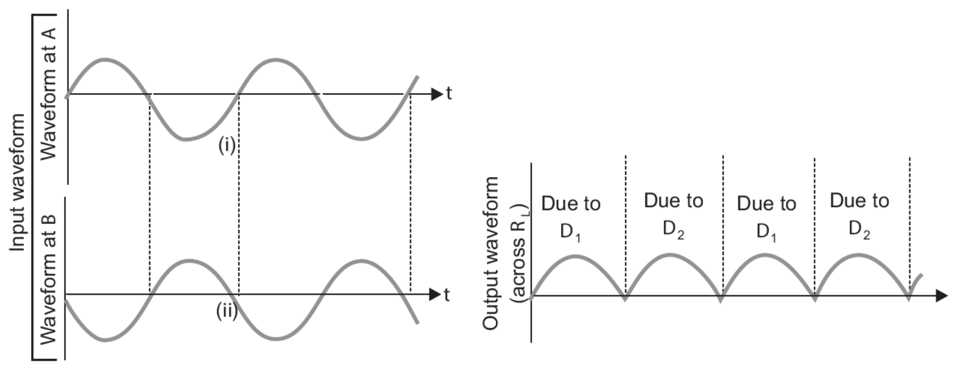
(*b*) Give the truth table and circuit symbol for NAND gate. 3

Ans. (*a*) During the first half of the cycle, if A is at higher potential with respect to centre tap and B is at lower potential, the diode D_1 being forward biased conducts and the diode D_2 being reverse biased does not conduct. The current flows through the load in the sense H to L. During the second half of the cycle, conditions get reversed and only diode D_2 conducts. Again, the current flows through the load in the sense H to L.



A full-wave rectifier

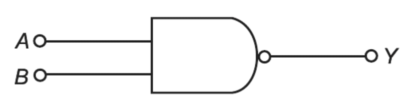
Thus, in the output, we get a unidirectional current.



(*b*) ***NAND Gate***

Truth Table		
A	*B*	*Y*
0	0	1
1	0	1
0	1	1
1	1	0

Logic Symbol

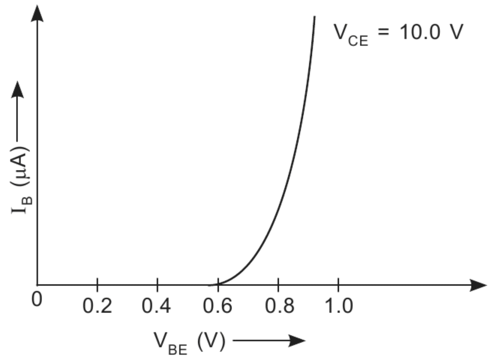


$Y = \overline{A \cdot B}$
(read as 'Y is A AND B NOT')

21. Draw the typical input and output characteristics of an *n-p-n* transistor in CE configuration. Show how these characteristics can be used to determine (*a*) the input resistance (r_i) and (*b*) current amplification factor (β). 3

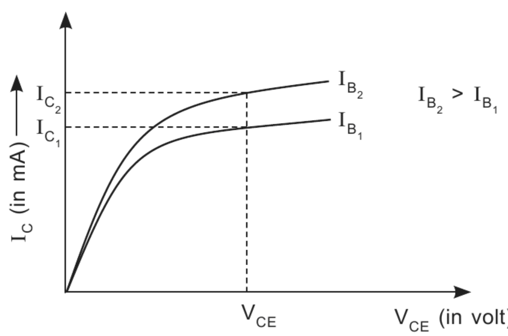
Ans. *n-p-n* transistor in CE configuration

Input characteristics:



(*a*) Input Resistance $r_i = \left(\frac{\Delta V_{BE}}{\Delta I_B}\right)_{V_{CE}}$

Output characteristics



(*b*) Current amplification factor $\beta_{a.c.} = \left(\frac{\Delta I_C}{\Delta I_B}\right)_{V_{CE}}$

Here, $\Delta I_B = I_{B_2} - I_{B_1}$

$\Delta I_C = I_{C_2} - I_{C_1}$

22. (*a*) Give three reasons why modulation of a message signal is necessary for long distance transmission.

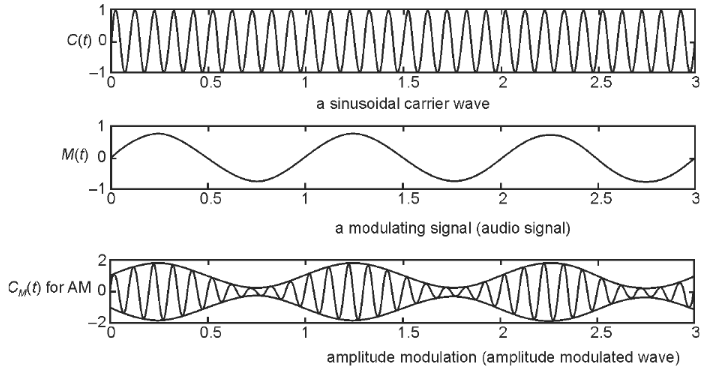
(*b*) Show graphically an audio signal, a carrier wave and an amplitude modulated wave. **3**

Ans. (*a*) (*i*) Transmission with reasonable antenna length is possible.

(*ii*) A large number of signals when sent through same channel do not get mixed up.

(*iii*) Power of radiation of signals increases.

(*b*)



SECTION D

23. The teachers of Geeta's school took the students on a study trip to a power generating station, located nearly 200 km away from the city. The teacher explained that electrical energy is transmitted over such a long distance to their city, in the form of alternating current (ac) raised to a high voltage. At the receiving end in the city, the voltage is reduced to operate the devices. As a result, the power loss is reduced. Geeta listened to the teacher and asked questions about how the ac is converted to a higher or lower voltage.

(*a*) Name the device used to change the alternating voltage to a higher or lower value. State one cause for power dissipation in this device.

(*b*) Explain with an example, how power loss is reduced if the energy is transmitted over long distances as an alternating current rather than a direct current.

(*c*) Write two values each shown by the teachers and Geeta. 4

Ans. (*a*) Transformer

Power losses in a transformer: Various power losses in a transformer and the ways by which they can be minimised are:

Power Loss	Minimised by
(*i*) Joule's heating of the primary and secondary windings	(*i*) Using thick wires of materials having low resistivity, e.g. copper.
(*ii*) Heating of the core due to eddy currents.	(*ii*) Using an insulated laminated core.
(*iii*) Hysteresis loss.	(*iii*) Using a material having low hysteresis loss as the core, e.g. soft iron.
(*iv*) Flux leakage or incomplete flux linkage.	(*iv*) Using a closed soft iron core shaped to follow field lines.

(*any one*)

(*b*) AC voltage can be stepped up to high value, which reduces the current in the output, therefore during transmission power loss (I^2R) is reduced considerably, while such increase in voltage is not possible for direct current.

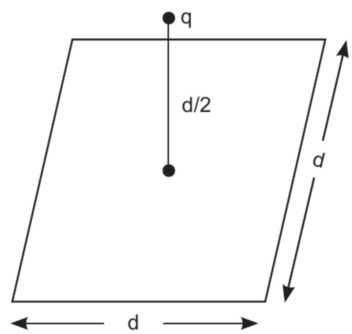
(*c*) **Teacher:** Concerned, caring, ready to share knowledge.

Geeta: Inquisitive, scientific temper, good. (*any two values for each*)

SECTION E

24. (*a*) Define electric flux. Is it a scalar or a vector quantity?

A point charge q is at a distance of $d/2$ directly above the centre of a square of side d, as shown in the figure. Use Gauss' law to obtain the expression for the electric flux through the square.



(*b*) If the point charge is now moved to a distance '*d*' from the centre of the square and the side of the square is doubled, explain how the electric flux will be affected. 5

Or

(*a*) Use Gauss' law to derive the expression for the electric field ($\vec{E}$) due to a straight uniformly charged infinite line of charge density λ C/m.

(*b*) Draw a graph to show the variation of E with perpendicular distance r from the line of charge.

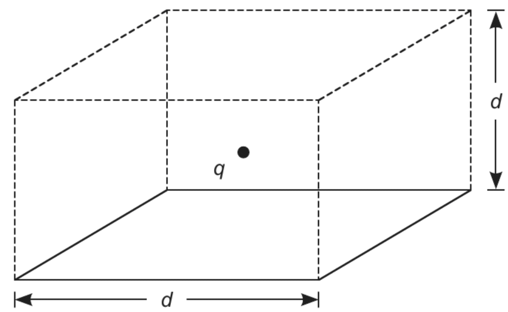
(*c*) Find the work done in bringing a charge q from perpendicular distance r_1 to r_2 ($r_2 > r_1$). 5

Ans. (*a*) Electric flux through an area is the product of the magnitude of the area and the component of electric field vector normal to it.

$$\phi_E = \Delta S\ (E \cos\theta) = \vec{E}.\Delta\vec{S}$$

Its SI unit is $NC^{-1}\ m^2$. It is a scalar quantity.

(*b*)



Enclosing a charge q in a cube each of edge 'd' and using Gauss's law that

Electric flux (ϕ) through the cube $= \dfrac{\text{Charge enclosed}}{\varepsilon_0} = \dfrac{q}{\varepsilon_0}$

There are 6 faces of cube in total.

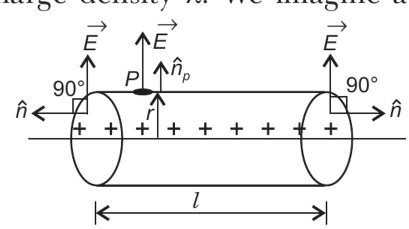
$\therefore$ Electric flux through one face $= \dfrac{1}{6} \cdot \dfrac{q}{\varepsilon_0}$

If side of a square is increased to $2d$ then we can again construct a Gaussian surface in the form of a cube of each side $2d$, which encloses same charge q, then also electric flux through the cube $= \dfrac{q}{\varepsilon_0}$

And through each face $= \dfrac{1}{6} \cdot \dfrac{q}{\varepsilon_0}$, i.e. remains unchanged.

Or

(*a*) Consider a linear charge distribution with charge density λ. We imagine a symmetrical Gaussian surface around length l of this distribution in such a way that the point P where we have to calculate electric field lies on it.



Electric flux through the circular faces of this Gaussian surface is zero.

$$\phi_s = \int \vec{E} \cdot \vec{ds} = E ds \cos 90° = 0 \qquad (\because \theta = 90°)$$

Electric flux through the curved surface is given by

$$\phi_{cs} = \oint \vec{E} \cdot \vec{ds} = \oint E\, ds$$

$$\phi_{cs} = E \oint ds = E(2\pi r l) \qquad (\because \theta = 0°)$$

Net flux through the Gaussian surface is given by

$$\phi_E = \phi_s + \phi_{cs} = E(2\pi r l) \qquad \ldots(i)$$

According to the Gauss's theorem

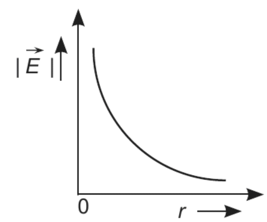
$$\phi_E = \frac{q}{\varepsilon_0} = \frac{\lambda l}{\varepsilon_0} \qquad (\because q = \lambda l) \ldots(ii)$$

From equations (*i*) and (*ii*), we get

$$E = \frac{\lambda}{2\pi\varepsilon_0 r} \Rightarrow E \propto \frac{1}{r}$$

$$\vec{E} = \frac{\lambda}{2\pi\varepsilon_0 r} . \hat{n}$$

(*b*)



(*c*) Work done in moving a charge '*q*' through a small displacement $d\vec{r}$ is given by

$$dW = \vec{F} . d\vec{r} = q\vec{E} . d\vec{r}$$

$$\text{dW} = qEdr \cos\theta \ (\theta = 0° \text{ and } \cos 0° = 1)$$

$$dW = q \times \frac{\lambda}{2\pi\varepsilon_0 r} dr$$

$$\because \quad E = \frac{\lambda}{2\pi\varepsilon_0 r}$$

Work done in moving the given charge from r_1 to r_2 ($r_2 > r_1$)

$$W = \int_{r_1}^{r_2} dW = \frac{\lambda q}{2\pi\varepsilon_0} \int_{r_1}^{r_2} \frac{dr}{r}$$

$$W = \frac{\lambda q}{2\pi\varepsilon_0} [\log_e r_2 - \log_e r_1]$$

$$W = \frac{\lambda q}{2\pi\varepsilon_0} \log_e \frac{r_2}{r_1}$$

25. (*a*) State the principle of an ac generator and explain its working with the help of a labelled diagram. Obtain the expression for the emf induced in a coil having *N* turns each of cross-sectional area *A*, rotating with a constant angular speed 'ω' in a magnetic field $\vec{B}$, directed perpendicular to the axis of rotation.

(*b*) An aeroplane is flying horizontally from west to east with a velocity of 900 km/hour. Calculate the potential difference developed between the ends of its wings having a span of 20 m. The horizontal component of the Earth's magnetic field is 5×10^{-4} T and the angle of dip is 30°. **5**

Or

A device X is connected across an ac source of voltage $V = V_0 \sin wt$. The current through X is given as $I = I_0 \sin\left(\omega t + \frac{\pi}{2}\right)$.

(*a*) Identify the device X and write the expression for its reactance.

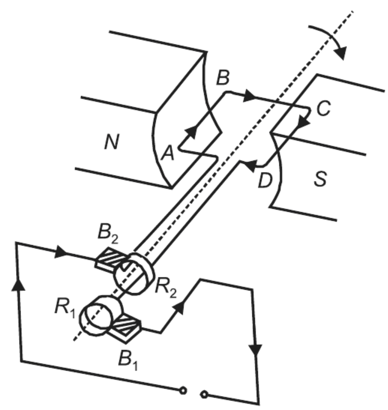
(*b*) Draw graphs showing variation of voltage and current with time over one cycle of ac, for X.

(*c*) How does the reactance of the device X vary with frequency of the ac? Show this variation graphically.

(*d*) Draw the phasor diagram for the device X. **5**

Ans. (*a*) **Principle:** An ac generator is based on the principle of electromagnetic induction.

Working: On rotating the coil in the magnetic field, the magnetic flux linked with the coil changes continuously. This changing magnetic flux induces an emf in the circuit.



Mathematically, $\varepsilon = -\frac{d\phi_B}{dt}$

$[\because \phi = NBA \cos \omega t]$

$= -\frac{d}{dt}(NBA \cos \omega t)$

$= NBA\omega \sin\omega t = \varepsilon_0 \sin \omega t$

Here $\varepsilon_0 = NBA\omega$ = peak value/amplitude of induced emf.

(*b*) Given: $v = 900 \text{ km h}^{-1} = 250 \text{ ms}^{-1}$; $l = 20$ m

B_v (vertical component of B) $= 5 \times 10^{-4} \sin 30°$

$= 2.5 \times 10^{-4}$ T $\quad [\because B_v = B \sin \delta]$

$\therefore$ Induced emf $= e = Blv$

$= 2.5 \times 10^{-4} \times 20 \times 250$ V

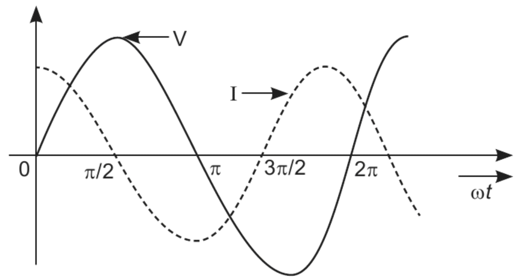
$= 1.44$ V

Or

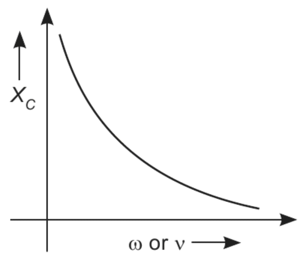
(*a*) $\because$ Current leads the voltage by a phase angle of $\pi/2$, therefore device X is a capacitor.

$$\text{Reactance } X_C = \frac{1}{\omega C} = \frac{1}{2\pi \nu C}$$

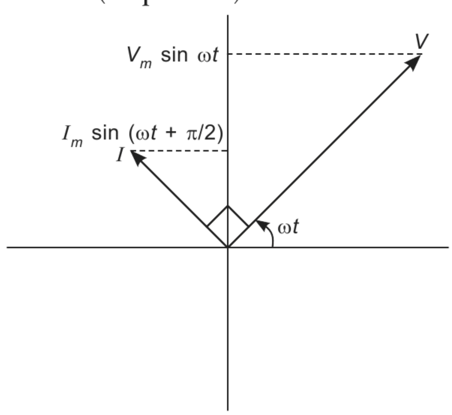
Here, ν = Frequency, C = Capacitance (*b*) Graphs of V and I with time.



(*c*) Reactance of a capacitor is inversely proportional to the frequency of a.c., i.e. $X_C \propto \frac{1}{\nu}$



(*d*) Phasor diagram for X (Capacitor)



26. (*a*) Draw a ray diagram to show image formation when the concave mirror produces a real, inverted and magnified image of the object.

(*b*) Obtain the mirror formula and write the expression for the linear magnification.

(*c*) Explain two advantages of a reflecting telescope over a refracting telescope. **5**

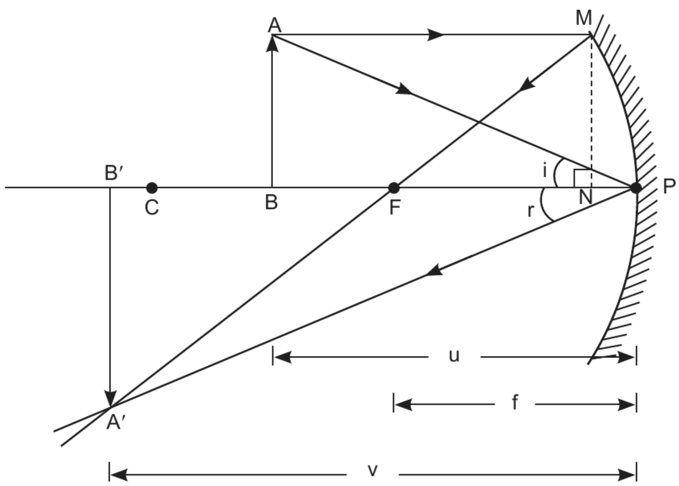
Or

(*a*) Define a wavefront. Using Huygens' principle, verify the laws of reflection at a plane surface.

(*b*) In a single slit diffraction experiment, the width of the slit is made double the original width. How does this affect the size and intensity of the central diffraction band? Explain.

(*c*) When a tiny circular obstacle is placed in the path of light from a distant source, a bright spot is seen at the centre of the obstacle. Explain why. 5

Ans. (*a*)



(*b*) In the figure

$$\Delta ABP \sim \Delta A'B'P \quad \text{(AA similarity)}$$

$$\Rightarrow \quad \frac{AB}{A'B'} = \frac{PB}{PB'} \quad ...(i)$$

Similarly, $\Delta MNF \sim \Delta A'B'F$ (AA similarity)

$$\Rightarrow \quad \frac{MN}{A'B'} = \frac{NF}{B'F} \quad ...(ii)$$

$\because$ $MN = AB$ and NF $\approx PF$, $FB' = PB' - PF$

$\therefore$ Equation (*ii*) becomes

$$\frac{AB}{A'B'} = \frac{PF}{PB' - PF} \quad ...(ii)$$

From equation (*i*) and (*iii*), we get

$$\frac{PB}{PB'} = \frac{PF}{PB' - PF} \quad ...(iv)$$

As per sign convention

$PB = -u$, $PB' = -v$, $PF = -f$

$$\therefore \qquad \frac{-u}{-v} = \frac{-f}{-v-(-f)} \Rightarrow \frac{u}{v} = \frac{-f}{-v+f}$$

$$-uv + uf = -vf$$

$$uf + vf = uv$$

Dividing both sides by uvf

$$\frac{1}{v} + \frac{1}{u} = \frac{1}{f}$$

$$\text{Linear magnification} = m = \frac{\text{Size of image}}{\text{Size of object}}$$

$\therefore$ From equation (i)

$$\frac{-u}{-v} = \frac{h_o}{-h_I}$$

$AB = h_o$, $A'B' = -h_I$

$$\therefore \qquad m = \frac{h_I}{h_o} = \frac{-v}{u}$$

(c) The following are the two advantages of a reflecting type telescope over a refracting type telescope:

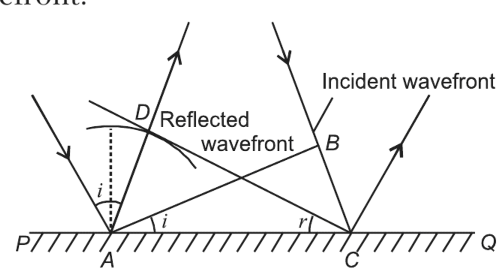
1. As there is no refraction, it is free from the chromatic aberration.
2. The light gathering power of the objective must be higher to get better resolution. It is easier to handle and cheaper to make mirrors of larger diameters.

Or

(a) A wavefront is the locus of all the points in space which receives the light waves from a source in phase.

To verify laws of reflection: A wavefront is the locus of all points oscillating in same phase.

A figure showing reflection of a plane wavefront using Huygen's construction is given below. In the figure AB is the incident wavefront and CD is the reflected wavefront.



If v is speed of the wave in the medium and t is the time taken by the wavefront to cover distance BC, then

$$BC = vt$$

Obviously, $AD = vt$

As ΔABC and ΔADC are congruent.

$\therefore$ $\angle i = \angle r$

(*b*) The size reduces by half according to the relation: size $\sim \lambda/d$. The intensity increases four fold.

Size of central maxima reduces to half.

$\because$ Width of central maximum $= \dfrac{2\lambda D}{a}$, a = size of aperture

$\therefore$ If a is doubled; width of central maxima is reduced to half.

Intensity increases because the amount of light, entering the slit, has increased. Intensity becomes four times.

(*c*) Waves diffracted from the edge of the circular obstacle interfere constructively at the centre of the shadow producing a bright spot.

Examination Papers, 2017

[Delhi Set-I, II, III]

Time Allowed: **3 Hours**] [Maximum Marks: **70**

General Instructions:

(*i*) **All** questions are **compulsory**. There are **26** questions in all.

(*ii*) This question paper has **five** sections: Section **A**, Section **B**, Section **C**, Section **D** and Section **E**.

(*iii*) Section **A** contains **five** questions of **one** mark each, Section **B** contains **five** questions of **two** marks each, Section **C** contains **twelve** questions of **three** marks each, Section **D** contains **one** value based question of **four** marks and Section **E** contains **three** questions of **five** marks each.

(*iv*) There is no overall choice. However, an internal choice has been provided in **one** question of **two** marks, **one** question of **three** marks and all **three** questions of **five** marks weightage. You have to attempt only **one** of the choices in such questions.

(*v*) You may use the following values of physical constants wherever necessary:

$$c = 3 \times 10^8 \text{ m/s}$$

$$h = 6.63 \times 10^{-34} \text{ Js}$$

$$e = 1.6 \times 10^{-19} \text{ C}$$

$$\mu_0 = 4\pi \times 10^{-7} \text{ T m A}^{-1}$$

$$\varepsilon_0 = 8.854 \times 10^{-12} \text{ C}^2\text{N}^{-1}\text{M}^{-2}$$

$$\frac{1}{4\pi\varepsilon_0} = 9 \times 10^9 \text{ N m}^2 \text{ C}^{-2}$$

$$\text{Mass of electron} = 9.1 \times 10^{-31} \text{ kg}$$

$$\text{Mass of neutron} = 1.675 \times 10^{-27} \text{ kg}$$

$$\text{Mass of proton} = 1.673 \times 10^{-27} \text{ kg}$$

$$\text{Avogadro's number} = 6.023 \times 10^{23} \text{ per gram mole}$$

$$\text{Boltzmann constant} = 1.38 \times 10^{-23} \text{ JK}^{-1}$$

SECTION A

1. Does the charge given to a metallic sphere depend on whether it is hollow or solid? Give reason for your answer.

Ans. No. Electric charge resides on the outer surface only.

2. A long straight current carrying wire passes normally through the centre of circular loop. If the current through the wire increases, will there be an induced emf in the loop? Justify.

Ans. No current will be induced since the field lines are lying in the plane of the closed loop.

3. At a place, the horizontal component of earth's magnetic field is *B* and angle of dip is 60°. What is the value of horizontal component of the earth's magnetic field at equator?

Ans. Given: $\delta = 60°$

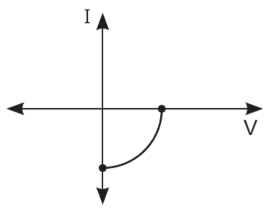
$$\because \quad B_H = B_{net} \cos \delta$$

$$\Rightarrow \quad B_H = B_{net} \cos 60° = B$$

$$\therefore \quad B_{net} \times \frac{1}{2} = B \quad \Rightarrow \quad B_{net} = 2B$$

At equator, dip $(\delta) = 0$, $\therefore \quad (B_H)_{equator} = B_{net} = 2B$

4. Name the junction diode whose I-V characteristics are drawn below.



Ans. Solar cell.

5. How is the speed of em-waves in vacuum determined by the electric and magnetic fields?

Ans. The speed v of e-m waves in vacuum is determined by the relation

$$c = \frac{E_o \text{ (peak value of electric field)}}{B_o \text{ (peak value of magnetic field)}}$$

SECTION B

6. How does Ampere-Maxwell law explain the flow of current through a capacitor when it is being charged by a battery? Write the expression for the displacement current in terms of the rate of change of electric flux.

Ans. When a capacitor is charged by a battery, conduction current flows through the connecting wires, due to which capacitor plates aquire electric charges. Therefore, electric flux between the capacitor plates changes and results in displacement current between the plates, which is given by

$$i_D = \varepsilon_0 \frac{d\phi_E}{dt}$$

7. Define the distance of closest approach. An α-particle of kinetic energy '*K*' is bombarded on a thin gold foil. The distance of the closest approach is '*r*'. What will be the distance of closest approach for an α-particle of double the kinetic energy?

OR

Write two important limitations of Rutherford nuclear model of the atom.

Ans. The minimum distance upto which an energetic α-particle travelling directly towards a nucleus can reach.

The relation between closest approach and kinetic energy of α-particle is given by

$$r = \frac{2Ze^2}{4\pi\varepsilon_0 K}$$

$$r \propto \frac{1}{K}$$

So, when kinetic energy is doubled, the distance of closest approach will reduce to half.

OR

Limitations of Rutherford's atomic model:

(*i*) This model cannot explain the stability of an atom, as according to electromagnetic theory revolving electron should continuously radiate energy and move in orbits of gradually decreasing radii and finally it should collapse into the nucleus.

(*ii*) As electron can revolve in orbits of all possible radii, so it should emit a continuous spectrum. But, spectrum of hydrogen atom is always a discrete line spectrum.

8. **Find out the wavelength of the electron orbiting in the ground state of hydrogen atom.**

Ans. ∵
$$E_n = \frac{-13.6\,\text{eV}}{n^2}$$

In ground state $n = 1$

∴
$$\text{K.E.} = 13.6\text{ eV} = 13.6 \times 1.6 \times 10^{-19}\text{ J}$$
$$\text{K.E.} = 2.2 \times 10^{-18}\text{ J}$$

∴ de Broglie wavelength associated with an electron

$$\lambda = \frac{h}{\sqrt{2m\text{K.E.}}} = \frac{6.63\times10^{-34}}{\sqrt{2\times9.1\times10^{-31}\times2.2\times10^{-18}}}$$
$$\lambda = 0.33 \times 10^{-9}\text{ m} = 3.3\text{ Å}$$

9. **Define the magnifying power of a compound microscope when the final image is formed at infinity. Why must both the objective and the eyepiece of a compound microscope has short focal lengths? Explain.**

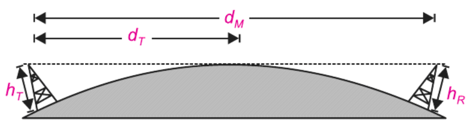
Ans. **Magnifying power:** It is the ratio of the angle subtended by the image formed at infinity to the angle subtended on the eye by the object placed at least distance of distinct vision.

∵
$$m = \frac{-D}{f_e}\cdot\frac{L}{f_o}$$

Therefore, to increase angular magnification, f_o and f_e should be small.

10. **Which basic mode of communication is used in satellite communication? What type of wave propagation is used in this mode? Write, giving reason, the frequency range used in this mode of propagation.**

Ans. The basic mode of communication used in satellite communication is broadcast. Space wave propagation is used in this mode.



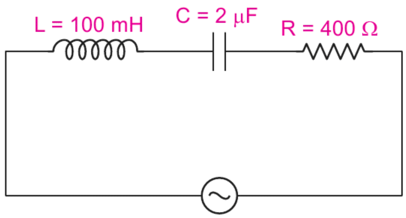
Space wave mode of propagation

Frequencies above 40 MHz cannot be reflected back by ionosphere. So, to increase the range, we use space waves. Space waves get intercepted by satellites and are retransmitted towards the earth station.

SECTION C

11. **(*i*) Find the value of the phase difference between the current and the voltage in the series LCR circuit shown below. Which one leads in phase : current or voltage?**

(*ii*) Without making any other change, find the value of the additional capacitor C_1, to be connected in parallel with the capacitor C, in order to make the power factor of the circuit unity.



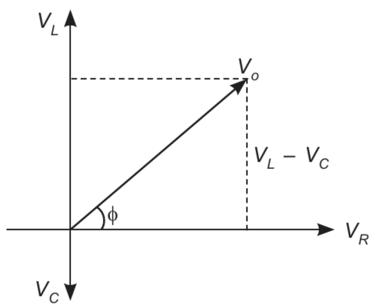
Ans. Given: $V = V_o \sin(100t + \phi)$, $L = 100$ mH, $C = 2$ μF

$\omega = 1000 \text{ rad s}^{-1}$, $R = 400\ \Omega$

$$X_L = \omega L = 1000 \times 100 \times 10^{-3} = 100\ \Omega$$

$$X_C = \frac{1}{\omega C} = \frac{1}{1000 \times 2 \times 10^{-6}} = 500\ \Omega$$

(*i*) $V = V_o \sin(1000t + \phi)$



$$\tan\phi = \frac{V_L - V_C}{V_R}$$

or
$$\tan\phi = \frac{X_L - X_R}{R} = \frac{100 - 500}{400} = \frac{-400}{400} = -1$$

$\therefore$
$$\phi = \frac{-\pi}{4}$$

$\because X_C > X_L$, $\therefore$ circuit is capacitative in nature and current will lead the voltage by a phase angle of $\pi/4$.

(*ii*) Power factor $= 1$ when $X_L = X_C'$

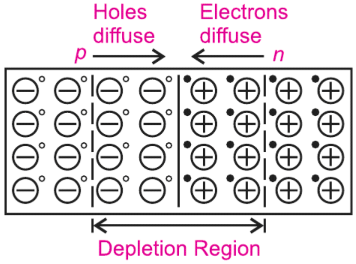
$\therefore$
$$100 = \frac{1}{\omega(C + C')}$$

$\Rightarrow$
$$C + C' = \frac{1}{100 \times 1000} = 10\ \mu\text{F}$$

$\therefore$
$$C' = (10 - 2) = 8\ \mu\text{F}$$

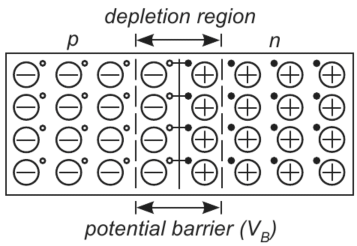
12. Write the two processes that take place in the formation of a *p-n* junction. Explain with the help of a diagram, the formation of depletion region and barrier potential in a *p-n* junction.

Ans. The two processes involved are diffusion and drift. As a result of concentration gradient, holes diffuse from *p*-side to *n*-side and free electrons diffuse from *n*-side to *p*-side. The moment charge carriers cross the junction and leave behind the ionised atoms, i.e. the acceptors on *p*-side (–ve ions) and the donars on *n*-side (+ve ions) of the junction.



The space charge region on either side of the junction where there are no free charges is known as depletion region.

Electrons are the majority charge carriers in *n*-type semiconductor. They move towards *p*-type semiconductor leaving behind the positive charged ions. Similarly, holes being in majority in the *p*-type semiconductor, move towards the *n*-type semiconductor. They leave behind the negatively charged ions. This way the accumulation of charges takes place near the junction. This stops further diffusion of the charges and the potential drop across the junction due to these fixed charges is called *potential barrier*.



13. (*i*) Obtain the expression for the cyclotron frequency.

(*ii*) A deuteron and a proton are accelerated by the cyclotron. Can both be accelerated with the same oscillator frequency? Give reason to justify your answer.

Ans. (*i*) Let r_1 be the radius of any orbit. Then the time for which the charged particle or ion remains in the dee is given by

$$t = \frac{\pi r_1}{v_1} \quad \text{...}(i)$$

Also, $$Bqv_1 = \frac{mv_1^2}{r_1}$$

$$\therefore \quad \frac{v_1}{r_1} = \frac{Bq}{m}$$

Putting this value of $\frac{v_1}{r_1}$ in (*i*), we get

$$\therefore \quad t = \pi \frac{m}{Bq}$$

$$\because \quad \text{Time period, } T = 2t = \frac{2m\pi}{Bq}$$

$\therefore$ Frequency, $\nu = \dfrac{1}{T} = \dfrac{qB}{2\pi m}$

(*ii*) No; as $m_d > m_p$, deuteron will require lesser oscillator frequency.

14. (*i*) How does one explain the emission of electrons from a photosensitive surface with the help of Einstein's photoelectric equation?

(*ii*) The work function of the following metals is given: Na = 2.75 eV, K = 2.3 eV, Mo = 4.17 eV and Ni = 5.15 eV. Which of these metals will not cause photoelectric emission for radiation of wavelength 3300 Å from a laser source placed 1 m away from these metals? What happens if the laser source is brought nearer and placed 50 cm away?

Ans. (*i*) According to Einstein's photoelectric equation the maximum kinetic energy of emitted electrons is given by

$$(\text{K.E.}) = \frac{hc}{\lambda} - \phi_o \qquad ...(i)$$

According to eq. (*i*), electrons will be emitted when $\dfrac{hc}{\lambda} \geq \phi_o$.

(*ii*) Wavelength of incident radiation, $\lambda = 3300 \text{ Å} = 3300 \times 10^{-10}$ m

$$\therefore \text{ Incident radiant energy, } E = \frac{hc}{\lambda e}$$

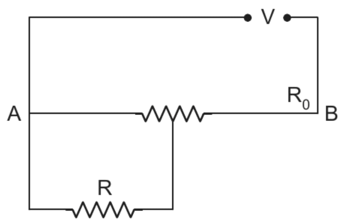
$$= \frac{6.63 \times 10^{-34} \times 3 \times 10^{8} \text{ eV}}{3300 \times 10^{-10} \times 1.6 \times 10^{-19}} = 3.76 \text{ eV}$$

$\because$ Work functions of Mo and Ni are greater than incident energy, therefore Mo and Ni will not cause photoelectric emission.

As the threshold frequency of incident radiation is greater than the threshold frequencies of Na and K metals but less than those of Mo and Ni metals, photoelectric emission will occur only in Na and K metals.

If the laser is brought nearer and placed 50 cm away, then the intensity of incident radiation increases. This does not affect the result regarding Mo and Ni. Only the emission from Na and K will increase in proportion to intensity

15. A resistance of *R* draws current from a potentiometer. The potentiometer wire, *AB*, has a total resistance of R_0. A voltage V is supplied to the potentiometer. Derive an expression for the voltage across *R* when the sliding contact is in the middle of potentiometer wire.



Ans. The total resistance between A and B is given by

$$R_1 = \frac{\left(\frac{R_0}{2}\right)R}{\frac{R_0}{2} + R} = \frac{R_0\,R}{R_0 + 2R}$$

The equivalent resistance between A and C is given by

$$\therefore \qquad R_2 = \frac{R_0 R}{R_0 + 2R} + \frac{R_0}{2} = \frac{2R_0 R + R_0^2 + 2R_0 R}{2\,(R_0 + 2R)} = \frac{R_0^2 + 4RR_0}{2\,(R_0 + 2R)}$$

$\therefore$ Current through potentiometer, $I = \dfrac{V}{R} = V\left[\dfrac{2\,(R_0 + 2R)}{R_0^2 + 4RR_0}\right]$

Let potential difference across AB be V_1, then $V_1 = I \times R_1$

$$\therefore \qquad V_1 = \frac{2V(R_0 + 2R)}{R_0(R_0 + 4R)} \times \frac{R_0 R}{(R_0 + 2R)} = \left(\frac{2R}{R_0 + 4R}\right)V$$

16. Define the term 'amplitude modulation'. Explain any two factors which justify the need for modulating a low frequency base-band signal.

Ans. **Amplitude modulation:** In amplitude modulation, the amplitude of the carrier wave is varied in accordance with the information signal.

Need for modulating:

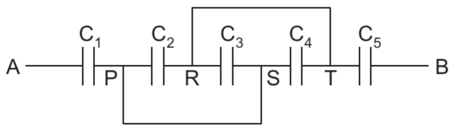
(*i*) The transmission of audio frequency electrical signal needs a long impracticable sized antenna ($\approx \lambda/4$).

(*ii*) The power radiated at audio frequency is quite small $\left(\text{as } P \propto \dfrac{1}{\lambda^2}\right)$.

(*iii*) The various information signals transmitted at low frequencies get intermixed.

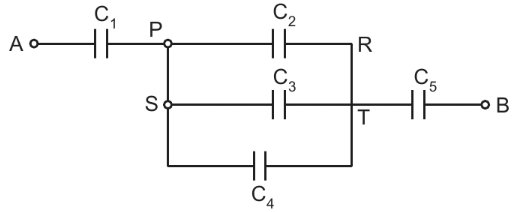
Therefore, in order to transmit a message signal effectively, it should be superimposed over the high frequency signal, called carrier wave by the process of modulation. (*any two*)

17. (*i*) Find equivalent capacitance between *A* and *B* in the combination given below. Each capacitor is of 2 μF capacitance.



(*ii*) If a dc source of 7 V is connected across *AB*, how much charge is drawn from the source and what is the energy stored in the network?

Ans. (*i*)



∵ C_2, C_3 and C_4 are in parallel

∴ $C_P = C_2 + C_3 + C_4 = 6\ \mu F$

Now, C_1 , C_P and C_5 are in series

$$\therefore \quad \frac{1}{C_{AB}} = \frac{1}{C_1} + \frac{1}{C_P} + \frac{1}{C_5}$$

$$= \frac{1}{2} + \frac{1}{6} + \frac{1}{2} = \frac{7}{6}$$

$$\therefore \quad C_{AB} = \frac{6}{7}\ \mu F$$

(*ii*) Charge drawn from the source of 7 V

$$Q = C_{AB}.V = \frac{6}{7} \times 10^{-6} \times 7\ C$$

$$Q = 6\ \mu C$$

$$\text{Energy stored} = \frac{1}{2} C_{AB} V^2 = \frac{1}{2} \times \frac{6}{7} \times 10^{-6} \times 7 \times 7\ J$$

$$U = 21\ \mu J$$

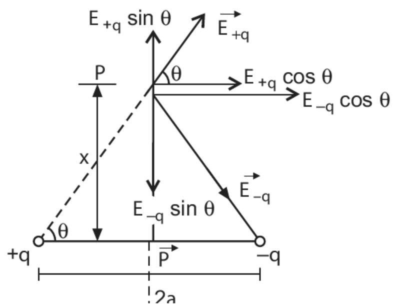
18. (*i*) Derive the expression for electric field at a point on the equatorial line of an electric dipole.

(*ii*) Depict the orientation of the dipole in (*i*) stable, (*ii*) unstable equilibrium in a uniform electric field.

Ans. (*i*) Magnitude of electric fields at point P is

$$E_{+q} = \frac{1}{4\pi\varepsilon_0} \frac{q}{(x^2 + a^2)}$$

$$E_{-q} = \frac{1}{4\pi\varepsilon_0} \frac{q}{(x^2 + a^2)}$$



As the components of electric fields normal to the dipole axis get cancelled and along the dipole axis add up, therefore, net electric field is

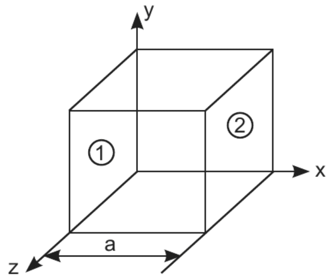
$$\vec{E} = -(E_{+q} + E_{-q}) \cos\theta\, \hat{p}$$

$$\vec{E} = -\frac{2qa}{4\pi\varepsilon_0 (x^2 + a^2)^{3/2}} \hat{p} \left[\because \cos\theta = \frac{a}{(x^2 + a^2)^{1/2}} \right]$$

$$\vec{E} = -\frac{\vec{p}}{4\pi\varepsilon_0(x^2 + a^2)^{3/2}} \qquad [\because \vec{p} = q(\overrightarrow{2a})]$$

(*ii*) (*a*) When dipole moment vector is parallel to electric field.

(*b*) When dipole moment vector is antiparallel to electric field.



19. **(*i*) A radioactive nucleus 'A' undergoes a series of decays as given below:**

$$\mathbf{A} \xrightarrow{\alpha} \mathbf{A_1} \xrightarrow{\beta} \mathbf{A_2} \xrightarrow{\alpha} \mathbf{A_3} \xrightarrow{\gamma} \mathbf{A_4}$$

The mass number and atomic number of A_2 are 176 and 71 respectively. Determined the mass and atomic numbers of A_4 and A.

(*ii*) Write the basic nuclear processes underlying β^+ and β^- decays.

Ans. (*i*) According to given sequence

$${}^{A}_{Z}A \xrightarrow{\alpha} {}^{A-4}_{Z-2}A_1 \xrightarrow{\beta} {}^{A-4}_{Z-1}A_2 \xrightarrow{\alpha} {}^{A-8}_{Z-3}A_3 \xrightarrow{\gamma} {}^{A-8}_{Z-3}A_4$$

$\therefore \quad A - 4 = 176; \; Z - 1 = 71$

$\because \quad$ Mass number and atomic number of A are: $A = 180$, $Z = 72$

Mass no. of $A_4 = A - 8 = 180 - 8 = 172$

Atomic no. of $A_4 = Z - 3 = 72 - 3 = 69$

(*ii*) Basic nuclear process for

β^+ decay: The basic nuclear process involved in the emission of β^+ in a symbolic form by a radioactive nucleus is given by

$$1p \longrightarrow {}^{1}_{0}n + \beta^+ + {}^{0}_{0}\bar{\nu}$$

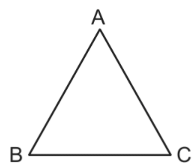
β^- decay : The basic nuclear process of neutron undergoing β-decay is given as

$$n \longrightarrow p + e^- + \bar{\nu}$$

Here $\bar{\nu}$ is antinutrino.

20. **(*i*) A ray of light incident on face *AB* of an equilateral glass prism, shows minimum deviation of 30°. Calculate the speed of light through the prism.**

(*ii*) Find the angle of incidence at face *AB* so that the emergent ray grazes along the face *AC*.



Ans. (*i*) Given: $A = 60°, D_m = 30°, v = ?$

$$\text{Refractive index} = \frac{c}{v} = \frac{\sin\left(\frac{A+D_m}{2}\right)}{\sin\frac{A}{2}}$$

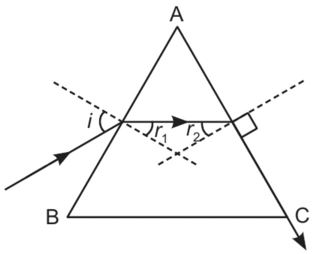
$$\frac{3\times10^8}{v} = \frac{\sin\left(\frac{60°+30°}{2}\right)}{\sin\left(\frac{60°}{2}\right)}$$

$$v = \frac{3\times10^8.\sin 30°}{\sin 45°} = \frac{3\times10^8\times\frac{1}{2}}{\frac{1}{\sqrt{2}}}$$

$$v = 1.5\sqrt{2}\times10^8 \text{ m/s}$$

$$v = 2.1 \times 10^8 \text{ m/s}$$

(*ii*)



$$A = r_1 + r_2$$

$\because$ Emergent ray grazes along face AC

$\therefore$ $r_2 = i_c$ = critical angle

$\therefore$ $\text{Refractive index} = \frac{\sin i}{\sin r_1} = \frac{\sin 90°}{\sin r_2} = \frac{c}{v}$

$\therefore$ $\sin r_2 = \frac{v}{c} = \frac{1.5\sqrt{2}\times10^8}{3\times10^8} = \frac{1}{\sqrt{2}} = \sin 45°$

$\Rightarrow$ $r_2 = 45°$

$$60° = r_1 + 45°$$

$\Rightarrow$ $r_1 = 60° - 45° = 15°$

$\therefore$ $\frac{\sin i}{\sin r_1} = 1.5$

$\Rightarrow$ $\sin i = 1.5 \sin 15° = 1.5 \times 0.2588$

$$\sin i = 0.3882$$

$$i = \sin^{-1}(0.3882) = 22.8°$$

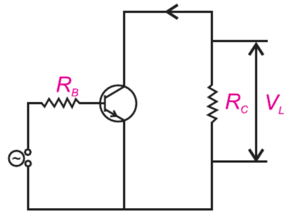
21. For a CE-transistor amplifier, the audio signal voltage across the collector resistance of 2 kΩ is 2 V. Given the current amplification factor of the transistor is 100, find the input signal voltage and base current, if the base resistance is 1 kΩ.

Ans. Given: $V_C = 2$ V, $\beta = 100$, $V_i = ?$, $I_B = ?$, $R_B = 1$ kΩ, $R_C = 2$ kΩ

and $$V_C = I_C R_C$$

∴ $$I_C = \frac{2}{2\times10^3} = 10^{-3}\text{A}$$

$$\beta = \frac{I_C}{I_B} \Rightarrow I_B = \frac{10^{-3}}{100} = 10^{-5}\text{A}$$



$$V_i = R_B \times I_B = 10^3 \times 10^{-5} = 10^{-2}\text{ V} = 0.01\text{ V}$$

22. Describe the working principle of a moving coil galvanometer. Why is it necessary to use (*i*) a radial magnetic field and (*ii*) a cylindrical soft iron core in a galvanometer? Write the expression for current sensitivity of the galvanometer.

Can a galvanometer as such be used for measuring the current? Explain.

OR

(*a*) Define the term 'self-inductance' and write its S.I. unit.

(*b*) Obtain the expression for the mutual inductance of two long co-axial solenoids S_1 and S_2 wound one over the other, each of length L and radii r_1 and r_2 and n_1 and n_2 number of turns per unit length, when a current I is set up in the outer solenoid S_2.

Ans. Principle: A current carrying loop placed in a uniform magnetic field experiences a torque.

(*i*) Radial magnetic field is used due to following:

- Maximum torque is experienced.
- Current is directly proportional to the deflection.
- The plane of the coil is parallel to the direction of magnetic field.

(*ii*) On introducing a soft iron cylindrical core, the magnetic field becomes more radial and its strength increases.

As $I_s = \frac{NBA}{k}$ and $V_s = \frac{NBA}{kR}$

With the increase in the magnetic field, the sensitivity of galvanometer increases.

A galvanometer is a sensitive device and can measure up to few microampere, and hence may get damaged, if strong current is passed through it.

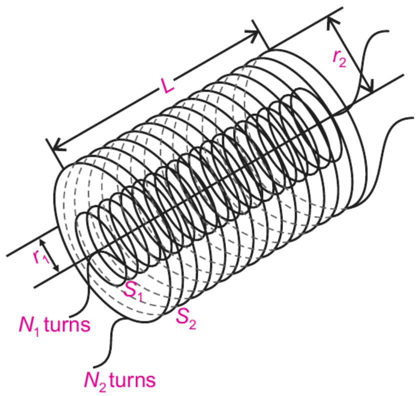
It also has larger resistance than an ammeter. Therefore, when it is connected in series with the circuit, the current in the circuit decreases.

OR

(*a*) Self-inductance is that property of a coil by virtue of which it opposes any change in the magnitude of current passing through it by inducing an emf in itself.

The S.I. unit of self-inductance is H (henry).

(*b*) Suppose current I_2 is flowing through outer solenoid S_2. Magnetic field at a point on the axis of the solenoid is



$$B_2 = \mu_0 n_2 I_2$$

where n_2 is number of turns per unit length of the solenoid S_2.

Flux linked with the inner solenoid S_1 is

$$\phi_{12} = B_2 \pi r^2{}_1 \ (n_1 L)$$

where r_1 is the radius of inner solenoid S_1 and n_1 is the number of turns per unit length of the solenoid S_1.

$$\phi_{12} = (\mu_0 n_1 n_2 \pi r_1^2 L) \ I_2 \qquad ...(i)$$

$\because$ $$\phi_{12} = M_{12} I_2 \qquad ...(ii)$$

Here $$M_{12} = \mu_0 n_1 n_2 \pi r_1^2 L$$ [Using eqns. (*i*) and (*ii*)]

M_{12} is mutual inductance of the solenoids.

SECTION D

23. Mrs. Rashmi Singh broke her reading glasses. When she went to the shopkeeper to order new spects, he suggested that she should get spectacles with plastic lenses instead of glass lenses. On getting the new spectacles, she found that the new ones were thicker than the earlier ones. She asked this question to the shopkeeper but he could not offer satisfactory explanation for this. At home. Mrs. Singh raised the same question to her daughter Anuja who explained why plastic lenses were thicker.

(*a*) Write two qualities displayed each by Anuja and her mother.

(*b*) How do you explain this fact using lens maker's formula?

Ans. (*a*) Qualities of (*i*) Anuja → Knowledgeable, intelligent, scientific temperament

(*ii*) Mother → Observant and inquisitive.

(*b*) Using Lens Maker's formula

$$\frac{1}{f} = (n - 1)\frac{2}{R}$$

∵ Refractive index of plastic is less than refractive index of glass, therefore plastic lens will have less radius of curvature or is thicker as compared to glass lens.

SECTION E

24. **(*a*) Draw a labelled diagram of AC generator. Derive the expression for the instantaneous value of the emf induced in the coil.**

(*b*) A circular coil of cross-sectional area 200 cm^2 and 20 turns is rotated about the vertical diameter with angular speed of 50 rad s^{-1} in a uniform magnetic field of magnitude 3.0×10^{-2} T. Calculate the maximum value of the current in the coil.

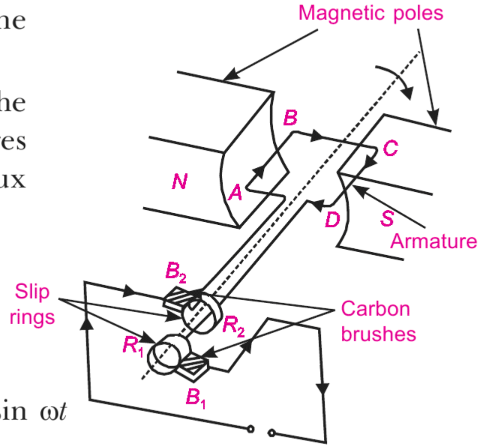
OR

(*a*) Draw a labelled diagram of a step-up transformer. Obtain the ratio of secondary to primary voltage in terms of number of turns and currents in the two coils.

(*b*) A power transmission line feeds input power at 2200 V to a step-down transformer with its primary windings having 3000 turns. Find the number of turns in the secondary to get the power output at 220 V.

Ans. (*a*) **Principle:** An ac generator is based on the principle of electromagnetic induction.

On rotating the coil in the magnetic field, the magnetic flux linked with the coil changes continuously. This changing magnetic flux induces an emf in the circuit.



$$\text{Mathematically, } \varepsilon = -\frac{d\phi_E}{dt}$$

$$= -\frac{d}{dt}(NBA \cos \omega t)$$

$$= NBA\omega \sin \omega t = \varepsilon_0 \sin \omega t$$

(*b*) Given: $A = 200 \text{ cm}^2 = 200 \times 10^{-4} \text{ m}^2$, $\omega = 50 \text{ rad s}^{-1}$

$B = 3.0 \times 10^{-2}$ T, $N = 20$ turns

$$\therefore \quad e_{max} = N\omega AB = 20 \times 50 \times 200 \times 10^{-4} \times 3 \times 10^{-2} \text{ V}$$
$$= 0.6 \text{ V}$$

Maximum induced current $= I_{max} = \dfrac{e_{max}}{R}$

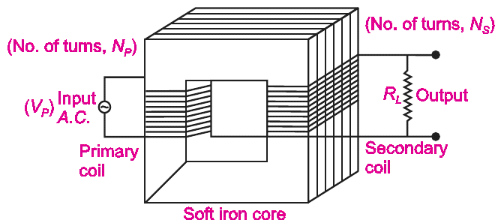
$$I_{max} = \frac{0.6}{R} \text{ A}$$

In the question R is not given, therefore, I_{max} cannot be calculated further.

OR

(*a*) A step-up transformer is based on the principle of mutual induction.

An alternating potential (V_p) when applied to the primary coil is induced an emf in it.



$$\varepsilon_p = -N_p \frac{d\phi}{dt}$$

If resistance of primary coil is low, then $V_p = \varepsilon_p \Rightarrow V_p = -N_p \dfrac{d\phi}{dt}$

As same flux is linked with the secondary coil with the help of soft iron core due to the mutual induction, an emf is induced in it.

$$\varepsilon_s = -N_s \frac{d\phi}{dt}$$

If an output circuit is open, $V_s = \varepsilon_s \Rightarrow V_s = -N_s \dfrac{d\phi}{dt}$

Thus, $$\frac{V_s}{V_p} = \frac{N_s}{N_p}$$

$\because$ Input power = Output power

$$\therefore \quad V_p I_p = V_s I_s$$

$$\therefore \quad \frac{V_s}{V_p} = \frac{I_p}{I_s} = \frac{N_s}{N_p}$$

(*b*) $\because$ $$\frac{N_s}{N_p} = \frac{V_s}{V_p}$$

$$\frac{N_s}{3000} = \frac{220}{2200}$$

$$\therefore \quad N_s = 300$$

25. **(*a*) Distinguish between unpolarised light and linearly polarised light. How does one get linearly polarised light with the help of a polaroid?**

(*b*) A narrow beam of unpolarised light of intensity I_0 is incident on a polaroid P_1. The light transmitted by it is then incident on a second polaroid P_2 with its pass axis making angle of 60° relative to the pass-axis of P_1. Find the intensity of the light transmitted by P_2.

OR

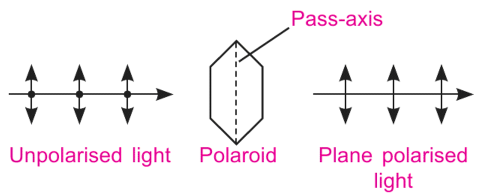
(*a*) Explain two features to distinguish between the interference pattern in Young's double slit experiment with the diffraction pattern obtained due to a single slit.

(*b*) A monochromatic light of wavelength 500 nm is incident normally on a single slit of width 0.2 mm to produce a diffraction pattern. Find the angular width of the central maximum obtained on the screen.

Estimate the number of fringes obtained in Young's double slit experiment with fringe width 0.5 mm, which can be accommodated within the region of total angular spread of the central maximum due to single slit.

Ans. (*a*) An unpolarised light is a beam of light in which the plane of oscillation of an optical vector keeps on changing rapidly and randomly and in a polarised light, an optical vector is made to oscillate in a fixed plane.

The components of an optical vector (electrical vector) associated with light wave, along the direction of alignment of the molecules of a polaroid, get absorbed. These are the components of the optical vector in a direction perpendicular to the direction of aligned molecules, which get transmitted. This way, we obtain a plane polarised wave.



(*b*) Intensity of incident unpolarised light on a polaroid $P_1 = I_o$

Intensity of polarised light transmitted from $P_1 = \dfrac{I_o}{2}$

Intensity of light transmitted from polaroid $P_2 = \dfrac{I_o}{2}\cos^2 60° = \dfrac{I_o}{8}$

[Law of Malus]

OR

(*a*) (*i*) Interference is the superposition of light waves from two different wavefronts originating from the same source, while the diffraction is the interaction of light waves from different parts of the same wavefront.

(*ii*) In an interference pattern, fringes may or may not be of the same width, while in diffraction pattern, they are never of the same width.

(*iii*) In an interference pattern, bright fringes are of uniform intensity, while in diffractions pattern, they are of varying intensity. (*any two*)

(*b*) Given: $\lambda = 500 \times 10^{-9}$ m; $a = 0.2 \times 10^{-3}$ m

Angular width of the central maximum

$$= 2\theta = \frac{2\lambda}{a} = \frac{2 \times 500 \times 10^{-9}}{0.2 \times 10^{-3}}$$

$$= 0.005 \text{ rad.}$$

If number of fringes $= n$

$$\text{Fringe width} = \beta = 0.5 \text{ mm} = 5 \times 10^{-4} \text{ m}$$

$$\therefore \quad \text{Angular fringe width} = \theta = \frac{\beta}{D}$$

According to question

Angular central fringe width = n × angular fringe width due to Y.D.S.E.

$$0.005 = n \times \frac{5 \times 10^{-2}}{D} \quad \Rightarrow \quad n = 0.1D$$

26. (*i*) **Derive an expression for drift velocity of electrons in a conductor. Hence deduce Ohm's law.**

(*ii*) **A wire whose cross-sectional area is increasing linearly from its one end to the other, is connected across a battery of V volts. Which of the following quantities remain constant in the wire?**

(*a*) **drift speed** (*b*) **current density**

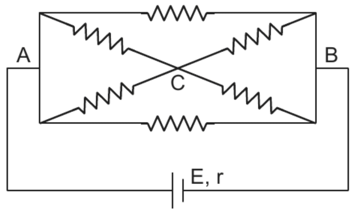
(*c*) **electric current** (*d*) **electric field**

Justify your answer.

OR

(*i*) **State the two Kirchhoff's laws. Explain briefly how these rules are justified.**

(*ii*) **The current is drawn from a cell of emf E and internal resistance r connected to the network of resistors each of resistance r as shown in the figure. Obtain the expression for (*i*) the current draw from the cell and (*ii*) the power consumed in the network.**



Ans. (*i*) In the absence of electric field, the motion of electron is random and the net velocity is zero, i.e. $\vec{u} = \dfrac{\vec{u_1} + \vec{u_2} + ... + \vec{u_N}}{N}$, here $\vec{u_1}, \vec{u_2}, ...\vec{u_N}$ are random velocities of N electrons.

In the presence of electric field, each electron experiences an acceleration

$$\vec{a} = \frac{-e\vec{E}}{m} \qquad ...(i)$$

Here m = mass of electron and $-e$ = charge on an electron.

If $\tau_1, \tau_2, ... \tau_N$ are the time intervals for which respective electrons accelerate then

$$\vec{v_1} = \vec{u_1} + \vec{a}\tau_1$$

$$\vec{v_2} = \vec{u_2} + \vec{a}\tau_2$$

$$\vdots$$

$$\vec{v_N} = \vec{u_N} + \vec{a}\tau_N$$

$\therefore$ Drift velocity, $$\vec{v_d} = \frac{\sum_{i=1}^{N}\vec{v_i}}{N} = \frac{\sum_{i=1}^{N}\vec{u_i}}{N} + \frac{\vec{a}\sum_{i=1}^{N}\tau_i}{N}$$

$\therefore$ $$\vec{v_d} = 0 + \left(\frac{-e\vec{E}}{m}\right)\tau = \frac{-e\vec{E}}{m}\tau \qquad ...(ii)$$

Here $\tau = \dfrac{\sum_{i=1}^{N}\tau_i}{N}$ = relaxation time

$\because$ $E = \dfrac{-V}{l}$, here V is potential difference applied across the ends of a conductor of length 'l' and cross-sectional area 'A', then eq. (*ii*) becomes (considering magnitude only)

$$v_d = \frac{e}{m}\frac{V}{l}\tau \qquad ...(iii)$$

Using relation, $$I = neAv_d$$

$$v_d = \frac{I}{neA} \qquad ...(iv)$$

From eqs. (*iii*) and (*iv*), we get

$$\tau = \frac{e}{m}\frac{V}{l} = \frac{I}{neA}$$

$$V = \left(\frac{m}{ne^2\tau}\right)\cdot\frac{l}{A}\cdot I$$

or $V = RI$ which is Ohm's law.

Here $\left(\frac{m}{ne^2\tau}\right)\frac{l}{A} = R =$ electrical resistance

(*ii*) (*a*) Drift speed, $v_d = \frac{I}{neA}$ (*b*) Current density, $J = \frac{I}{A}$

(*d*) Electric field, $E = \rho J = \rho\frac{I}{A}$

It can be seen that quantities in parts (*a*), (*b*) and (*d*) vary with cross-sectional area. Only (*c*) electric current will remain the same throughout the conductor.

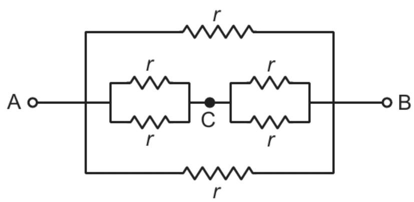
OR

(*i*) **Kirchhoff's Rules:**

- **Junction rule:** At any junction, the sum of the currents entering the junction is equal to the sum of currents leaving the junction.
- **Loop rule:** The algebraic sum of changes in potential around any closed loop involving resistors and cells in the loop is zero.

Junction rule obeys the law of conservation of charge, as at any junction, there is no accumulation of charge while loop rule obeys the law of conservation of energy. At any instant of time, the total energy supplied by cells is equal to the total energy consumed by resistors.

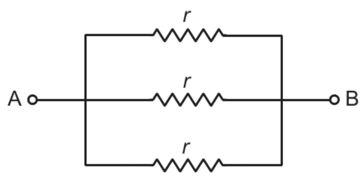
(*ii*) Equivalent circuit diagram will be



$\because$ $$R_{AC} = R_{CB} = \frac{r}{2}$$

R_{AC} and R_{CB} are in series.

$\therefore$ $$R_{AC} + R_{CB} = \frac{r}{2} + \frac{r}{2} = r$$



$$\therefore \qquad \frac{1}{R_{AB}} = \frac{1}{r}+\frac{1}{r}+\frac{1}{r}$$

$$\Rightarrow \qquad R_{AB} = \frac{r}{3}$$

(*i*) The current drawn from the cell is calculated as

$$\therefore \qquad I = \frac{E}{r+\frac{r}{3}} = \frac{3}{4r}E$$

(*ii*) The power consumer in the network is calculated as

$$P = I^2\left(r+\frac{r}{3}\right) = \frac{3}{4r}E \times \frac{3}{4r}E \times \frac{4}{3}r$$

$$P = \frac{3}{4r}E^2$$

Set-II (Uncommon Questions to Set-I)

SECTION B

6. Find the wavelength of the electron orbiting in the first excited state in hydrogen atom.

Ans. In first excited state (n = 2), $E_2 = \frac{-13.6}{(2)^2}$ eV

$$\therefore \qquad \text{K.E.} = \frac{13.6}{4}\text{ eV} \qquad [\because \text{K.E.} = -E_2]$$

$$= 3.4 \text{ eV} = 3.4 \times 1.6 \times 10^{-19} \text{ J}$$

$$\lambda_2 = \frac{h}{\sqrt{2mK}} = \frac{6.63\times10^{-34}}{\sqrt{2\times9.1\times10^{-31}\times3.4\times1.6\times10^{-19}}}$$

$$= 0.6663 \times 10^{-9} \text{ m} = 6.663 \text{ Å}$$

7. Distinguish between a transducer and a repeater.

Ans. **Transducer:** It converts one form of energy into another.

Repeater: It is a combination of a receiver and a transmitter.

10. Why should the objective of a telescope have large focal length and large aperture? Justify your answer.

Ans. Magnifying power and resolving power of a telescope is given by

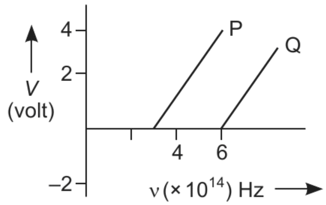
$$m = \frac{-f_o}{f_e}; \quad \text{R.P.} = \frac{D}{1.22\,\lambda} \text{ respectively.}$$

If focal length of objective (f_o) is large, then magnifying power will be large.

If large aperture (D-diameter) of objective is used then resolving power as well as brightness of image will increase.

SECTION C

12. In the study of a photoelectric effect the graph between the stopping potential V and frequency ν of the incident radiation on two different metals P and Q is shown below:



(i) Which one of the two metals has higher threshold frequency?

(ii) Determine the work function of the metal which has greater value.

(iii) Find the maximum kinetic energy of electron emitted by light of frequency 8×10^{14} Hz for this metal.

Ans. (i) Metal Q will have higher threshold frequency.

(ii) Work function of the metal $Q = h\nu_o = 6.63 \times 10^{-34} \times 6 \times 10^{14}$ J

$$\phi_o = \frac{39.78 \times 10^{-20}}{1.6 \times 10^{-19}} \text{ eV}$$

$$\phi_o = 2.49 \text{ eV}$$

(iii)
$$K_{max} = h\nu - \phi_o$$

$$K_{max} = \frac{6.63 \times 10^{-34} \times 8 \times 10^{14}}{1.6 \times 10^{-19}} - 2.49$$

$$K_{max} = 3.32 - 2.49 = 0.83 \text{ eV}$$

13. A 12 pF capacitor is connected to a 50 V battery. How much electrostatic energy is stored in the capacitor? If another capacitor of 6 pF is connected in series with it with the same battery connected across the combination, find the charge stored and potential difference across each capacitor.

Ans. Given: $C = 12 \times 10^{-12}$ F, $V = 50$ V; $U = ?$

$$\therefore \quad U = \frac{1}{2}CV^2 = \frac{1}{2} \times 12 \times 10^{-12} \times 50 \times 50 = 1.5 \times 10^{-8} \text{ J}$$

Now, if 6 pF is connected in series with 12 pF

Then, $$C_{eq.} = \frac{C_1 C_2}{C_1 + C_2} = \frac{6 \times 12}{6 + 12} \times 10^{-12}\,\text{F} = 4 \times 10^{-12}\ \text{F}$$

$\therefore$ Electric charge stored, $Q = C_{eq} V = 4 \times 10^{-12} \times 50 = 2 \times 10^{-10}$ C

$$\text{P.D. across 12 pF} = \frac{Q}{C_1} = \frac{2 \times 10^{-10}}{12 \times 10^{-12}} = 16.7\ \text{V}$$

$$\text{P.D. across 6 pF} = 50 - 16.7 = 33.3\ \text{V}$$

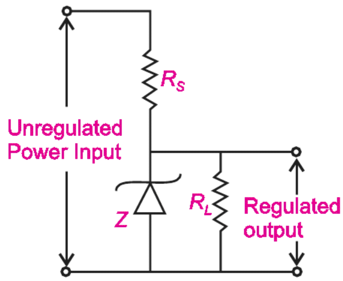
18. A zener diode is fabricated by heavily doping both p- and n- sides of the junction. Explain, why? Briefly explain the use of zener diode as a dc voltage regulator with the help of a circuit diagram.

Ans. Zener diode is fabricated by heavily doped p and n types of semiconductors. Due to heavy doping the depletion region is very thin ($< 10^{-6}$ m).

We know $V = Ed$.

As d is thin for a given value of a low reverse bias voltage, the electric field of the junction is very high.

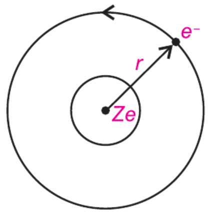
Zener as a voltage regulator:



The unregulated dc is given as an input through a series resistor R_S. The zener is always kept under reverse bias. As the input voltage increases, the current through resistance R_S and zener increases. This causes more voltage rise in resistance R_S keeping the voltage across Z the same. This is possible, as at zener voltage, the current increases without any change in potential. As the input drops, the current through resistance R_S and Z drops causing no change in voltage across zener. Thus, at both higher and lower potential inputs, a regulated output is obtained.

21. An electron of mass m_e revolves around a nucleus of charge $+Ze$. Show that it behaves like a tiny magnetic dipole. Hence prove that the magnetic moment associated with it is expressed as $\vec{\mu} = -\frac{e}{2\,m_e}\vec{L}$, where $\vec{L}$ is the orbital angular momentum of the electron. Give the significance of negative sign.

Ans. Consider an electron revolving around the nucleus of an atom. The electron is in a uniform circular motion around the nucleus of charge $+Ze$. This constitutes a current.



$\therefore$ $$I = \frac{e}{T} \quad \text{... }(i)$$

If r is the orbital radius of the electron and v is the orbital speed, then the time period is given as

$$T = \frac{2\pi r}{v} \quad \text{...}(ii)$$

From equations (i) and (ii), we get

$$I = \frac{ev}{2\pi r} \quad \text{...}(iii)$$

As the magnetic moment is given by

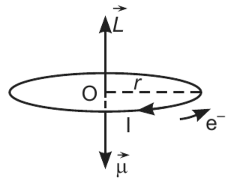
$$\mu_L = I\pi r^2$$

We have $$\mu_L = \left(\frac{ev}{2\pi r}\right)\pi r^2 = \frac{evr}{2}$$

Multiplying and dividing by m_e in above equation, we get

$$\mu_L = \frac{evm_e r}{2m_e}$$

$$\mu_e = \frac{e}{2m_e}L$$



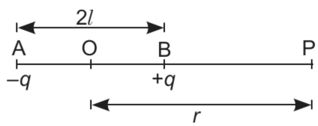
Since magnetic dipole moment and angular momentum are oppositely directed,

$$\therefore \quad \vec{\mu}_e = -\frac{e}{2m_e}\vec{L}$$

22. **(i) Derive the expression for the electric potential due to an electric dipole at a point on its axial line.**

(ii) Depict the equipotential surfaces due to an electric dipole.

Ans. (i) Potential at P due to charge at A is



$$V_{PA} = \frac{-kq}{r+l}$$

Potential at P due to charge at B is

$$V_{PB} = +\frac{kq}{r-l}$$

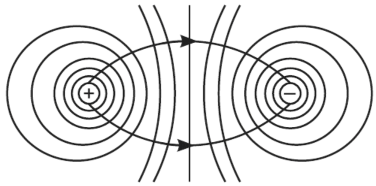
Net potential at P, $$V_P = V_{PA} + V_{PB} = kq\left[\frac{-1}{r+l} + \frac{1}{r-l}\right]$$

$$= kq\left[\frac{-r+l+r+l}{r^2-l^2}\right] = +\frac{kq(2l)}{r^2-l^2}$$

$$V_P = +\frac{kp}{r^2-l^2} \quad [\because p = q(2l)]$$

In case $r >> l$, $$V_P = +\frac{kp}{r^2}, \text{ here } k = \frac{1}{4\pi \in_0}$$

(*ii*) The equipotential surfaces of a system of two equal and opposite charges, i.e. a dipole are as shown below.



Set-III (Uncommon Questions to Set-I and II)

SECTION B

7. When are two objects just resolved? Explain. How can the resolving power of a compound microscope be increased? Use relevant formula to support your answer.

Ans. Resolving power of a microscope is given as

$$\frac{1}{d} = \frac{2\mu \sin\theta}{\lambda}$$

As resolving power is proportional to μ, hence, on increasing the refractive index of the medium between an object and an objective lens, the resolving power increases.

8. (*i*) What is the line-of-sight communication?

(*ii*) Why is it not possible to use sky waves for transmission of TV signals? Upto what distance can a signal be transmitted using an antenna of height '*h*'?

Ans. (*i*) Line-of-sight communication is one in which the signal is carried from the transmitter to the receiver antenna directly.

(*ii*) TV signals carry high frequency beyond 40 MHz and are not reflected by the ionosphere. So, it is not possible to use sky wave propagation.

The range of transmission using antenna of height h is $d = \sqrt{2Rh}$,
here R = radius of the earth.

9. An α-particle and a proton are accelerated through the same potential difference. Find the ratio of their de Broglie wavelengths.

Ans. $\because$

$$\lambda_\alpha = \frac{h}{\sqrt{2m_\alpha q_\alpha V}}$$

and

$$\lambda_p = \frac{h}{\sqrt{2m_p q_p V}}$$

$\because$ $m_\alpha = 4m_p$

$q_\alpha = 4q_p$

$\because$ $q_p = e$

$q_\alpha = 4e$

$$\therefore \quad \frac{\lambda_\alpha}{\lambda_p} = \sqrt{\frac{m_p \cdot e}{4m_p \cdot 2e}} = \frac{1}{2\sqrt{2}}$$

SECTION C

14. **(*a*) State two important features of Einstein's photoelectric equation.**

(*b*) Radiation of frequency 10^{15} Hz is incident on two photosensitive surfaces *P* and *Q*. There is no photoemission from surface *P*. Photoemission occurs from surface *Q* but photoelectrons have zero kinetic energy. Explain these observations and find the value of work function for surface *Q*.

Ans. (*a*) Einstein's photoelectric equation is $K_{max} = h\nu - \phi_0$.

(*i*) We find K_{max} depends linearly on ν only. It is independent of the intensity of radiation.

(*ii*) Since K_{max} must be positive,

$\therefore$ $h\nu > \phi_0$ $(\because \phi_0 = h\nu_0)$

or $\nu > \nu_0$

So greater the work function (ϕ_0), higher is the minimum frequency (threshold frequency) required to emit the photoelectrons.

Greater the number of energy quanta, greater is the number of photoelectrons. So photoelectric current is proportional to intensity.

(*b*) Given: $\nu = 10^{15}$ Hz $\therefore$ Incident radiation energy $= h\nu$

$$\therefore \quad E = 6.63 \times 10^{-34} \times 10^{15} \text{ J} = \frac{6.63\times10^{-19}}{1.6\times10^{-19}} \text{ eV} = 4.14 \text{ eV}$$

$\because$ Einstein's photoelectric equation is given by

$$K_{max} = h\nu - \phi_o \qquad ...(i)$$

From the surface *P*, no photoemission is occurred.

$\therefore$ Work function of *P* is greater than incident energy.

But from the surface *Q*, photoemission occurred, with maximum kinetic energy of electron is zero. If ϕ_0 is the work function for surface *Q*, then

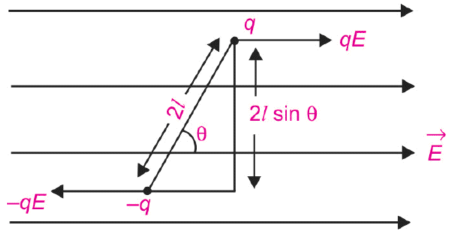
$$0 = h\nu - \phi_o$$

$\Rightarrow$ $$\phi_o = h\nu = 4.14 \text{ eV}$$

16. **(*i*) Obtain the expression for the torque $\vec{\tau}$ experienced by an electric dipole of dipole moment $\vec{p}$ in a uniform electric field, $\vec{E}$.**

(*ii*) What will happen if the field is not uniform?

Ans. (*i*) Let an electric dipole of length $2l$ and charges $-q$ and q be situated in the electric field as shown in the figure.



As the forces $q\vec{E}$ and $-q\vec{E}$ act at two different points, they will produce a torque.

Torque = Magnitude of either force × Perpendicular distance between them

$\therefore$ $$\tau = qE \times 2l \sin\theta = q\,2lE \sin\theta$$

$$\tau = pE \sin\theta$$

Vectorically, the torque is given by

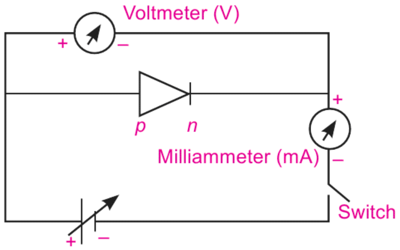
$$\vec{\tau} = \vec{p} \times \vec{E} = pE \sin\theta \, \hat{n}$$

where $\hat{n}$ is a vector perpendicular to the plane containing vectors $\vec{p}$ and $\vec{E}$. The turning effect of the torque on the dipole will be clockwise and will make the dipole moment $\vec{p}$ parallel to the field $\vec{E}$, reducing θ to zero and the dipole will align itself parallel to the electric field.

(*ii*) If the field is non-uniform, then dipole will experience translatory force as well as the torque.

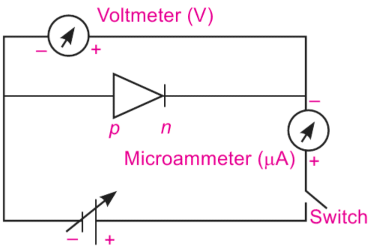
17. **Explain briefly with the help of necessary diagrams, the forward and the reverse biasing of a p-n junction diode. Also draw their characteristic curves in the two cases.**

Ans. (*i*)



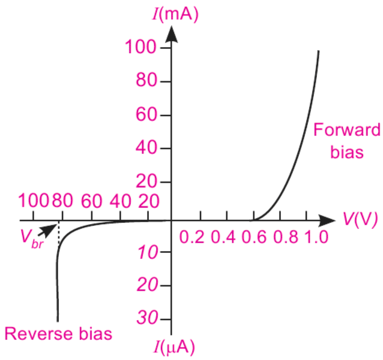
Forward bias

(*ii*)



Reverse bias

The battery is connected to the silicon diode through a potentiometer (or rheostat), so that the applied voltage can be changed. For different values of voltages, the value of current is noted. In forward bias the current increases at a negligibly slow rate till the voltage, across the diode reaches the threshold voltage. After this the current increases significantly even for a very small voltage (This threshold voltage is –0.2 V for Ge and –0.7 V for Si diode).



Now, in reverse bias, the current is very small (–μA) and almost remains constant for large change in bias voltage till the bias voltage reaches the breakdown voltage. At this reverse bias voltage, the current suddenly increases.

20. Two identical capacitors of 12 pF each are connected in series across a battery of 50 V. How much electrostatic energy is stored in the combination? If these were connected in parallel across the same battery, how much energy will be stored in the combination now?

Also find the charge drawn from the battery in each case.

Ans. Given: $C_1 = C_2 = 12$ pF $= 12 \times 10^{-12}$ F, $V = 50$ V

C_1 and C_2 are connected in series then

$\therefore$ net capacitance, $C_s = \dfrac{12}{2} \times 10^{-12}$ F

$$C_s = 6 \times 10^{-12} \text{ F}$$

$\therefore$ $Q_s = C_s V = 6 \times 10^{-12} \times 50 = 3 \times 10^{-10}$ C

Electrostatic energy stored, $U_s = \dfrac{1}{2} QV = \dfrac{1}{2} \times 3 \times 10^{-10} \times 50$ J

$$U = 7.5 \times 10^{-9} \text{ J}$$

When C_1 and C_2 are connected in parallel then

$$C_P = C_1 + C_2 = 24 \times 10^{-12} \text{ F}$$

$\therefore$ $Q_P = C_P V = 24 \times 10^{-12} \times 50 = 1.2 \times 10^{-9}$ C

and $U_P = \dfrac{1}{2} Q_P V = \dfrac{1}{2} \times 1.2 \times 10^{-9} \times 50$

$$U_P = 3 \times 10^{-8} \text{ J}$$

21. (*a*) Write the expression for the force $\vec{F}$ acting on a particle of mass *m* and charge *q* moving with velocity $\vec{v}$ in a magnetic field $\vec{B}$. Under what conditions will it move in (*i*) a circular path and (*ii*) a helical path?

(*b*) Show that the kinetic energy of the particle moving in magnetic field remains constant.

Ans. (*a*) Lorentz magnetic force $(\vec{F_m}) = q(\vec{v} \times \vec{B})$. The direction of magnetic force is perpendicular to the plane containing velocity and magnetic field vectors.

(*i*) When $\vec{v} \perp \vec{B}$.

(*ii*) When an electric charge moves in a direction, making an angle (θ) with the direction of magnetic field $(\vec{B})$.

(*b*) Kinetic energy does not change irrespective of the direction of the motion of charge as,

$$\text{Power delivered} = \frac{\Delta W}{\Delta t} = \vec{F} \cdot \vec{v} = q(\vec{v} \times \vec{B}).\vec{v} = 0$$

[∵ Scalar triple product $(\vec{v} \times \vec{B}) \cdot \vec{v} = 0$]

∴ Work done = 0

∴ Change in kinetic energy = 0 or kinetic energy remains constant.

Examination Papers, 2017

[All India Set-I, II, III]

Time Allowed: **3 Hours**] [Maximum Marks: **70**

General Instructions:

(*i*) **All** questions are **compulsory**. There are **26** questions in all.

(*ii*) This question paper has **five** sections: Section **A**, Section **B**, Section **C**, Section **D** and Section **E**.

(*iii*) Section **A** contains **five** questions of **one** mark each, Section **B** contains **five** questions of **two** marks each, Section **C** contains **twelve** questions of **three** marks each, Section **D** contains **one** value based question of **four** marks and Section **E** contains **three** questions of **five** marks each.

(*iv*) There is no overall choice. However, an internal choice has been provided in **one** question of **two** marks, **one** question of **three** marks and all **three** questions of **five** marks weightage. You have to attempt only **one** of the choices in such questions.

(*v*) You may use the following values of physical constants wherever necessary:

$$c = 3 \times 10^8 \text{ m/s}$$

$$h = 6.63 \times 10^{-34} \text{ Js}$$

$$e = 1.6 \times 10^{-19} \text{ C}$$

$$\mu_0 = 4\pi \times 10^{-7} \text{ T m A}^{-1}$$

$$\varepsilon_0 = 8.854 \times 10^{-12} \text{ C}^2\text{N}^{-1}\text{M}^{-2}$$

$$\frac{1}{4\pi\varepsilon_0} = 9 \times 10^9 \text{ N m}^2 \text{ C}^{-2}$$

Mass of electron $= 9.1 \times 10^{-31}$ kg

Mass of neutron $= 1.675 \times 10^{-27}$ kg

Mass of proton $= 1.673 \times 10^{-27}$ kg

Avogadro's number $= 6.023 \times 10^{23}$ per gram mole

Boltzmann constant $= 1.38 \times 10^{-23}$ JK^{-1}

SECTION A

1. Nichrome and copper wires of same length and same radius are connected in series. Current I is passed through them. Which wire gets heated up more? Justify your answer.

Ans. Nichrome wire having more resistivity (ρ) will heat up more, as heat produced $= I^2R = I^2\rho\frac{l}{A}$.

2. Do electromagnetic waves carry energy and momentum?

Ans. Yes. For example, the tail of the comet always stays away from the sun due to the radiation pressure exerted on the tail by the light.

3. How does the angle of minimum deviation of a glass prism vary, if the incident violet light is replaced by red light? Give reason.

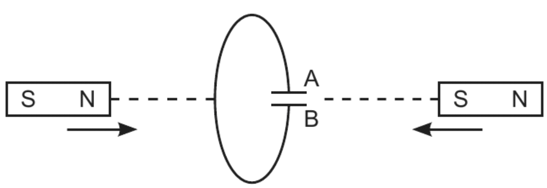
Ans.
$$\text{R.I.} = \frac{\sin\left(\frac{A+D_m}{2}\right)}{\sin\frac{A}{2}} \quad \text{and} \quad n_V > n_R$$

Therefore, the angle of deviation will decrease.

4. Name the phenomenon which shows the quantum nature of electromagnetic radiation.

Ans. Photoelectric effect.

5. Predict the polarity of the capacitor in the situation described below:



Ans. (*i*) Plate A — positive

(*ii*) Plate B — negative.

SECTION B

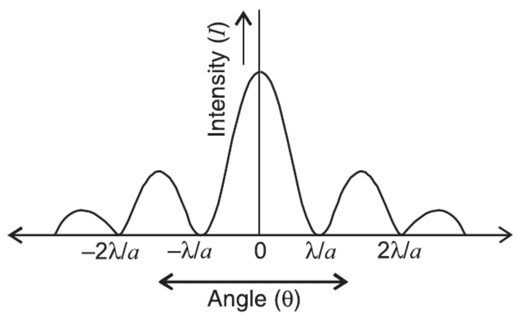
6. Draw the intensity pattern for single slit diffraction and double slit interference. Hence, state two differences between interference and diffraction patterns.

OR

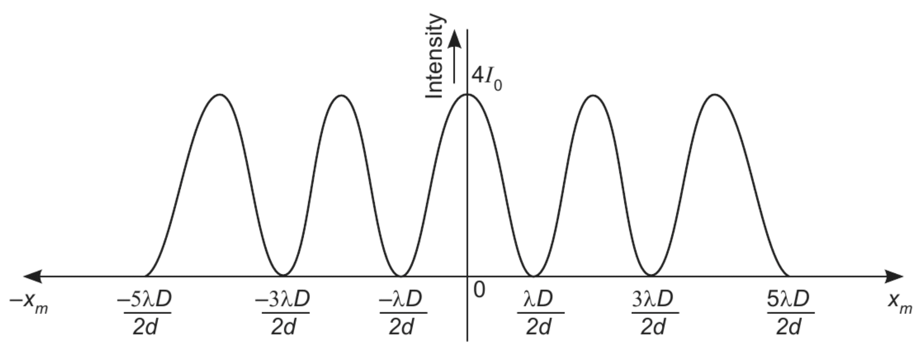
Unpolarised light is passed through a polaroid P_1. When this polarised beam passes through another polaroid P_2 and if the pass-axis of P_2 makes angle θ with the pass-axis of P_1, then write the expression for the polarised beam passing through P_2. Draw a plot showing the variation of intensity when θ varies from 0 to 2π.

Ans. Intensity pattern for:

(*a*) **Single slit diffraction**



(*b*) **Double slit interference**



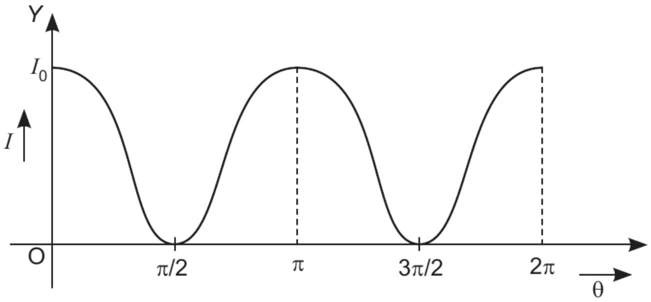
Differences between interference and diffraction patterns:

(*i*) Interference is the superposition of light waves from two different wavefronts originating from the same source, while the diffraction is the interaction of light waves from different parts of the same wavefront.

(*ii*) In an interference pattern, fringes may or may not be of the same width, while in diffraction pattern, they are never of the same width.

(*iii*) In an interference pattern, bright fringes are of uniform intensity, while in diffractions pattern, they are of varying intensity. (*any two*)

OR



If intensity of incident unpolarised light $= I_0$

then, intensity of polarised light transmitted through polaroid $P_1 = \frac{I_0}{2}$

intensity of polarised light transmitted through polaroid $P_2 = \frac{I_0}{2}\cos^2\theta$

As $I = I_0 \cos^2\theta$ (Law of Malus)

7. Identify the electromagnetic waves whose wavelengths vary as

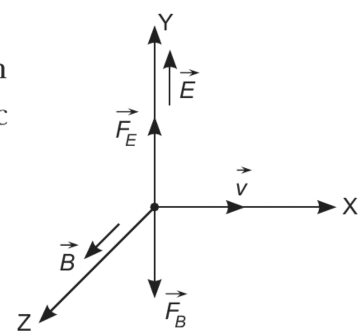
(*a*) 10^{-12} m < λ < 10^{-8} m (*b*) 10^{-3} m < λ < 10^{-1} m

Write one use for each.

Ans. (*a*) X-rays, used as a diagnostic tool.

(*b*) Microwave, used in RADAR.

8. Find the condition under which the charged particles moving with different speeds in the presence of electric and magnetic field vectors can be used to select charged particles of a particular speed.



Ans. Let an electric charge '*q*' is moving with velocity $\vec{v}$ in a region where uniform electric field $\vec{E}$ and magnetic field $\vec{B}$ are applied as shown in the figure

$$\vec{F} = q(\vec{E} + \vec{v} \times \vec{B})$$

when $\vec{F} = 0$; then electric charge will go undeflected.

$$\therefore \quad q(\vec{E} + \vec{v} \times \vec{B}) = 0$$

$$E\hat{j} + v\hat{i} \times B\hat{k} = 0$$

$$\Rightarrow \quad E\hat{j} - vB\hat{j} = 0 \qquad [\because \ \hat{i} \times \hat{k} = -\hat{j}]$$

$$\hat{j}(E - vB) = 0$$

$$\therefore \quad E = v.B$$

$$\text{or} \quad v = \frac{E}{B}$$

9. A 12.5 eV electron beam is used to excite a gaseous hydrogen atom at room temperature. Determine the wavelengths and the corresponding series of the lines emitted.

Ans.

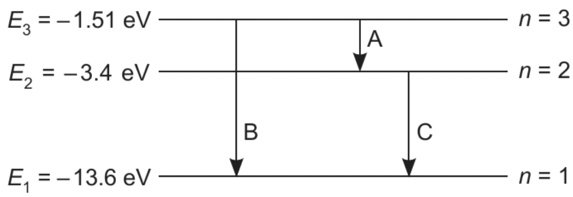
$$12.5 \text{ eV} = E_f - E_i$$

$$12.5 \text{ eV} = E_f - (-13.6 \text{ eV})$$

$$E_f = -1.1 \text{ eV} = \frac{-13.6 \text{ eV}}{n^2}$$

$$\Rightarrow \quad n = 3.4$$

So, the, hydrogen atoms would be exited up to third energy level (i.e. $n = 3$). Only three transitions are possible.



Transition A (for $n_i = 3$ to $n_f = 2$) will correspond to the Balmer series.

Transition B and C will corresponds to the Lyman series wavelength emitted in transition.

$$A: \quad \lambda_A = \frac{ch}{E_3 - E_2} = \frac{3\times10^8\times6.63\times10^{-34}}{(-1.51+3.4)\,1.6\times10^{-19}} \text{ m} = 6577 \text{ Å} = 657.7 \text{ nm}$$

$$B: \quad \lambda_B = \frac{3\times10^8\times6.63\times10^{-34}}{(-1.51+13.6)\,1.6\times10^{-19}} = 102.8 \text{ nm}$$

$$C: \quad \lambda_C = \frac{3\times10^8\times6.63\times10^{-34}}{(-3.4+13.6)} = 121.9 \text{ nm}$$

10. Write two properties of a material suitable for making (*a*) a permanent magnet, and (*b*) an electromagnet.

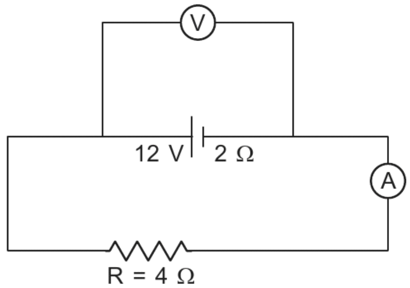
Ans. (*a*) Material should have (*i*) high retentivity. (*ii*) high coercitivity.

(*b*) The material used for making core of electromagnet must have minimum coercivity. For a low value of magnetic field intensity (H), the values of the magnetic induction ($\vec{B}$) and the intensity of magnetisation ($\vec{I}$) must be high.

SECTION C

11. (*a*) The potential difference applied across a given resistor is altered so that the heat produced per second increases by a factor of 9. By what factor does the applied potential difference change?

(*b*) In the figure shown, an ammeter A and a resistor of 4 Ω are connected to the terminals of the source. The emf of the source is 12 V having an internal resistance of 2 Ω. Calculate the voltmeter and ammeter readings.



Ans. (*a*) Heat produced per second i.e. power

$$P_2 = 9P_1$$

$$\therefore \quad \frac{V_2^2}{R} = \frac{9V_1^2}{R} \qquad V_2 = 3V_1$$

i.e. potential difference applied is 3 times, or change in potential difference

$$= 3V - V = 2 \text{ V}$$

(*b*) $E = 12$ V; $r = 2\ \Omega$, $R = 4\ \Omega$

$\therefore$ Ammeter reading $\quad I = \dfrac{E}{r+R} = \dfrac{12}{2+4} = 2$ A

12. (*a*) How is amplitude modulation achieved?

(*b*) The frequencies of two side bands in an AM wave are 640 kHz and 660 kHz respectively. Find the frequencies of carrier and modulating signal. What is the bandwidth required for amplitude modulation?

Ans. (*a*) **Amplitude modulation:** In amplitude modulation, the amplitude of the carrier wave is varied in accordance with the information signal.

(*b*)

$$\nu_c + \nu_m = 660 \text{ kHz} \qquad \ldots(i)$$

$$\nu_c - \nu_m = 640 \text{ kHz} \qquad \ldots(ii)$$

On adding eqs. (*i*) and (*ii*), we get

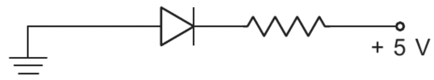
$$2\nu_c = 1300 \Rightarrow \nu_c = 650 \text{ kHz}$$

Substituting ν_c in eq. (*i*), we get

$$\nu_m = 660 - 650 = 10 \text{ kHz}$$

$$\therefore \quad \text{Bandwidth required} = 2\nu_m = 20 \text{ kHz}$$

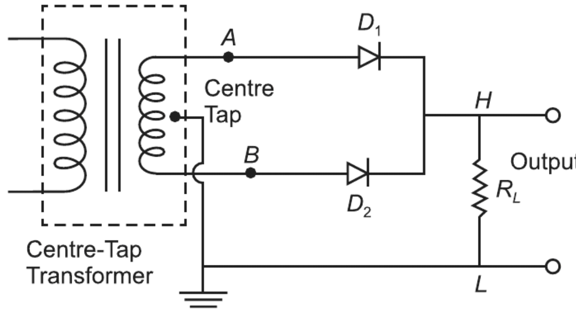
13. **(*a*) In the following diagram, is the junction diode forward biased or reverse biased?**



(*b*) Draw the circuit diagram of a full-wave rectifier and state how it works.

Ans. (*a*) Reverse biased.

(*b*) During the first half of the cycle, if *A* is at higher potential with respect to centre tap and *B* is at lower potential, the diode D_1 being forward biased conducts and the diode D_2 being reverse biased does not conduct. The current flows through the load in the sense *H* to *L*. During the second half of the cycle, conditions get reversed and only diode D_2 conducts. Again, the current flows through the load in the sense *H* to *L*.



A full-wave rectifier

Thus, in the output, we get a unidirectional current.

14. **Using photon picture of light, show how Einstein's photoelectric equation can be established. Write two features of photoelectric effect which cannot be explained by wave theory.**

Ans. Radiation energy is built up of discrete units called quanta of energy of radiation. Each quantum of radiant energy has energy $h\nu$, where h is Planck's constant and ν is the frequency of light.

In photoelectric effect, an electron absorbs a quantum of energy ($h\nu$) of radiation. If this quantum of energy absorbed is more than the minimum energy ϕ_0 needed to eject an electron from the metal surface, then electron is emitted with a maximum kinetic energy

$$K_{\max} = h\nu - \phi_0$$

The following are the two key features:

(*i*) According to the wave picture of light, the free electrons at the metal surface absorb radiant energy continuously over the entire wavefront of radiation. As large number of electrons absorb energy, the energy absorbed per electron per unit time turns out to be small. It is estimated that it can take hours or more for a single electron to pick up sufficient energy to overcome the work function and come out of the metal.

This observation does not match with the photon picture, according to which photoelectric emission is instantaneous.

(*ii*) According to the wave picture, greater is the intensity of radiation greater is the amplitude of electric and magnetic fields. Thus, greater the intensity, there should be the energy absorbed by each electron. This fact indicates that the maximum kinetic energy of photoelectrons must depend on intensity of light, i.e. concept of threshold frequency should not exist. Again, this conclusion contradicts the photon picture of electromagnetic radiation according to which the maximum kinetic energy of photoelectron depends on frequency and not on the intensity of radiation.

15. (*a*) Monochromatic light of wavelength 589 nm is incident from air on a water surface. If μ for water is 1.33, find the wavelength, frequency and speed of the refracted light.

(*b*) A double convex lens is made of a glass of refractive index 1.55, with the both faces of the same radius of curvature. Find the radius of curvature required, if the focal length is 20 cm.

Ans. (*a*) For refracted light,

$$\text{Wavelength, } \lambda' = \frac{\lambda}{\mu}, \text{ here } \lambda = 589 \text{ nm} = 589 \times 10^{-9} \text{ m}, \ \mu = 1.33$$

$$= \frac{589 \times 10^{-9}}{1.33} = 444 \text{ nm}$$

$$\text{Frequency, } \nu = \frac{c}{\lambda} = \frac{3 \times 10^{8}}{589 \times 10^{-9}} = 5.09 \times 10^{14} \text{ Hz}$$

$$\text{Speed, } v = \frac{c}{\mu} = \frac{3 \times 10^{8}}{1.33} = 2.25 \times 10^{8} \text{ m/s}$$

(*b*) Given: $\mu = 1.55$, $R_1 = R$, $R_2 = -R$, $f = 20$ cm

$$\frac{1}{f} = (\mu - 1)\left[\frac{1}{R_1} - \frac{1}{R_2}\right] \Rightarrow \frac{1}{20} = (1.55 - 1)\left[\frac{2}{R}\right]$$

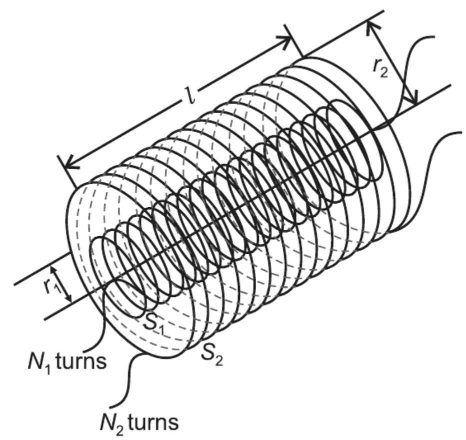
$$R = 22 \text{ cm}$$

16. Define mutual inductance between a pair of coils. Derive an expression for the mutual inductance of two long coaxial solenoids of same length wound one over the other.

OR

Define self-inductance of a coil. Obtain the expression for the energy stored in an inductor *L* connected across a source of emf.

Ans. Mutual inductance between two long co-axial solenoids is defined as the magnetic flux linked to the second coil when unit current is flowing in the first coil.



It is the phenomenon by virtue of which a coil resists any change in the strength of current in its neighbouring coil.

Suppose current I_2 is flowing through outer solenoid. Magnetic field at a point on the axis of the solenoid is

$$B_2 = \mu_0 n_2 I_2$$

where n_2 is number of turns per unit length of the outer solenoid.

Flux linked with the inner solenoid is

$$\phi_{12} = B_2 \pi r^2{}_1 \, (n_1 l)$$

where r_1 is the radius of inner solenoid and n_1 is the number of turns per unit length of the 1st solenoid.

$$\phi_{12} = (\mu_0 n_1 n_2 \pi r^2{}_1 l) \, I_2 \qquad ...(i)$$

$\because$ $$\phi_{12} = M_{12} I_2 \qquad ...(ii)$$

Here $$M_{12} = \mu_0 n_1 n_2 \pi r^2{}_1 l \qquad \text{[Using eqns. } (i) \text{ and } (ii)\text{]}$$

M_{12} is mutual inductance of the solenoids.

OR

Self-inductance is that property of a coil by virtue of which it opposes any change in the magnitude of current passing through it by inducing an emf in itself.

Consider an inductor of inductance *L*, carrying alternating current through it.

Suppose at any instant of time an emf induced in the inductor is

$$\varepsilon = -L \frac{dI}{dt}$$

To maintain the growth of current through the inductor, power has to be supplied from external source.

$$P = \frac{dW}{dt} = -\varepsilon I = L\frac{dI}{dt} I, \quad \because \varepsilon = -L\frac{dI}{dt} \quad \Rightarrow \quad dW = LI\,dI$$

Total amount of work done to build up current from zero to I is

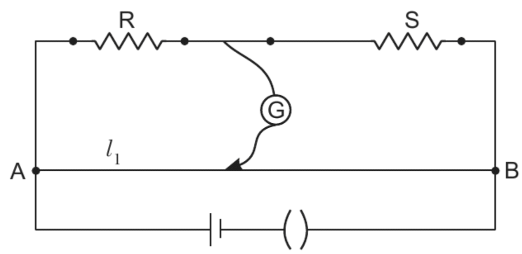
$$W = L\int_0^I I\,dI = \frac{1}{2}LI^2$$

This work done gets stored in the inductor in the form of magnetic energy.

Thus, $$U = \frac{1}{2}LI^2$$

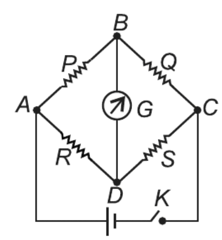
17. **(*a*) Write the principle of working of a metre bridge.**

(*b*) In a metre bridge, the balance point is found at a distance l_1 with resistances R and S as shown in the figure.



An unknown resistance X is now connected in parallel to the resistance S and the balance point is found at a distance l_2. Obtain a formula for X in terms of l_1, l_2 and S.

Ans. (*a*) Meter bridge is a practical form of wheatstone bridge and it works on it. Wheatstone bridge is a network of four resistors P, Q, R and S connected as shown in the figure. When some potential difference is applied between A and C and when $\frac{P}{Q} = \frac{R}{S}$, the potential difference between B and D becomes zero and the wheatstone bridge is said to be balanced. At the balance condition, no current flows through the galvanometer arm.

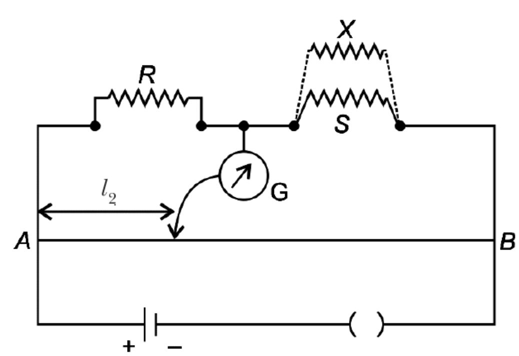


(*b*) With R and S alone, we have

$$\frac{R}{S} = \frac{l_1}{(100 - l_1)}$$

$\Rightarrow$ $$R(100 - l_1) = Sl_1 \quad ...(i)$$

With S and X in parallel with R on the left gap,



$$\frac{R}{\left(\frac{SX}{S+X}\right)} = \frac{l_2}{(100 - l_2)}$$

$$\Rightarrow \quad R(100 - l_2) = \frac{SXl_2}{(S+X)} \qquad ...(ii)$$

Dividing equations (*i*) and (*ii*), we get

$$\frac{100 - l_1}{100 - l_2} = \frac{l_1(S+X)}{Xl_2}$$

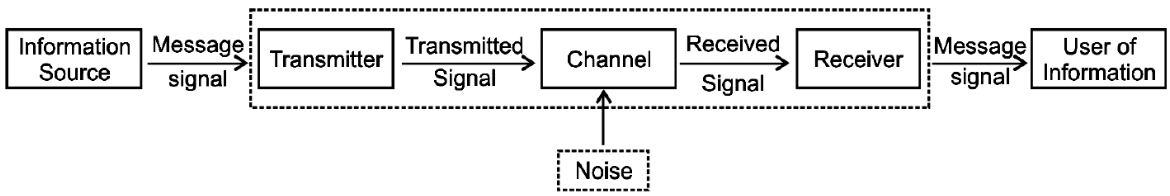
$$\Rightarrow \quad 100\,Xl_2 - l_1 l_2 X = 100\,l_1 S + 100\,l_1 X - l_2 l_1 S - l_2 l_1 X$$

$$\therefore \quad X = \frac{100 l_1 S - l_1 l_2 S}{100(l_2 - l_1)}$$

18. Draw a block diagram of a generalized communication system. Write the functions of each of the following:

(*a*) Transmitter (*b*) Channel (*c*) Receiver

Ans. The block diagram of communication system



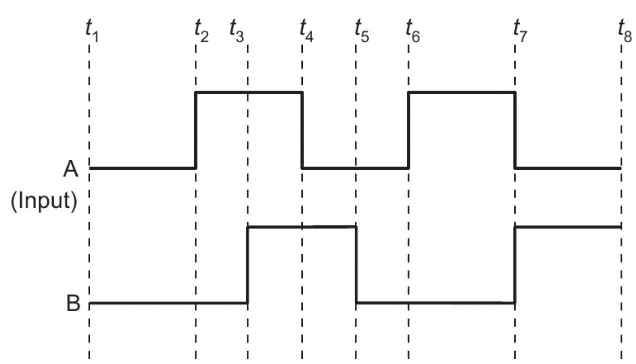
(*a*) **Transmitter:** It processes the message signal and makes it suitable for transmission through a channel and its reception.

(*b*) **Channel:** A physical channel is the physical medium, that may be in the form of wires/cables/wireless connecting the transmitter and the receiver. A receiver extracts the desired signals from the received signals at the channel output.

(*c*) **Receiver:** A receiver extracts the desired message signals from the received signals and makes them suitable for a user.

19. (*a*) Write the functions of the three segments of a transistor.

(*b*) The figure shows the input waveforms A and B for 'AND' gate. Draw the output waveform and write the truth table for this logic gate.



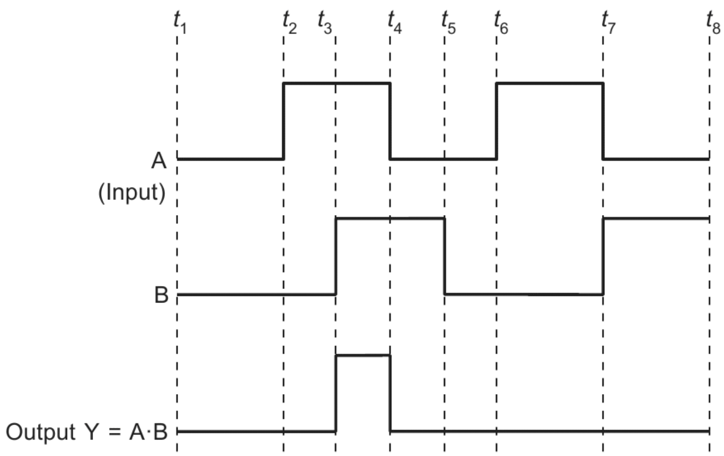
Ans. (*a*) The functions of three segments emitter, base and collector of a transistor are

(*i*) **Emitter:** It supplies a large number of majority carriers for the current flow through the transistor.

(*ii*) **Base:** This is the central segment. It is very thin and lightly doped.

(*iii*) **Collector:** This segment collects a major portion of the majority carriers supplied by the emitter.

(*b*)



Truth table

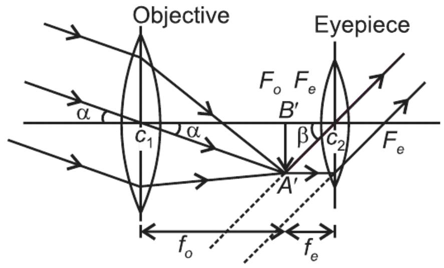
Time interval	Inputs		Output
	A	*B*	$Y = A \cdot B$
t_1 to t_2	0	0	0
t_2 to t_3	1	0	0
t_3 to t_4	1	1	1
t_4 to t_5	0	1	0
t_5 to t_6	0	0	0
t_6 to t_7	1	0	0
t_7 to t_8	0	0	0

20. **(*a*) Draw a ray diagram depicting the formation of the image by an astronomical telescope in normal adjustment.**

(*b*) You are given the following three lenses. Which two lenses will you use as an eyepiece and as an objective to construct an astronomical telescope? Give reason.

Lenses	Power (D)	Aperture (cm)
L_1	3	8
L_2	6	1
L_3	10	1

Ans. (*a*) Astronomical Telescope—Refracting Type



(*b*) To construct an astronomical telescope lenses L_1 and L_3 will be used as an objective and eyepiece respectively.

Reason: For an objective, lens should have less power (3 D) and larger aperture (8 cm) and eyepiece should have more power (10 D) and shorter aperture (1 cm) so as to have more angular magnification and more resolving power as angular magnification $= \frac{f_o}{-f_e} = \frac{-P_e}{P_o}$ and resolving power $= \frac{D}{1.22\lambda}$

where D = diameter of aperture of objective.

21. **(*a*) State Biot-Savart's law and express this law in the vector form.**

(*b*) Two identical circular coils, *P* and *Q* each of radius *R*, carrying currents 1 A and $\sqrt{3}$ A respectively, are placed concentrically and perpendicular to each other lying in the *XY* and *YZ* planes. Find the magnitude and direction of the net magnetic field at the centre of the coils.

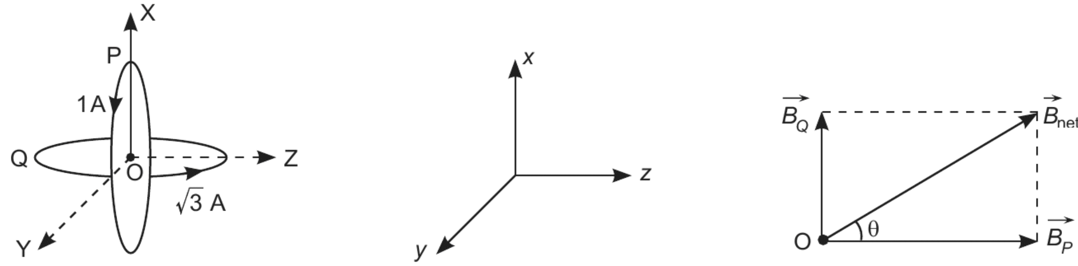
Ans. (*a*) Biot-Savart law states that the magnitude of the magnetic field *dB* at any point due to a small current element *dl* is given by

$$dB = \frac{\mu_0}{4\pi} \frac{I\,dl \sin\theta}{r^2}$$

where *I* is the magnitude of current, *dl* is the length of element, θ is the angle between the length of element and the line joining the element to the point of observation, and *r* is the distance of the point from the element.

In vector notation, $$d\vec{B} = \frac{\mu_0}{4\pi} \frac{I\,(d\vec{l} \times \vec{r})}{r^3}$$

(*b*)



At centre *O*

$$\text{Magnetic field due to coil, } P = \vec{B_P} = \frac{\mu_0 I}{2r}\hat{k}$$

$$\vec{B_P} = \frac{4\pi \times 10^{-7} \times 1}{2r}\hat{k}$$

$$\text{Magnetic field due to coil, } Q = \vec{B_Q} = \frac{4\pi \times 10^{-7} \times \sqrt{3}}{2R}\hat{i}$$

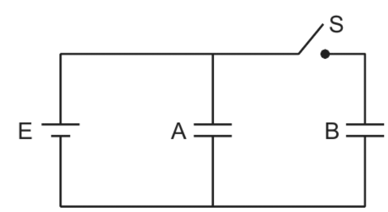
$$\therefore \qquad \vec{B}_{\text{net}} = \vec{B_P} + \vec{B_Q} = \frac{4\pi \times 10^{-7}}{2R}[\hat{k} + \sqrt{3}\,\hat{i}]$$

$$\therefore \qquad |\vec{B}_{\text{net}}| = \frac{4\pi \times 10^{-7}}{2R}\sqrt{1+3} = \frac{4\pi \times 10^{-7}}{R}\text{ T}$$

Direction of $\vec{B}_{\text{net}}$ $\qquad \theta = \tan^{-1}\left(\frac{B_Q}{B_P}\right) = \tan^{-1}(\sqrt{3}) = \frac{\pi}{6}$ rad.

w.r.t. *z*-axis.

22. Two identical parallel plate capacitors *A* and *B* are connected to a battery of *V* volts with the switch *S* closed. The switch is now opened and the free space between the plates of the capacitors is filled with a dielectric of dielectric constant *K*. Find the ratio of the total electrostatic energy stored in both capacitors before and after the introduction of the dielectric.



Ans. When switch *S* is closed energy stored in each capacitor will be the same.

$$U_A = U_B = \frac{1}{2}C_0 E^2 \qquad ...(i)$$

$\therefore$ Total energy stored initially, $U_i = U_A + U_B = C_0 E^2$

and, charge on each capacitor,

$$Q = C_0 E \qquad ...(ii)$$

When switch *S* is opened and dielectric is introduced between plates then

$$C_A' = C_B' = KC_0$$

$\because$ P.D. across $A = E$

$\therefore$ Energy stored in $A = U_A' = \frac{1}{2} KC_0E^2$

In capacitor B,
$$U_B' = \frac{Q^2}{2C_B'} \qquad [\because Q \text{ remains same.}]$$

$$U_B' = \frac{(C_0E)^2}{2\,KC_0} = \frac{1}{2K} C_0E^2$$

Energy stored in both the capacitors after the insertion of dielectric is calculated as

$$U_f = U_A' + U_B' = \frac{1}{2}KC_0E^2 + \frac{C_0E^2}{2K} = \frac{1}{2}\left(\frac{K^2+1}{K}\right)C_0E^2$$

$$\therefore \qquad \frac{U_f}{U_i} = \frac{K^2+1}{2K}$$

SECTION D

23. Asha's mother read an article in the newspaper about a disaster that took place at Chernobyl. She could not understand much from the article and asked a few questions from Asha regarding the article. Asha tried to answer her mother's questions based on what she learnt in Class XII Physics:

(*a*) What was the installation at Chernobyl where the disaster look place? What, according to you, was the cause of this disaster?

(*b*) Explain the process of release of energy in the installation at Chernobyl.

(*c*) What, according to you, were the values displayed by Asha and her mother?

Ans. (*a*) Nuclear reactors were installed at Chernobyl. Sudden surge of power during a reactor system test destroyed one of the units of nuclear reactor. The accident and the fire followed release of massive amounts of radioactive materials into the environment.

(*b*) Large amount of energy is released due to uncontrolled nuclear fission reaction.

(*c*) Asha is knowledgeable, and well aware of scientific news around the world and her mother is curious, and wants to gain knowledge.

SECTION E

24. **(*a*) Derive an expression for the electric field *E* due to a dipole of length '2*a*' at a point distant *r* from the centre of the dipole on the axial line.**

(*b*) Draw a graph of *E* versus *r* for *r* >> *a*.

(*c*) If this dipole were kept in a uniform external electric field E_0, diagrammatically represent the position of the dipole in stable and unstable equilibrium and write the expressions for the torque acting on the dipole in both the cases.

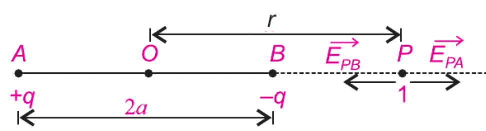
OR

(*a*) Use Gauss's theorem to find the electric field due to a uniformly charged infinitely large plane thin sheet with surface.

(*b*) An infinitely large thin plane sheet has a uniform surface charge density +σ. Obtain the expression for the amount of work done in bringing a point charge *q* from infinity to a point, distant *r*, in front of the charged plane sheet.

Ans. (*a*) Electric field intensity at a point on the axis of an electric dipole.

Electric field at *P* due to charge at *A*



$$\vec{E}_{PA} = \frac{kq}{(r+a)^2}\hat{j}$$

Electric field at *P* due to charge at *B*

$$\vec{E}_{PB} = -\frac{kq}{(r-a)^2}\hat{j}$$

Net electric field at *P*,

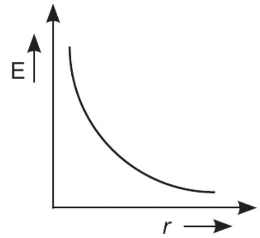
$$\vec{E}_{ax} = \vec{E}_{PA} + \vec{E}_{PB} = kq\left[\frac{1}{(r+a)^2} - \frac{1}{(r-a)^2}\right]$$

$$\vec{E}_{ax} = kq\left[\frac{r^2+a^2-2ra-r^2-a^2-2ra}{(r^2-a^2)^2}\right] = \frac{2k(q2r)a}{(r^2-a^2)^2} = \frac{2kpr}{(r^2-a^2)^2} = \frac{2kr\vec{p}}{(r^2-a^2)^2}$$

In the limiting case when $r >> a$, $(r^2 - a^2) \simeq r^4$

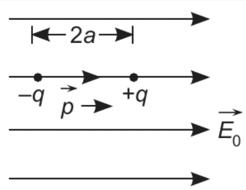
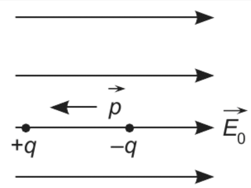
$$\vec{E}_{ax} = \frac{2\vec{p}}{4\pi\varepsilon_0 r^3}$$

(*b*)



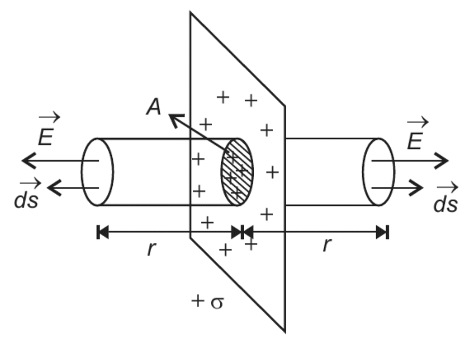
$$E \propto \frac{1}{r^3}$$

(*c*)

Dipole in stable equilibrium		Dipole in Unstable equilibrium	
	$\theta = 0°$ $\therefore\ \tau = pE \sin 0°$ $= 0$		$\theta = 180°$ $\therefore\ \tau = pE \sin 180°$ $= 0$

OR

(*a*) Consider a thin infinite sheet of charge having uniform surface charge density σ. To calculate electric field at a point *P* distant *r* from the sheet we imagine a symmetrical Gaussian surface in such a way that the point charge lies on it. Here we assume a cylinder of cross-sectional area *A* and length 2*r* with its axis perpendicular to the sheet.



Flux through the curved surface of the cylinder,

$$\phi_1 = \int \vec{E}.\vec{ds} = 0 \qquad (\because\ \theta = 90°)$$

Total flux through plane faces of the cylinder,

$$\phi_2 = 2\int \vec{E}.\vec{ds} = 2EA \qquad (\because\ \theta = 0°)$$

Net flux through the Gaussian surface is

$$\phi = \phi_1 + \phi_2 = 2EA \qquad ...(i)$$

Net charge enclosed by the Gaussian surface is

$$Q = \sigma A$$

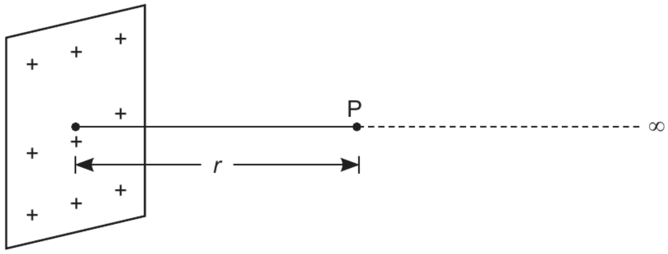
According to the Gauss's theorem, $\phi = \dfrac{Q}{\varepsilon_0}$

$$\therefore \qquad \phi = \frac{\sigma A}{\varepsilon_0} \qquad ...(ii)$$

From equations (*i*) and (*ii*), we get

$$2EA = \frac{\sigma A}{\varepsilon_0} \quad \Rightarrow \quad E = \frac{\sigma}{2\varepsilon_0}$$

(*b*)

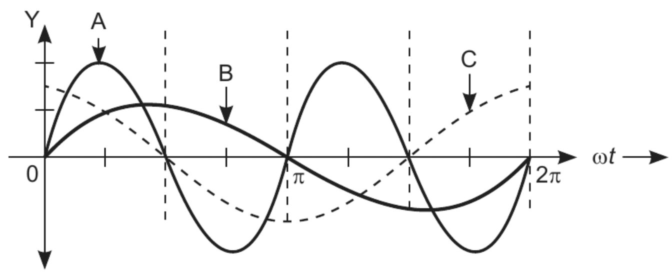


Work done in bringing a charge from ∞ to given point P is given by

$$W = q\int_{r=\infty}^{r}\vec{E}\cdot\vec{dr} = q\int_{\infty}^{r}\left(\frac{\sigma}{2\varepsilon_0}dr\right) = q\cdot\frac{\sigma}{2\varepsilon_0}\int_{r=\infty}^{r}dr$$

$$W = \frac{q.\sigma}{2\varepsilon_0}[r-\infty] = \frac{\infty}{2\varepsilon_0}[r-\infty] = \infty$$

25. A device X is connected to an ac source $V = V_0 \sin \omega t$. The variation of voltage, current and power in one cycle is shown in the following graph.



(*a*) Identify the device X.

(*b*) Which of the curves A, B and C represent the voltage, current and the power consumed in the circuit? Justify your answer.

(*c*) How does its impedance vary with frequency of the ac source? Show graphically.

(*d*) Obtain an expression for the current in the circuit and its phase relation with ac voltage.

OR

(*a*) Draw a labelled diagram of an ac generator. Obtain the expression for the emf induced in the rotating coil of N turns each of cross-sectional area A, in the presence of a magnetic field $\vec{B}$.

(*b*) A horizontal conducting rod 10 m long extending from east to west is falling with a speed 5.0 ms^{-1} at right angles to the horizontal component of the Earth's magnetic field, 0.3×10^{-4} Wb m^{-2}. Find the instantaneous value of the emf induced in the rod.

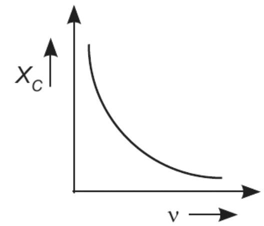
Ans. (*a*) X is a capacitor.

(*b*) Curve B represents voltage, C represents current and A represents power consumed in the circuit.

Justification: Current leads the voltage by a phase angle of $\pi/2$.

(*c*) Capacitor has reactance X_C which is given by the relation

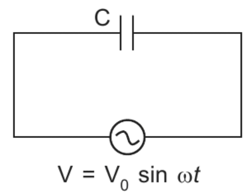
$$X_C = \frac{1}{2\pi\nu C} \propto \frac{1}{\nu}$$



(*d*) $\because$ $$V = V_0 \sin \omega t$$

$\therefore$ At any instant, electric current, $I = \dfrac{dq}{dt}$,

where q = instantaneous charge = CV, $q = CV_0 \sin \omega t$



$$\text{Electric current, } I = \frac{d}{dt}(CV_0 \sin \omega t)$$

$$I = V_0\, \omega C \cos \omega t$$

$$I = \frac{V_0}{\frac{1}{\omega C}} \cos \omega t = \frac{V_0}{X_C} \cos \omega t$$

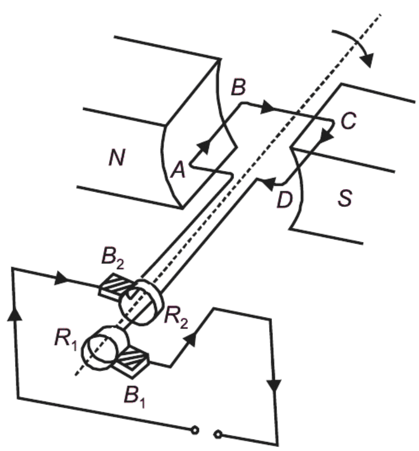
$$I = I_0 \cos \omega t$$

$$I = I_0 \sin (\omega t + \pi/2)$$

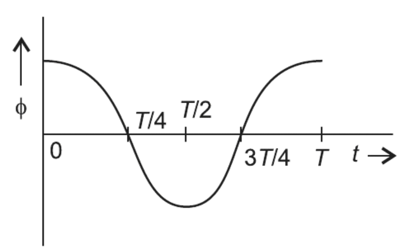
$\therefore$ Electric current will lead V by a phase angle of $\pi/2$.

OR

(*a*)



Working: As the armature coil *ABCD* rotates, the magnetic flux linked with it changes. Hence, an emf is induced in the coil and current flows in it.



(*i*) The variation of magnetic flux with time is given by

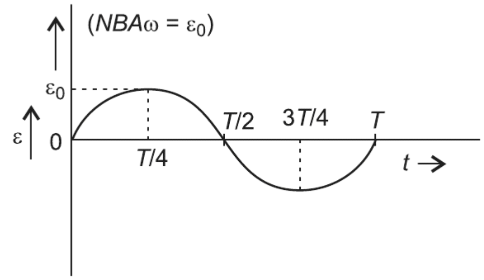
$$\phi = NBA \cos \omega t$$

(*ii*) The variation of alternating emf with time is given by

$$\frac{d\phi}{dt} = -BA\omega \sin \omega t$$

$$\varepsilon = \frac{-Nd\phi}{dt}$$

$$\varepsilon = NBA\omega \sin \omega t$$



(*b*) Given: $B_H = 0.30 \times 10^{-4}$ Wbm^{-2}, $l = 10$ m, $v = 5.0$ ms^{-1}

As we know $\varepsilon = B_H l v$;

$$\varepsilon = 0.30 \times 10^{-4} \times 10 \times 5.0 = 1.5 \times 10^{-3} \text{ V}$$

26. **(*a*) Define wavefront. Use Huygens' principle to verify the laws of refraction.**

(*b*) How is linearly polarised light obtained by the process of scattering of light? Find the Brewster angle for air – glass interface, when the refractive index of glass = 1.5

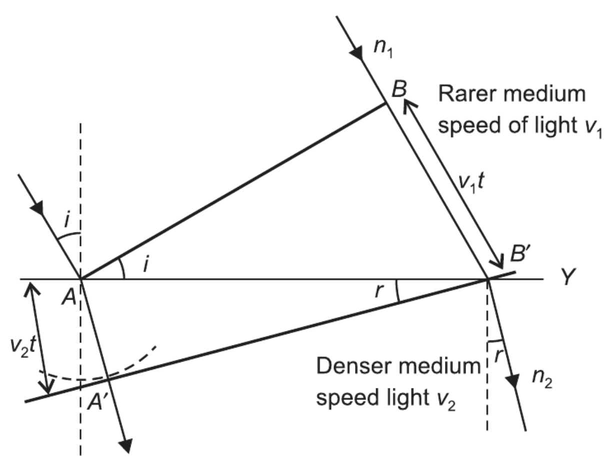
OR

(*a*) Draw a ray diagram to show the image formation by a combination of two thin convex lenses in contact. Obtain the expression for the power of this combination in terms of the focal lengths of the lenses.

(*b*) A ray of light passing from air through an equilateral glass prism undergoes minimum deviation when the angle of incidence is $\frac{3}{4}$th of the angle of prism. Calculate the speed of light in the prism.

Ans. (*a*) **Wavefront:** A wavefront is the locus of all the points in space which receives the light waves from a source in phase.

According to the Huygen's principle, each point of the wavefront is the source of secondary disturbance and the wavelets emanting from these points spread out in all directions with the speed of the wave. A common tangent to all the wavelets in the forward direction gives the new position of wavefront at a later time.



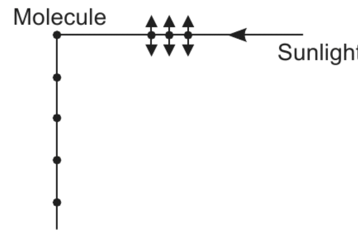
From $\Delta ABB'$, $\quad \sin i = \dfrac{BB'}{AB'} = \dfrac{v_1 \times t}{AB'}$ ...(*i*)

From $\Delta AA'B'$, $\sin r = \frac{AA'}{AB'} = \frac{v_2 \times t}{AB'}$ ...(*ii*)

$\therefore$ $\frac{\sin i}{\sin r} = \frac{v_1}{v_2}$

which is Snell's las of rafraction.

(*b*) It is noticed that an unpolarised sunlight incident on a small dust particle or air molecule is scattered in all directions. The light scattered in a perpendicular direction to the incident light is found to be completely polarised.



The optical (electrical) vector of incident light has components both in the plane of the paper as well as perpendicular to the plane of the paper. The electrons under the influence of the electric vector acquire motion in both directions. However, the radiation scattered in perpendicular direction contains only components represented by dots (•), i.e. polarised, perpendicular to the plane of the paper.

Given: $n_2 = n_g = 1.5$, $n_1 = n_a = 1$

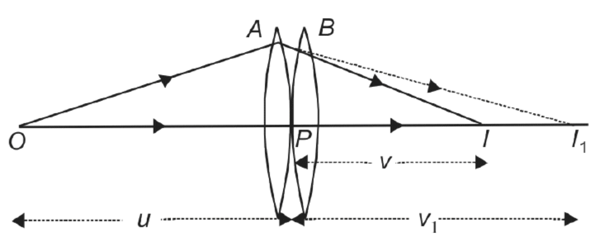
$\because$ $\frac{n_2}{n_1} = \frac{1.5}{1} = \tan i_p$

$\therefore$ $i_p = \tan^{-1} 1.5$

$i_p = 56.30°$

OR

(*a*) O is the point object lying on principal axis and I_1 is the image formed by lens A, which will act as a virtual object for lens B. If the object distance for lens A is O then the image distance will be I_1.



For the lens A, we have relation

$$\frac{1}{f_1} = \frac{1}{v_1} - \frac{1}{u} \quad ...(i)$$

For the lens B, the relation is

$$\frac{1}{f_2} = \frac{1}{v} - \frac{1}{v_1} \quad \text{...}(ii)$$

here: v_1 = object distance for lens B and v = image distance.

Here an image formed by the lens A acts as a virtual object for the lens B.

Adding equations (*i*) and (*ii*), we get

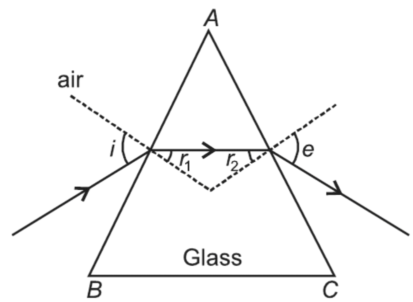
$$\frac{1}{v} - \frac{1}{u} = \frac{1}{f_1} + \frac{1}{f_2}$$

If this two lens system is considered as an equivalent single lens of focal length f, we have

$$\frac{1}{v} - \frac{1}{u} = \frac{1}{f}$$

$$\therefore \quad \frac{1}{f} = \frac{1}{f_1} + \frac{1}{f_2}$$

(*b*) Given: $i = \frac{3}{4}A$



We know $$\mu = \frac{\sin\left(\frac{A+\delta_m}{2}\right)}{\sin\frac{A}{2}}$$

or $$\frac{c_1}{c_2} = \frac{\sin\left(\frac{A+\delta_m}{2}\right)}{\sin\frac{A}{2}}$$

$$\because \quad \delta_m = 2i - A = 2 \times \frac{3}{4}A - A = \frac{A}{2} = \frac{60^\circ}{2} = 30^\circ$$

Now, $$\frac{c_1}{c_2} = \frac{\sin 45^\circ}{\sin 30^\circ} = \sqrt{2} \quad \Rightarrow \quad c_2 = \frac{3\times10^8}{\sqrt{2}}$$

$$c_2 = 1.5\sqrt{2} \times 10^8 \text{ ms}^{-1} = 2.12 \times 10^8 \text{ ms}^{-1}$$

Alternative

$$\because \quad r_1 + r_2 = A$$

At minimum deviation, $r_1 = r_2$

i.e. $$r = \frac{A}{2} = 30^\circ$$

As $i = \frac{3}{4} \times A = 45^\circ$

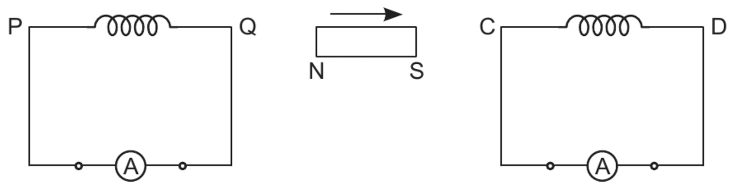
$$\therefore \quad \mu = \frac{c_1}{c_2} = \frac{\sin 45^\circ}{\sin 30^\circ}$$

$$\Rightarrow \quad c_2 = 2.12 \times 10^8 \text{ ms}^{-1}$$

Set-II (Uncommon Questions to Set-I)

SECTION A

1. A bar magnet is moved in the direction indicated by the arrow between two coils *PQ* and *CD*. Predict the direction of the induced current in each coil.



Ans. *D* to *C* through ammeter

Q to *P* through ammeter

2. Write the relation for the speed of electromagnetic waves in terms of the amplitudes of electric and magnetic fields.

Ans.

$$v = \frac{|\vec{E}|}{|\vec{B}|}$$

SECTION B

7. Identify the electromagnetic waves whose wavelengths lie in the range

(*a*) 10^{-11} m < λ < 10^{-14} m

(*b*) 10^{-4} m < λ < 10^{-6} m

Write one use of each.

Ans. (*a*) γ-rays

These are used in treatment of cancer.

(*b*) Infrared rays

These are used in remote control.

9. The short wavelength limit for the Lyman series of the hydrogen spectrum is 913.4 Å. Calculate the short wavelength limit for Balmer series of the hydrogen spectrum.

Ans. Given: λ = 913.4 Å = 913.4×10^{-10} m

For short wavelength the limit in Lyman series

$n_i = \infty$, $n_f = 1$, $\lambda = 913.4 \times 10^{-10}$

$$\therefore \qquad \frac{1}{\lambda} = R\left[\frac{1}{1^2} - \frac{1}{\infty^2}\right]$$

$$\Rightarrow \qquad R = \frac{1}{913.4 \times 10^{-10}} \text{ m}^{-1} \qquad ...(i)$$

For short wavelength limit in Balmer series

$n_i = \infty$, $n = 2$

$$\frac{1}{\lambda} = R\left[\frac{1}{2^2} - \frac{1}{\infty}\right]$$

$$\frac{1}{\lambda} = \frac{1}{913.4 \times 10^{-10}}\left[\frac{1}{4}\right]$$

$$\lambda = 3653.6 \times 10^{-10} \text{ m}$$

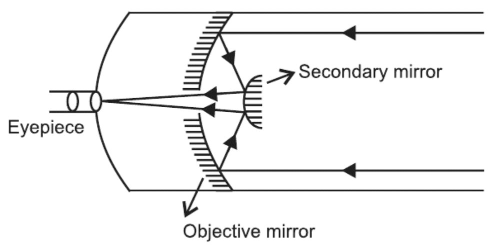
$$\lambda = 3653.6 \text{ Å}$$

SECTION C

12. **(*a*) Draw a ray diagram showing the formation of image by a reflecting telescope.**

(*b*) Write two advantages of a reflecting telescope over a refracting telescope.

Ans. (*a*) Reflecting telescope



(*b*) The following are the two advantages of a reflecting type telescope over a refracting type telescope:

(*i*) As there is no refraction, it is free from the chromatic aberration.

(*ii*) The light gathering power of the objective must be higher to get better resolution. It is easier to handle and cheaper to make mirrors of larger diameters.

15. **Explain giving reasons for the following:**

(*a*) Photoelectric current in a photocell increase with the increase in the intensity of the incident radiation.

(*b*) The stopping potential (V_0) varies linearly with the frequency (ν) of the incident radiation for a given photosensitive surface with the slope remaining the same for different surfaces.

(*c*) Maximum kinetic energy of the photoelectrons is independent of the intensity of incident radiation.

Ans. (*a*) $\because$ Intensity $\propto$ no. of incident photons

Therefore, when the photons of frequency above threshold frequency strike the metal surface, the electrons are emitted. Hence, the photoelectric current increases.

(*b*) We find K_{max} depends linearly on ν only. It is independent of the intensity of radiation.

$\because$ $$eV_0 = h\nu - \phi_0 \qquad [\because\ K_{max} = h\nu - \phi_0]$$

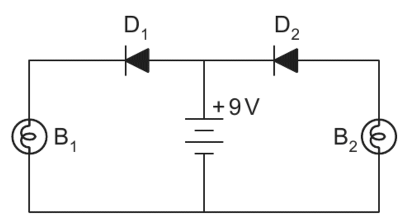
$\Rightarrow$ $$V_0 = \frac{h}{e}\nu - \frac{\phi_0}{e}$$

$\therefore$ From the equation we can conclude that if frequency $\nu\,(> \nu_0)$ increases then stopping potential (V_0) increases. But the slope $\frac{h}{e}$ remains constant, where h is Planck's constant.

(*c*) $\because$ Max. K.E. $= h(\nu - \nu_0)$

$\therefore$ Maximum kinetic energy depends on frequency only and is independent of intensity.

16. (*a*) In the following diagram, which bulb out of B_1 and B_2 will glow and why?

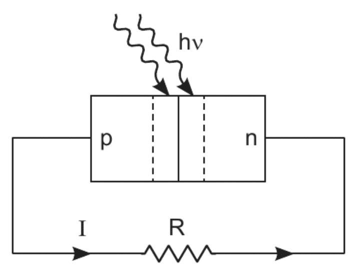


(*b*) Draw a diagram of an illuminated *p-n* junction solar cell.

(*c*) Explain briefly the three processes due to which generation of emf takes place in a solar cell.

Ans. (*a*) Bulb B_1 will glow as diode D_1 is in forward bias, therefore it will conduct.

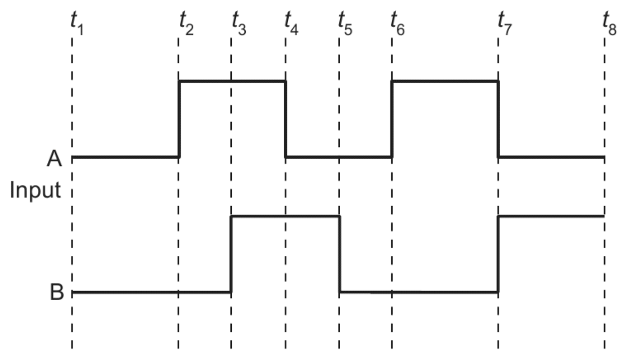
(*b*)



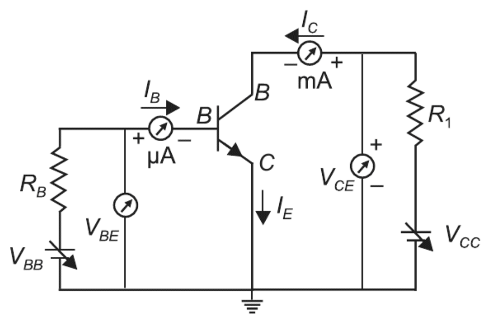
(*c*) It is due to the following three basic processes: generation, separation and collection—(*i*) generation of *e-h* pairs due to light (with $h\nu > E_g$) close to the junction; (*ii*) separation of electrons and holes due to electric field of the depletion region. Electrons are swept to *n*-side and holes to *p*-side; (*iii*) the electrons reaching the *n*-side are collected by the front contact and holes reaching *p*-side are collected by the back contact. Thus, *p*-side becomes positive and *n*-side becomes negative giving rise to *photovoltage*.

19. **(*a*) Draw the circuit diagram for studying the characteristics of a transistor in common emitter configuration. Explain briefly and show how input and output characteristics are drawn.**

(*b*) The figure shows input waveforms *A* and *B* to a logic gate. Draw the output waveform for an OR gate. Write the truth table for this logic gate and draw its logic symbol.



Ans. (*a*)

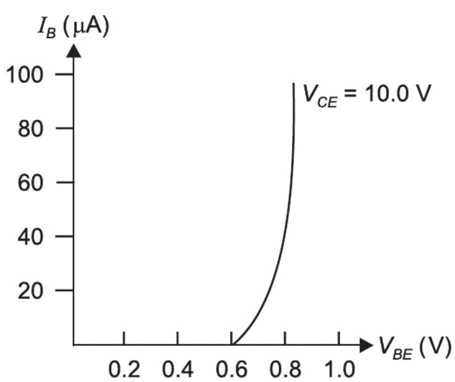


An *n-p-n* transistor

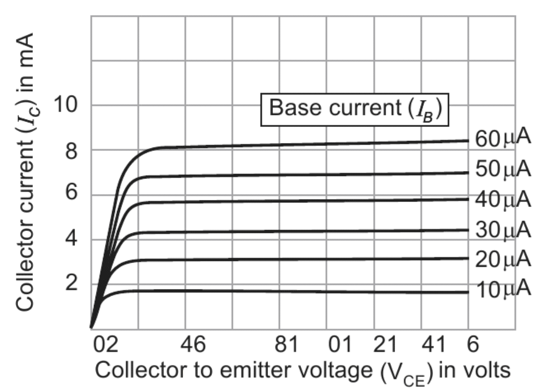
To obtain the input characteristics, we keep V_{CE} constant and vary the voltage across base-emitter (V_{BE}) to get base current.

The inverse of the slope of input characteristics gives an input resistance.

To obtain the output characteristics, we keep base current I_B constant and vary collector-emitter voltage (V_{CE}) to find out corresponding values of collector current.

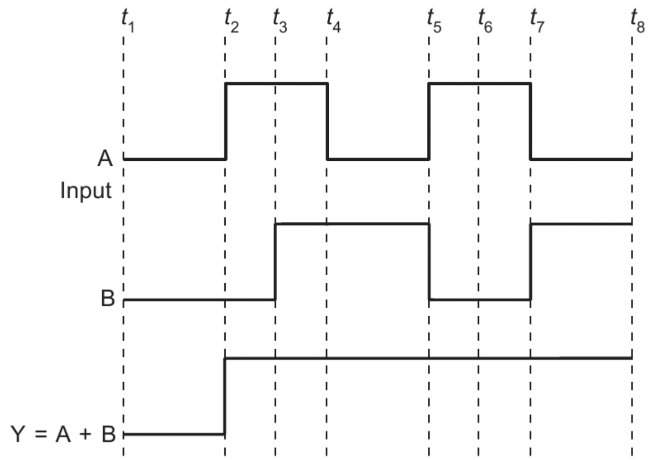


Input characteristics



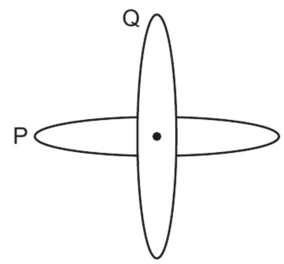
Output characteristics

(*b*)

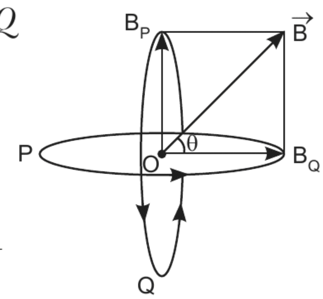


Time interval	*A*	*B*	*Y* = *A* + *B*
$t_1 - t_2$	0	0	0
$t_2 - t_3$	1	0	1
$t_3 - t_4$	1	1	1
$t_4 - t_5$	0	1	1
$t_5 - t_6$	1	0	1
$t_6 - t_7$	1	0	1
$t_7 - t_8$	0	1	1

20. Two identical loops *P* and *Q* each of radius 5 cm are lying in perpendicular planes such that they have a common centre as shown in the figure. Find the magnitude and direction of the net magnetic field at the common centre of the two coils, if they carry currents equal to 3 A and 4 A respectively.



Ans. Assuming the direction of currents in the loops *P* and *Q* are as shown in the diagram.



$r_P = r_Q = 5$ cm $= 0.05$ m, $I_P = 3$ A, $I_Q = 4$ A

∴ Net magnetic field at the centre *O*,

As $$B = \sqrt{B_P^2 + B_Q^2}, \text{ where } B_P = \frac{\mu_0 I_P}{2r}, B_Q = \frac{\mu_0 I_Q}{2r}$$

∴ $$B_{\text{net}} = \sqrt{\left(\frac{\mu_0 I_P}{2r}\right)^2 + \left(\frac{\mu_0 I_Q}{2r}\right)^2}$$

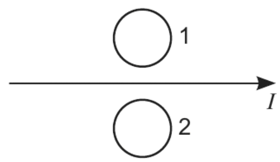
$$B_{\text{net}} = \frac{4\pi \times 10^{-7} \times 5}{2 \times 0.05} = 6.28 \times 10^{-5} \text{ T}$$

Direction of net magnetic field, $\vec{B} = \tan\theta = \frac{B_P}{B_Q} = \frac{I_P}{I_Q} = \frac{3}{4}$

$$\theta = \tan^{-1}\left(\frac{3}{4}\right) = 36.86° \approx 37°$$

SECTION A

3. What is the direction of induced currents in metal rings 1 and 2 when current *I* in the wire is increasing steadily?



Ans. The direction of induced current is clockwise in metal ring 1 and anticlockwise in metal ring 2.

4. In which directions do the electric and magnetic field vectors oscillate in an electromagnetic wave propagating along the *x*-axis?

Ans. *y*-axis and *z*-axis respectively.

SECTION B

8. Why does current in a steady state not flow in a capacitor connected across a battery? However, momentary current does flow during charging or discharging of the capacitor. Explain.

Ans. In the steady state, the displacement current and conduction current both become zero, as the electric field is uniform between the plates. But during charging/discharging, electric field changes due to which displacement current and therefore conduction current are produced for a moment.

9. The ground state energy of hydrogen atom is –13.6 eV. If an electron makes a transition from an energy level –1.51 eV to –3.4 eV, calculate the wavelength of the spectral line emitted and name the series of hydrogen spectrum to which it belongs.

Ans. Given: $E_1 = -13.6$ eV; $E_i = -1.51$ eV, $E_f = -3.4$ eV

$$\because \quad \frac{hc}{\lambda} = E_i - E_f \qquad [\because E_i > E_f]$$

$$\lambda = \frac{6.63\times10^{-34}\times3\times10^{8}}{(-1.51+3.4)\times1.6\times10^{-19}} \text{ m}$$

$$\lambda = 657.7 \text{ nm}$$

$\because$ $$E_i = \frac{-13.6}{n_i^2}\text{ eV} = -1.51\text{ eV}$$

$$n_i^2 = 9 \quad \Rightarrow \quad n_i = 3$$

$$E_f = \frac{-13.6}{n_f^2} = -3.4 \quad \Rightarrow \quad n_f = 2$$

As transition is from $n = 3$ to $n = 2$

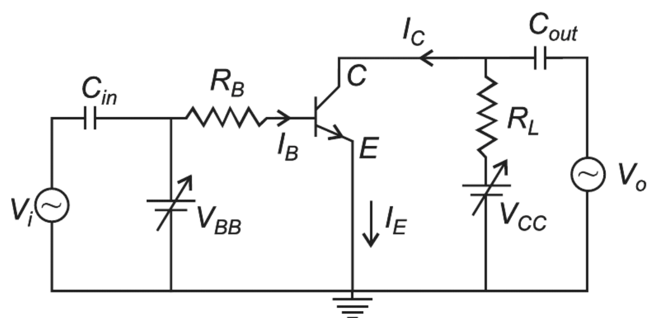
$\therefore$ The given wavelength belongs to Balmer series.

SECTION C

14. **(*a*) Draw the circuit diagram of an *n–p–n* transistor amplifier in common emitter configuration.**

(*b*) Derive an expression for voltage gain of the amplifier and hence show that the output voltage is in opposite phase with the input voltage.

Ans. (*a*)



A simple circuit of a CE transistor amplifier

(*b*) When a transistor acts as an amplifier, it operates in active region.

When an ac input signal V_i is superimposed on the base bias V_{BB}, the output, which is measured between collector and ground, increases.

$$V_{CC} = V_{CE} + I_C R_L \text{ and } V_{BB} = V_{BE} + I_B R_B$$

when V_i is non-zero, we have

$$V_{BB} + V_i = V_{BE} + I_B R_B + \Delta I_B (R_B + R_i) \Rightarrow V_i = \Delta I_B (R_B + R_i)$$

$$(\because R_B + R_i = r_i)$$

$$V_i = r_i \Delta I_B \qquad ...(i)$$

Change in I_B causes a change in I_C. So $\beta_{ac} = \frac{\Delta I_C}{\Delta I_B}$

As $\quad \Delta V_{CC} = \Delta V_{CE} + R_L\, \Delta I_C$

$$\Delta V_{CE} = -R_L\, \Delta I_C \qquad [\because \Delta V_{CC} = 0]$$

$$V_o = -R_L \, \Delta I_C \qquad [\because \quad \Delta V_{CE} = V_o]$$

$$V_o = -R_L \, (\beta_{ac} \, \Delta I_B) \qquad ...(ii) \quad [\because \Delta I_C = \beta_{ac} \, \Delta I_B]$$

Using equations (*i*) and (*ii*), we get

Voltage gain of the amplifier, $A_V = \dfrac{V_o}{V_i} = \dfrac{\Delta V_{CE}}{r\Delta I_B} = \dfrac{-\beta_{ac}\Delta I_B R_L}{r_i \Delta I_B} = -\beta_{ac}\dfrac{R_L}{r_i}$

The negative sign in the above expression indicates that the output signal is having a phase difference of π with respect to input signal.

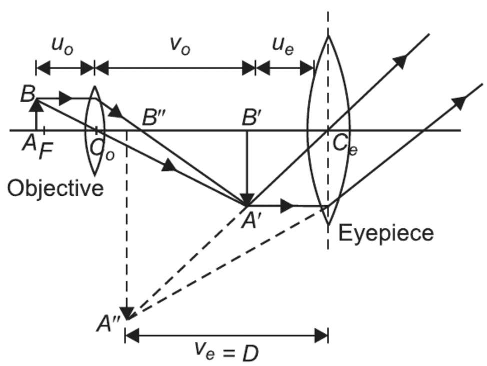
17. **(*a*)** **Draw a ray diagram for the formation of image by a compound microscope.**

(*b*) **You are given the following three lenses. Which two lenses will you use as an eyepiece and as an objective to construct a compound microscope?**

Lenses	Power (*D*)	Aperture (*cm*)
L_1	3	8
L_2	6	1
L_3	10	1

(*c*) **Define resolving power of a microscope and write one factor on which it depends.**

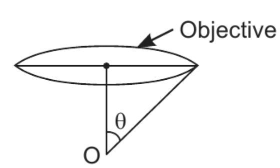
Ans. (*a*)



A compound microscope

(*b*) Refer to Ans. 20 (*b*) Set I

(*c*) It is an ability of an instrument to resolve the images of two point objects lying close to each other.



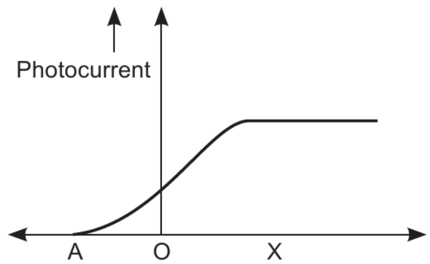
Resolving power of a microscope is given as

$$\frac{1}{d} = \frac{2\mu \sin\theta}{1.22\lambda}$$

where $\mu \sin \theta$ is numerical aperture.

θ is half the angle subtended on to the objective lens by the cone of light of wavelength λ, from the point object under observation. *d* is the minimum distance between the two point objects for which they can be seen as separate through a microscope.

18. **The following graph shows the variation of photocurrent for a photosensitive metal:**



(*a*) Identify the variable *X* on the horizontal axis.

(*b*) What does the point *A* on the horizontal axis represent?

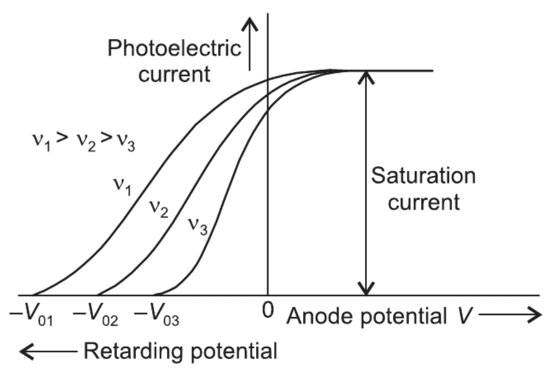
(*c*) Draw this graph for three different values of frequencies of incident radiation ν_1, ν_2 and ν_3 ($\nu_1 > \nu_2 > \nu_3$) for same intensity.

(*d*) Draw this graph for three different values of intensities of incident radiation I_1, I_2 and I_3 ($I_1 > I_2 > I_3$) having same frequency.

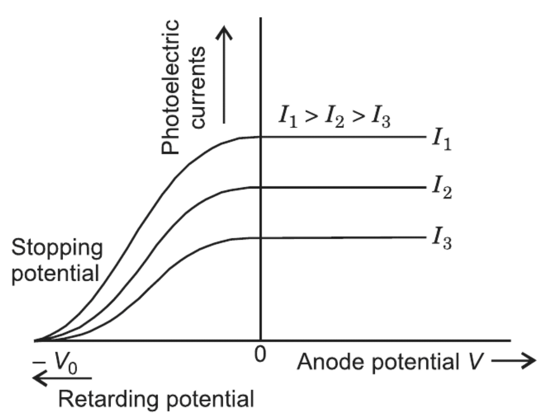
Ans. (*a*) The variable *X* is collector plate potential.

(*b*) The point *A* represents stopping potential V_0.

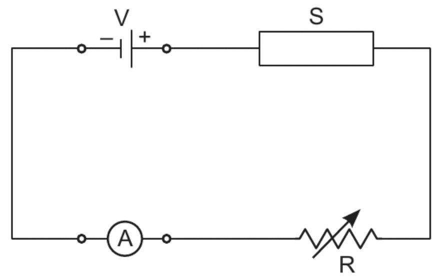
(*c*) Graph for the same intensity but different frequencies $\nu_1 > \nu_2 > \nu_3$ of incident radiation.



(*d*) Graph for the same frequency but different intensities $I_1 > I_2 > I_3$ of incident radiation.



21. **(*a*) In the following diagram *S* is a semiconductor. Would you increase or decrease the value of *R* to keep the reading of the ammeter *A* constant when *S* is heated? Give reason for your answer.**

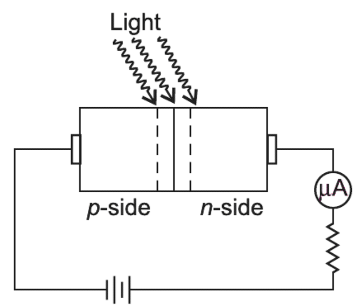


(*b*) Draw the circuit diagram of a photodiode and explain its working. Draw its I-V characteristics.

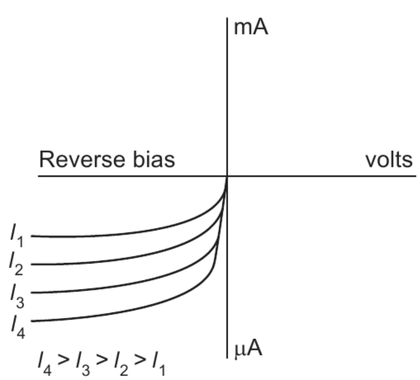
Ans. (*a*) $\because$ Electric current, $I = \dfrac{V}{R + R_S}$

As the resistivity of the semiconductor decreases on heating, so R_S will decrease and to maintain constant current R should be increased.

(*b*) When a photodiode is illuminated with light having photons of energy ($h\nu$) greater than energy gap (E_g) of semiconductor, the electron-hole pairs are generated in the depletion region. An electric field across the junction separates the holes and electrons. Thus, the electrons reach n-side and holes reach p-side. Hence, the accumulation of electrons on n-side and holes on p-side develops an emf.



When an external load is connected, current flows.



Illumination intensities

Examination Papers, 2017
[Foreign Set-I, II, III]

Time Allowed: **3 Hours**] [Maximum Marks: **70**

General Instructions:

(*i*) **All** questions are **compulsory**. There are **26** questions in all.

(*ii*) This question paper has **five** sections: Section **A**, Section **B**, Section **C**, Section **D** and Section **E**.

(*iii*) Section **A** contains **five** questions of **one** mark each, Section **B** contains **five** questions of **two** marks each, Section **C** contains **twelve** questions of **three** marks each, Section **D** contains **one** value based question of **four** marks and Section **E** contains **three** questions of **five** marks each.

(*iv*) There is no overall choice. However, an internal choice has been provided in **one** question of **two** marks, **one** question of **three** marks and all **three** questions of **five** marks weightage. You have to attempt only **one** of the choices in such questions.

(*v*) You may use the following values of physical constants wherever necessary:

$$c = 3 \times 10^{8} \text{ m/s}$$

$$h = 6.63 \times 10^{-34} \text{ Js}$$

$$e = 1.6 \times 10^{-19} \text{ C}$$

$$\mu_0 = 4\pi \times 10^{-7} \text{ T m A}^{-1}$$

$$\varepsilon_0 = 8.854 \times 10^{-12} \text{ C}^2\text{N}^{-1}\text{M}^{-2}$$

$$\frac{1}{4\pi\varepsilon_0} = 9 \times 10^{9} \text{ N m}^2 \text{ C}^{-2}$$

Mass of electron = 9.1×10^{-31} kg

Mass of neutron = 1.675×10^{-27} kg

Mass of proton = 1.673×10^{-27} kg

Avogadro's number = 6.023×10^{23} per gram mole

Boltzmann constant = 1.38×10^{-23} JK^{-1}

SECTION A

1. A point charge Q is placed at point O as shown in the figure. Is the potential at point A, i.e. V_A, greater, smaller or equal to potential, V_B, at point B, when Q is (*i*) positive, and (*ii*) negative charge?

O●　　　A●　　　B●

Ans. $\because$ Electric potential, $V = \dfrac{1}{4\pi\varepsilon_0} \cdot \dfrac{Q}{r}$ and $r_A < r_B$

(*i*) When Q is positive, $V_A > V_B$

(*ii*) When Q is negative, $V_A < V_B$.

2. Write the expression for speed of electromagnetic waves in a medium of electrical permittivity ε and magnetic permeability μ.

Ans. Speed of electromagnetic waves in a medium is given by

$$v = \frac{1}{\sqrt{\mu\varepsilon}}$$

3. Does the magnifying power of a microscope depend on the colour of the light used? Justify your answer.

Ans. Magnifying power of a microscope, $m = -\dfrac{L}{f_o}\left(1 + \dfrac{D}{f_e}\right)$

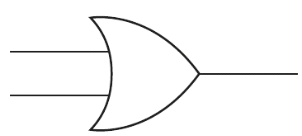
Since the focal length of a convex lens depends on the refractive index, and refractive indices for different colours are different, so according to the lens maker's formula

$$\frac{1}{f} = (n - 1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$$

The magnifying power of a microscope depends on the colour of the light used.

4. Draw logic symbol of an OR gate and write its truth table.

Ans. Logic symbol of OR Gate



Truth Table

A	B	Y = A + B
0	0	0
0	1	1
1	0	1
1	1	1

5. A photosensitive surface emits photoelectrons when red light falls on it. Will the surface emit photoelectrons when blue light is incident on it? Give reason.

Ans. Since condition for photoemission is $\frac{hc}{\lambda} \geq \phi_0$ (work function) and $\lambda_B < \lambda_R$, hence, surface will emit photoelectrons.

SECTION B

6. Find the intensity at a point on a screen in Young's double slit experiment where the interfering waves of equal intensity have a path difference of (*i*) λ/4, and (*ii*) λ/3.

Ans.
$$\text{Intensity, } I = 4I_0 \cos^2 \frac{\phi}{2}$$

(*i*) For a path difference of $\frac{\lambda}{4}$; phase difference is $\phi = \frac{2\pi}{4} = \frac{\pi}{2}$

$$\therefore \quad I = 4I_0 \cos^2 \frac{\pi}{2 \times 2}$$

$$\therefore \quad I = \frac{4I_0}{2} = 2I_0 \qquad \left[\because \cos\frac{\pi}{4} = \frac{1}{\sqrt{2}}\right]$$

(*ii*) For a path difference $= \frac{\lambda}{3}$; phase difference is $\phi = \frac{2\pi}{3}$

$$\therefore \quad I = 4I_0 \cos^2 \frac{2\pi}{2 \times 3} \qquad \left[\because \cos\frac{\pi}{3} = \frac{1}{2}\right]$$

$$\therefore \quad I = \frac{4I_0}{4} = I_0$$

7. Write two points of difference between intrinsic and extrinsic semiconductors.

Ans.

Intrinsic semiconductor	*p*-type semiconductor
(*i*) This form of semiconductor does not contain any impurity.	(*i*) It is doped semiconductor with trivalent impurity.
(*ii*) Here $n_e = n_h$	(*ii*) Here $n_h > n_e$

8. Distinguish between broadcast mode and point-to-point mode of communication and give one example for each.

Ans. **Broadcast:** In broadcast, there is one transmitter and many receivers. For example, television and radio broadcast.

Point-to-point: In point-to-point communication, there is one transmitter and one receiver. For example, telephony.

9. A light bulb and a solenoid are connected in series across an ac source of voltage. Explain, how the glow of the light bulb will be affected when an iron rod is inserted in the solenoid.

Ans. $\because$ Impedance, $Z = \dfrac{V_{rms}}{\sqrt{R^2 + (2\pi\nu L)^2}}$, here $L = \mu_0 n^2 Al$

When the iron rod is inserted in a solenoid, the inductance increases according to $L' = \mu_r \mu_0 n^2 Al$, as μ_r for iron is very large. Therefore, the current in the circuit decreases and bulb will glow dimmer.

10. Use the mirror equation to show that an object placed between f and $2f$ of a concave mirror forms an image beyond $2f$.

OR

(a) State the condition under which a large magnification can be achieved in an astronomical telescope.

(b) Give two reasons to explain why a reflecting telescope is preferred over a refracting telescope.

Ans. For a concave mirror, $f < 0$, $u < 0$, $2f < u < f$ (according to question)

or $\quad \dfrac{1}{2f} > \dfrac{1}{u} > \dfrac{1}{f}, \ -\dfrac{1}{2f} < \left(-\dfrac{1}{u}\right) < \left(-\dfrac{1}{f}\right)$

$$\frac{1}{f} - \frac{1}{2f} < \frac{1}{f} - \frac{1}{u} < \frac{1}{f} - \frac{1}{f}, \ \frac{1}{2f} < \frac{1}{v} < 0 \qquad \left(\because \frac{1}{f} = \frac{1}{v} + \frac{1}{u}\right)$$

This implies that

(*i*) $v < 0$, i.e. image is formed on the left of the mirror

(*ii*) $2f > v$

or $|2f| < |v|$ $\qquad$ [$\because$ $2f$ and v are negative]

i.e. real image is formed beyond $2f$.

OR

(*a*) $\because$ Magnification, $m = \dfrac{f_o}{-f_e}\left(1 + \dfrac{f_e}{D}\right)$

$\therefore$ Condition for larger magnification is $f_o >> f_e$.

(*b*) The following are the two advantages of a reflecting type telescope over a refracting type telescope:

(*i*) As there is no refraction, it is free from the chromatic aberration.

(*ii*) The light gathering power of the objective must be higher to get better resolution. Therefore, mirrors of larger diameters are easier to handle and are cheaper.

SECTION C

11. **(*a*) Define the term 'modulation index', used in communication system. Why is its value kept less than or equal to one?**

(*b*) A massage signal of frequency 10 kHz and peak voltage of 10 V is used to modulate a carrier frequency 1 MHz and peak voltage 10 V. Determine the (*i*) modulation index, and (*ii*) side bands produced.

Ans. (*a*) The ratio of amplitude of modulating wave to the amplitude of carrier wave is called modulation index, i.e. $\mu = \frac{A_m}{A_c}$.

In order to avoid distortion $A_m \leq A_c$, i.e. $\mu \leq 1$.

(*b*) Given: $\nu_m = 10$ kHz, $\nu_c = 1$ MHz $= 1000$ kHz, $A_m = 10$ V, $A_c = 10$ V

(*i*) Modulation index, $\mu = \frac{A_m}{A_c} = \frac{10 \text{ V}}{10 \text{ V}} = 1$

(*ii*) Upper side band $= \nu_c + \nu_m = 1000 + 10 = 1010$ kHz

Lower side band $= \nu_c - \nu_m = 1000 - 10 = 990$ kHz

12. **Using Bohr's postulates, derive the expression for the orbital period of the electron moving in the n^{th} orbit of hydrogen atom.**

Ans. According to Bohr's second postulate

$$\text{Angular momentum} = mv_n r_n = \frac{nh}{2\pi} \quad \text{...}(i)$$

Here, m = Mass of e^-, v_n = Velocity of revolving electron in n^{th} orbit;

r_n = Radius of n^{th} orbit

∵ Centripetal force for revolution is provided by electrostatic force between nucleus and electron

$$\therefore \quad \frac{mv_n^2}{r_n} = \frac{1}{4\pi\varepsilon_0}\frac{e^2}{r_n^2} \quad \text{...}(ii)$$

Dividing equation (*ii*) by equation (*i*), we get

$$v_n = \frac{e^2}{2\varepsilon_0 nh} \quad \text{...}(iii)$$

Using equations (*i*) and (*iii*), we get

$$r_n = \frac{\varepsilon_0 n^2 h^2}{\pi m e^2} \quad \text{...}(iv)$$

∴ Orbital period of electron in nth orbit is given by

$$T = \frac{2\pi r_n}{v_n} = \frac{4\varepsilon_0^2 n^3 h^3}{me^4} \quad \text{[Using equations (iii) and (iv)]}$$

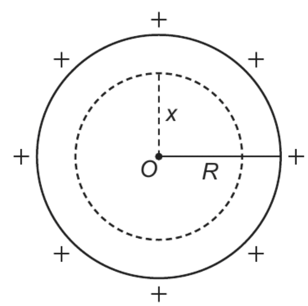
13. A charge Q is distributed uniformly over a metallic sphere of radius R. Obtain the expressions for the electric field (E) and electric potential (V) at a point $0 < x < R$.

Show on a plot the variation of E and V with x for $0 < x < 2R$.

Ans. Draw a Gaussian surface (sphere) of radius $x < R$. Applying Gauss's theorem

$$\oint \vec{E} \cdot \vec{ds} = \frac{1}{\varepsilon_0} \times 0 \qquad \text{[As no charge is enclosed]}$$

$\therefore$ $E = 0$ at a point $0 < x < R$

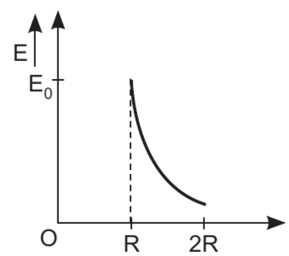


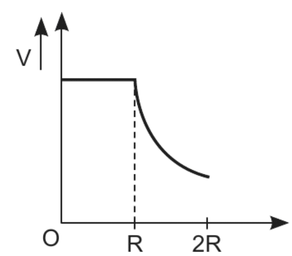
For a uniformly charged sphere, the electric field outside the metallic sphere is as if the whole charge is concentrated at the centre. Thus potential on the surface will be

$$V = \frac{1}{4\pi\varepsilon_0} \frac{Q}{R}$$

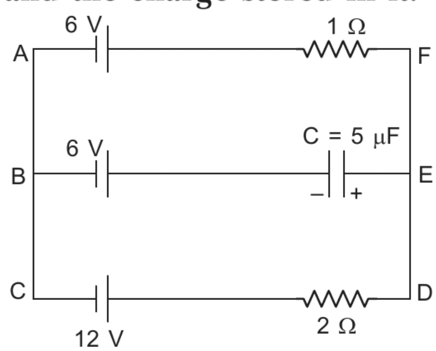
and as no work is done in moving a charge inside the shell,

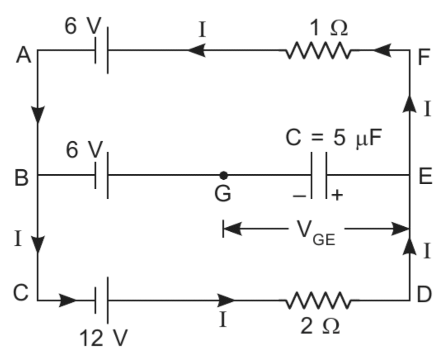
therefore inside the cell $V = \dfrac{Q}{4\pi\varepsilon_0 R}$





14. In the given circuit, with steady current, calculate the potential difference across the capacitor and the charge stored in it.





Ans. Applying Kirchhoff's voltage rule to the loop ABCDEFA

$$12 - 2I - I - 6 = 0$$

$$3I = 6 \quad \Rightarrow \quad I = 2 \text{ A}$$

$\because$ P.D. across BE = P.D. across CD

$\therefore$ $V_{BE} = 12 - 2I = 12 - 2 \times 2 = 8$ V

$\therefore \quad V_{BE}$ = P.D. across a capacitor

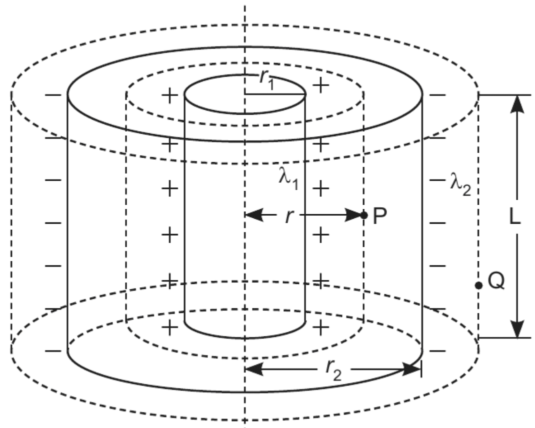
$= 8 - 6 = 2$ V

$\therefore$ Charge stored in a capacitor, $Q = C.V_{GE} = 5 \times 2\ \mu C$

$Q = 10\ \mu C$

15. A long charged cylinder of linear charge density $+\lambda_1$ is surrounded by a hollow coaxial conducting cylinder of linear charge density $-\lambda_2$. Use Gauss's law to obtain expressions for the electric field at a point (*i*) in the space between the cylinders, and (*ii*) outside the larger cylinder.

Ans. Let r_1, r_2 be the radii of inner and outer cylinders and a point P lies at a distance r such that $r_1 < r < r_2$ then net electric field at P



$$E_1 = \frac{\lambda_1}{2\pi\varepsilon_0 r}$$

directed radially outwards.

Consider the length L of both the cylinders.

According to Gauss's law, net electric flux

(*i*) in the space between the two cylinders is given by

$$\oint \vec{E}_1 . \vec{ds}_1 = \frac{\lambda_1 L}{\varepsilon_0}$$

$$E_1 \cdot 2\pi r L = \frac{\lambda_1 L}{\varepsilon_0}$$

$$E_1 = \frac{\lambda_1}{2\pi r\varepsilon_0}, \text{ radially outwards}$$

(*ii*) To determine net electric field at a point outside the sphere, draw a Gaussian cylinder of radius r, coaxial with other two cylinders such that $r > r_2$

According to Gauss's theorem

$$\text{Net electric flux} = \oint \vec{E} . \vec{ds} = \frac{q}{\varepsilon_0}$$

$$E . 2\pi r L = \frac{(\lambda_1 - \lambda_2)L}{\varepsilon_0} \qquad [\because q_{net} = \lambda_1 L - \lambda_2 L = (\lambda_1 - \lambda_2)L]$$

$$\vec{E} = \frac{(\lambda_1 - \lambda_2)}{2\pi\varepsilon_0 r} . \hat{n}$$

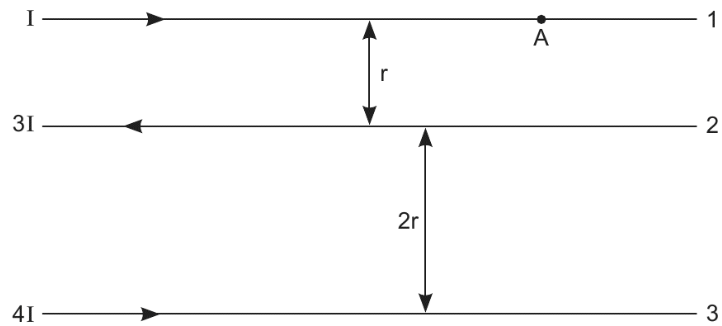
16. Using Biot-Savart law, deduce the expression for the magnetic field at a point (*x*) on the axis of a circular current carrying loop of radius *R*. How is the direction of the magnetic field determined at this point?

OR

The figure shows three infinitely long straight parallel current carrying conductors. Find the

(*i*) magnitude and direction of the net magnetic field at point A laying on conductor 1,

(*ii*) magnetic force on conductor 2.



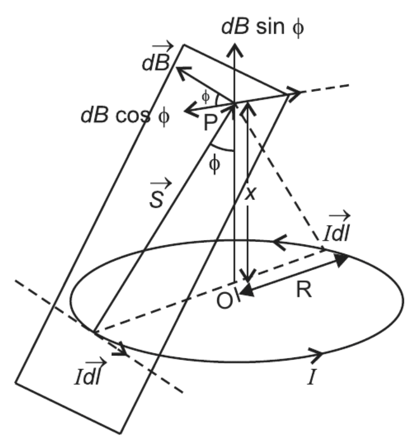
Ans. Consider a circular current carrying conductor of radius R.

According to the Biot-Savart law, the magnetic field at P due to current element $I\vec{dl}$ is given by

$$\vec{dB} = \frac{\mu_0}{4\pi}\frac{Idl\sin 90°}{S^2}$$

$$dB = \frac{\mu_0}{4\pi}\frac{Idl}{S^2} = \frac{\mu_0}{4\pi}\frac{Idl}{(R^2+x^2)} \qquad (\because S = \sqrt{R^2+x^2})$$

The direction of $\vec{dB}$ is perpendicular to the plane containing $\vec{S}$ and $\vec{dl}$. We resolve $\vec{dB}$ into rectangular components. The components $dB\cos\phi$ and $dB\sin\phi$ get cancelled by the corresponding component of magnetic field at P produced by the current element diametrically opposite to the previous one. It is only $dB\sin\phi$ that is added up for magnetic field of every current element on the loop.



Thus, total magnetic field is given by

$$B = \int dB\sin\phi = \int \frac{\mu_0 Idl\sin\phi}{4\pi(R^2+x^2)} \qquad \left[\because \sin\phi = \frac{R}{\sqrt{x^2+R^2}}\right]$$

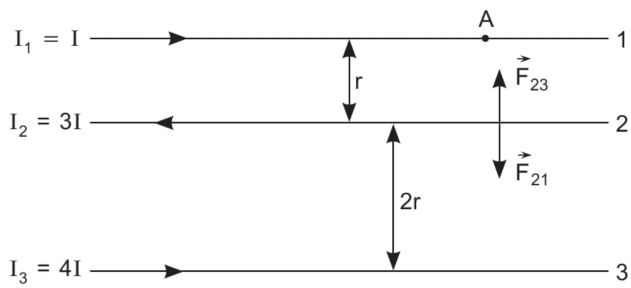
$$B = \frac{\mu_0 I}{4\pi(R^2+x^2)}\frac{R}{(x^2+R^2)^{1/2}}.2\pi R = \frac{\mu_0 IR^2}{2(R^2+x^2)^{3/2}}$$

$$\therefore \qquad \vec{B} = \frac{\mu_0 IR^2\hat{i}}{2(R^2+x^2)^{3/2}}$$

The direction of magnetic field is determined by Right-Hand thumb rule stated as: Curl the palm of right hand around the circular wire with fingers pointing in the direction of the current. Then, the thumb of right hand will give the direction of the magnetic field.

OR

(*i*)



At A

Magnetic field due to conductor 2 $= B_1 = \dfrac{\mu_0(3I)}{2\pi r}$ perpendicularly inwards

Magnetic field due to conductor 3 $= B_2 = \dfrac{\mu_0(4I)}{2\pi(3r)}$ perpendicular outwards

$\therefore$ Net magnetic field at A

$$B = B_1 - B_2 = \frac{\mu_0 I}{2\pi r}\left[3 - \frac{4}{3}\right]$$

$$B = \frac{5\mu_0 I}{6\pi r}, \text{ perpendicularly inwards}$$

(*ii*) Magnetic force per unit length on conductor 2 due to conductor 1

$= F_{21} = \dfrac{\mu_0}{4\pi}\cdot\dfrac{2I_1I_2}{r}$

Magnetic force per unit length on conductor 2 and due to current flowing in conductor 3

$$F_{23} = \frac{\mu_0}{4\pi}\cdot\frac{2I_2I_3}{2r}$$

Since forces F_{23} and F_{21} are in opposite directions (as shown)

$\therefore$ Net force experienced by conductor 2

$$F_2 = F_{23} - F_{21} = \frac{\mu_0}{2\pi r}\left[3I^2 - \frac{12I^2}{2}\right]$$

$$F_2 = \frac{3\mu_0 I^2}{2\pi r}, \text{ towards conductor 1.}$$

17. (*a*) State the law of radioactive decay. Write the SI unit of 'activity'.

(*b*) There are $4\sqrt{2} \times 10^6$ radioactive nuclei in a given radioactive sample. If the half life of the sample is 20 s, how many nuclei will decay in 10 s?

Ans. (*a*) The rate of decay of nuclei at any instant is proportional to the number of undecayed radioactive nuclei present at that instant.

$$\frac{dN}{dt} = -\lambda N$$

where λ is called decay constant or disintegration constant.

SI unit of 'activity' is becquerel (Bq).

(*b*) $N_0 = 4\sqrt{2} \times 10^6$; $T_{1/2} = 20$ s, $t = 10$ sec

$$\lambda = \frac{0.693}{T_{1/2}} = \frac{0.693}{20}\ \text{s}^{-1}$$

$$N = N_0 e^{-\lambda t}$$

$$\therefore \quad N = 4\sqrt{2} \times 10^6\, e^{\frac{-0.693}{20} \times 10}$$

$$N = 4\sqrt{2} \times 10^6\, e^{-0.3465}$$

Taking log on both sides

$$\ln N = \ln 4\sqrt{2} + \ln 10^6 - 0.3465$$

$$\log N = \log 4 + \log 2^{1/2} + \log 10^6 - \frac{0.3465}{2.3036}$$

$$= 0.6020 + \left(\frac{1}{2} \times 0.3010\right) + 6 - 0.1504$$

$$= 0.6020 + 0.1505 + 6 - 0.1504 = 6.6021$$

$$\therefore \quad \text{Antilog}(\log N) = \text{Antilog}(6.6021)$$

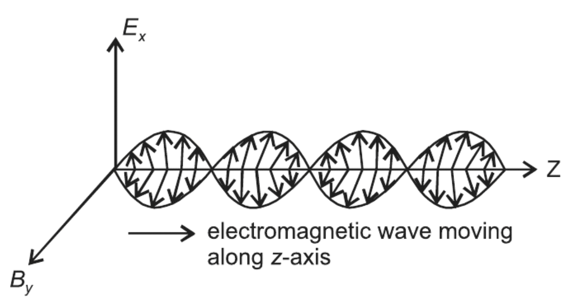
$$N = 4.0 \times 10^6$$

18. **(*a*) How are electromagnetic waves produced? Explain.**

(*b*) A plane electromagnetic wave is travelling through a medium along the +ve *z*-direction. Depict the electromagnetic wave showing the directions of the oscillating electric and magnetic fields.

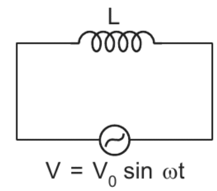
Ans. (*a*) Electromagnetic waves are produced by an oscillating charge. This gives rise to an oscillating emf, which causes an oscillating electric field. This oscillating electric field produces an oscillating magnetic field, which in turn is a source of oscillating electric field and the process continues.

(*b*)



19. A source of ac voltage $V = V_0 \sin \omega t$, is connected across a pure inductor of inductance L. Derive the expressions for the instantaneous current in the circuit. Show that average power dissipated in the circuit is zero.

Ans. The given ac source of alternating voltage $V = V_0 \sin \omega t$ is connected to an inductor.



$$V = L\frac{dI}{dt}$$

$$\Rightarrow \quad dI = \frac{V}{L}dt$$

$$\therefore \quad dI = \frac{V_0}{L}\sin \omega t\, dt$$

Integrating $$I = \int dI = \frac{V_0}{L}\int \sin \omega t\, dt$$

$$I = -\frac{V_0}{\omega L}\cos \omega t$$

$$\therefore \quad I = I_0 \sin(\omega t - \pi/2)$$

where $I_0 = \dfrac{V_0}{\omega L}$

The small work done in sending the electric current through the inductor in small time interval dt given by

$$dw = VI\, dt$$

where $V = V_0 \sin \omega t$, and $I = -I_0 \cos \omega t$

Therefore, the net work done, during one complete cycle ($t = 0$ to $t = T$ s)

$$W = \int dw = -V_0 I_0 \int_0^T \sin\omega t \cos \omega t\, dt$$

$$= \frac{-V_0 I_0}{2}\int_0^T 2\sin \omega t \cos \omega t\, dt$$

$$W = \frac{-V_0 I_0}{2}\int_0^T \sin 2\omega t\, dt = \frac{-V_0 I_0}{2}\left[\frac{-\cos 2\omega t}{2\omega}\right]_0^T$$

$$W = \frac{+V_0 I_0}{4\omega}\left[\cos 2.\frac{2\pi}{T}.T - \cos 0\right]$$

$$W = 0$$

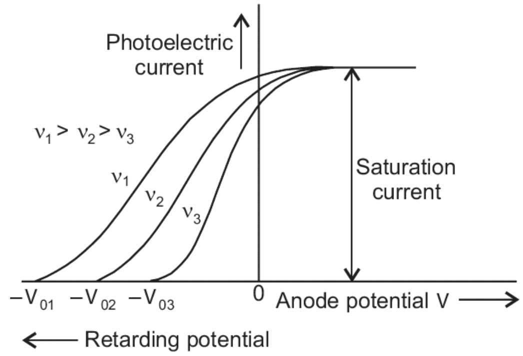
$$\therefore \quad P_{av} = \frac{W}{T} = 0$$

20. **(*a*) Draw a plot showing the variation of photoelectric current with collector potential for different frequencies but same intensity of incident radiation.**

(*b*) Use Einstein's photoelectric equation to explain the observations from this graph.

(*c*) What change will you observe if intensity of incident radiation is changed but the frequency remains the same?

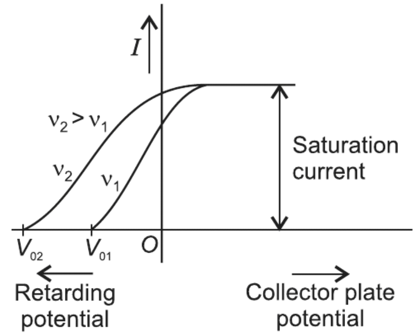
Ans. (*a*) For same intensity but different frequencies $\nu_1 > \nu_2 > \nu_3$ of incident radiation.



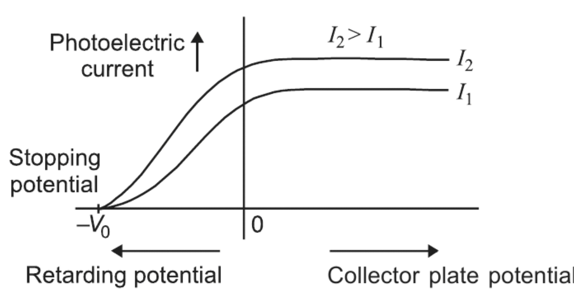
(*b*)
$$K_{max} = h(\nu - \nu_0) \text{ and } K_{max} = eV_0$$

Einstein's photoelectric equation

The energy of emitted photoelectrons depends on the frequency of incident radiation. Greater the frequency; greater is stopping potential. Saturation current depends on intensity of radiation, so it remains same.



(*c*) Stopping potential remains same. It depends upon the frequency of incident radiation.



21. **(*a*) State the condition under which a charged particle moving with velocity *v* goes undeflected in a magnetic field B.**

(*b*) An electron, after being accelerated through a potential difference of 10^4 V, enters a uniform magnetic field 0.04 T, perpendicular to its direction of motion. Calculate the radius of curvature of its trajectory.

Ans. (*a*) As force experienced, $\vec{F} = q(\vec{v} \times \vec{B})$

When a charge particle moves parallel or antiparallel to magnetic field.

(*b*) Given: $B = 0.04$ T, $V = 10^4$ V, $m = 9.1 \times 10^{-31}$ kg, $q = e = 1.6 \times 10^{-19}$ C

$\because$ Radius of curvature of a trajectory, $r = \dfrac{mv}{Bq}$

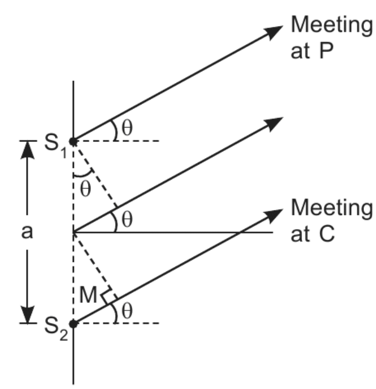
$$\therefore \quad \text{Radius, } r = \frac{\sqrt{2mqV}}{Bq} \Rightarrow r = \frac{1}{B}\sqrt{\frac{2mV}{q}}$$

$$r = \frac{1}{0.04}\sqrt{\frac{2 \times 9.1 \times 10^{-31} \times 10^4}{1.6 \times 10^{-19}}} \text{ m}$$

$$r = 8.4 \times 10^{-3} \text{ m}$$

22. **A monochromatic light of wavelength λ is incident normally on a narrow slit of width '*a*' to produce a diffraction pattern on the screen placed at a distance *D* from the slit. With the help of a relevant diagram, deduce the conditions for obtaining maxima and minima on the screen. Use these conditions to show that angular width of central maximum is twice the angular width of secondary maximum.**

Ans. We treat each point on the wavefront at the slit as secondary sources [Using Huygen's principle].



As the incoming wavefront is parallel to the plane of the slit, these sources are in phase [using Huygen's principle].

The path difference between the waves coming out from the two edges of the slits is $S_2P - S_1P = S_2M$.

$$\therefore \quad S_2M = a \sin\theta \approx a\theta$$

For the central point on the screen, $\theta = 0 \Rightarrow \Delta P = 0$

i.e. $\Delta\phi = 0$

All the parts of the slit contribute in phase. So, the maximum intensity is obtained at *C*.

Secondary Maxima: These are found at $\theta = \left(n + \frac{1}{2}\right)\frac{\lambda}{a}$

For n^{th} secondary maxima, we can imagine as if the slit is divided into $(2n + 1)$ parts.

The contributions from $2n$ parts of the slit get cancelled. Only $(2n+1)^{th}$ part of the slit contributes to the intensity at a point between two minima.

With an increase in n, the secondary maxima become weaker.

Secondary Minima: These are found at $\theta = \frac{n\lambda}{a}$

For n^{th} minima, we can imagine as if slit is divided into $2n$ parts. The separation between two point sources on consecutive parts will be $\frac{a}{2n}$.

As $$\Delta P = \theta y \qquad \left[\because\ y = \frac{a}{2n}\right]$$

$$\Delta P = \frac{n\lambda}{a} \times \frac{a}{2n} = \frac{\lambda}{2}$$

The path difference of $\frac{\lambda}{2}$ corresponds to phase difference of π (i.e. waves meet out of phase). There are even number of parts so net intensity is zero at the point on the screen.

Condition for 1st minimum on the screen is $a \sin \theta_1 = \lambda$

As angle is very small i.e. $\sin \theta \approx \theta$

$$\therefore \qquad \theta_1 = \frac{\lambda}{a}$$

For 2^{nd} minimum, $$\theta_2 = \frac{2\lambda}{a}$$

Angular width of 1^{st} secondary maximum,

$$\Delta\theta = \frac{2\lambda}{a} - \frac{\lambda}{a} = \frac{\lambda}{a}$$

The central fringe lies between 1^{st} minima on both sides of the central maximum.

Hence, the angular width of central fringe is given by $2\theta = \frac{2\lambda}{a}$

Hence, the angular width of central fringe is twice the angular width of first fringe.

SECTION D

23. Sunil and his parents were travelling to their village in their car. On the way his mother noticed some grey coloured panels installed on the roof of a low building. She enquired from Sunil what those panels were and Sunil told his mother that those were solar panels.

(a) What were the values displayed by Sunil and his mother? State one value for each.

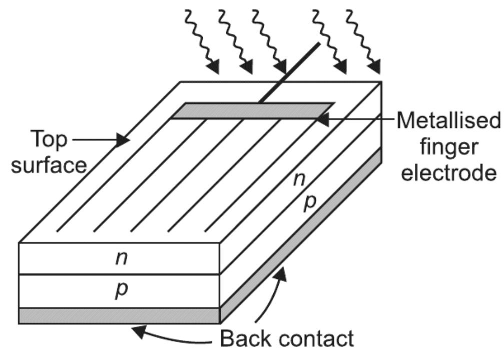
(b) In what way would the use of solar panels prove to be very useful?

(c) Name the semiconductor device used in solar panels. Briefly explain with the help of a diagram, how this device works.

Ans. (a) Sunil is knowledgeable and has awareness of basic concepts of solar panels. His mother is inquisitive and understanding.

(b) Solar panels provide electricity by converting solar energy into electrical energy.

(c) Soar cells are used in solar panels.

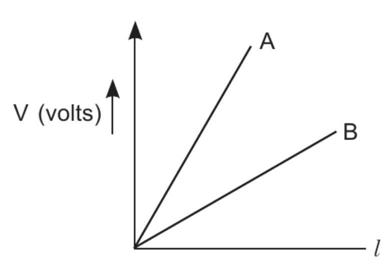


When light falls on the solar cell, three basic processes take place: generation, separation and collection—(i) generation of e-h pairs due to light (with $h\nu > E_g$) close to the junction; (ii) separation of electrons and holes due to electric field of the depletion region. Electrons are swept to n-side and holes to p-side; (iii) the electrons reaching the n-side are collected by the front contact and holes reaching p-side are collected by the back contact. Thus, p-side becomes positive an n-side becomes negative giving rise to *photovoltage*.

SECTION E

24. (a) (i) State the principle on which a potentiometer works. How can given potentiometer be made more sensitive?

(ii) In the graph shown below for two potentiometers, state with reason which of the two potentiometers, A or B, is more sensitive.



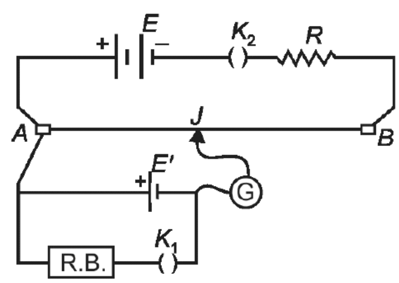
(*b*) **Two metallic wires, P_1 and P_2 of the same material and same length but different cross-sectional areas, A_1 and A_2 are joined together and connected to a source of emf. Find the ratio of the drift velocities of free electrons in the two wires when they are connected (*i*) in series, and (*ii*) in parallel.**

OR

(*a*) **Define the capacitance of a capacitor. Obtain the expression for the capacitance of a parallel plate capacitor in vacuum in terms of plate area A and separation d between the plates.**

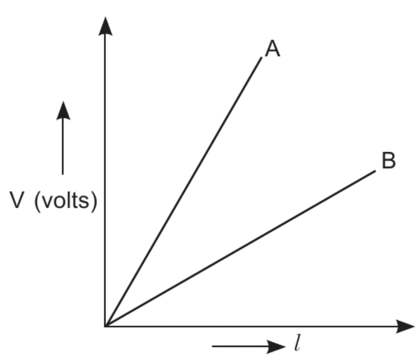
(*b*) **A slab of material of dielectric constant K has the same area as the plates of a parallel plate capacitor but has a thickness $\frac{3d}{4}$. Find the ratio of the capacitance with dielectric inside it to its capacitance without the dielectric.**

Ans. (*a*) **Principle:** When there is a constant current in a wire of uniform cross-sectional area and composition, the fall of potential along any length of the wire is directly proportional to the length, i.e. $V \propto l$ provided the physical conditions like temperature, mechanical strain, etc. remain constant.

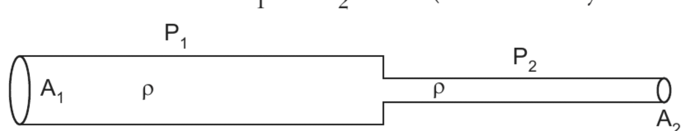


Potentiometer can be made more sensitive by reducing potential gradient. It can be reduced by (*i*) increasing length of the wire, and (*ii*) reducing current in the main circuit.

(*ii*) Potentiometer B is more sensitive because its slope $= \frac{V}{l}$ is low



(*b*)
$$l_1 = l_2 \text{ (Given)}$$
$$\rho_1 = \rho_2 \text{ (same material)}$$
$$\therefore \quad n_1 = n_2 = n \text{ (no. density of electrons)}$$



(*i*) In series, electric current flowing through the wire is same.

$$\therefore \quad I = neA_1 v_{d1} = neA_2 v_{d2}$$

$$\therefore \quad \frac{v_{d1}}{v_{d2}} = \frac{A_2}{A_1}$$

(*ii*) In parallel, P.D. is same

$$\therefore \quad \frac{v_{d1}}{v_{d2}} = \frac{\frac{eV}{l}\tau}{\frac{eV}{l}\tau} = \frac{1}{1}$$

$$\because \quad v_d = \frac{eV\tau}{lm}$$

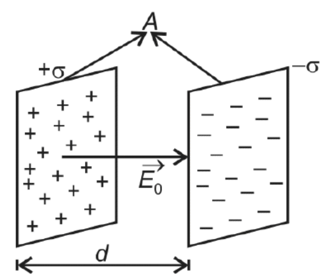
$$\therefore \quad \frac{v_{d1}}{v_{d2}} = \frac{1}{1}$$

OR

(*a*) **Capacitance:** It is equal to the magnitude of charge in each plate required to raise the potential difference between the plates by unity.

or

It is the ratio of the magnitude of charge on the plates to the potential difference between the plates.



$$C = \frac{Q}{V}.$$

Consider a capacitor with surface charge density σ on its plates. Suppose area of each plate is A and separation between the plates is d.

We know $\quad Q = CV$

$$C = \frac{Q}{V}$$

Here, $\quad Q = \sigma A \quad \ldots(i)$

$$V = E_0 d$$

$$V = \frac{\sigma}{\varepsilon_0} d \quad \left(\because E_0 = \frac{\sigma}{\varepsilon_0}\right) \ldots(ii)$$

From equations (1) and (2), we get

$$C_0 = \frac{\varepsilon_0 A}{d}$$

(*b*) Given: $\quad t = \frac{3d}{4}$

Capacitance without dielectric $= C_0 = \frac{A\varepsilon_0}{d}$

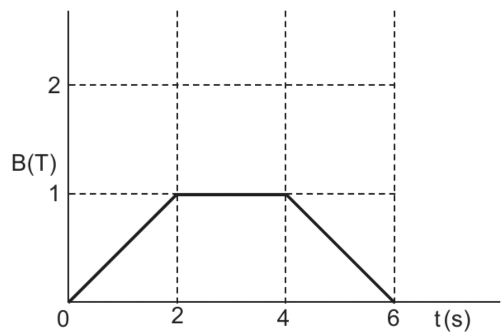
Capacitance with dielectric inside $C = \dfrac{A\varepsilon_0}{d - t\left(1 - \frac{1}{k}\right)} = \dfrac{C_0}{1 - \frac{t}{d}\left(1 - \frac{1}{k}\right)}$

$$\frac{C}{C_0} = \frac{1}{1 - \frac{3}{4}\frac{d}{d}\left(1 - \frac{1}{k}\right)}$$

$$\frac{C}{C_0} = \frac{4k}{k+3}$$

25. **(*a*) State Faraday's law of electromagnetic induction.**

(*b*) The magnetic field through a circular loop of wire 12 cm in radius and 8.5 Ω resistance, changes with time as shown in the figure. The magnetic field is perpendicular to the plane of the loop. Calculate the induced current in the loop and plot it as a function of time.



(*c*) Show that Lenz's law is a consequence of conservation of energy.

Or

(*a*) Describe, with the help of a suitable diagram, the working principle of a step-up transformer. Obtain the relation between input and output voltages in terms of the number of turns of primary and secondary windings and the currents in the input and output circuits.

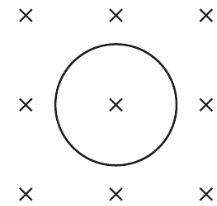
(*b*) Given the input current 15 A and the input voltage of 100 V for a step-up transformer having 90% efficiency, find the output power and the voltage in the secondary if the output current is 3 A.

Ans. (*a*) (*i*) Whenever there is a change in the magnetic flux linked with a circuit, an induced emf is set up in it and lasts as long as the magnetic flux linked with it is changing.

(*ii*) The magnitude of the induced emf ε in a circuit is directly proportional to the rate of change of magnetic flux linked with the circuit.

i.e. $$\varepsilon \propto \frac{-d\phi}{dt}$$

(*b*) Radius $r = 12$ cm = 0.12 m, Resistance $R = 8.5\ \Omega$, $\theta = 0°$



$$A = \pi r^2$$
$$= 3.14 \times (0.12)^2 = 0.045\ \text{m}^2$$

Magnetic flux passing through the loop

$$\phi = BA \cos 0° = BA$$

$\therefore$ Induced current $i = \frac{-1 d\phi}{R dt} = \frac{-A}{R}\frac{dB}{dt}$

In time interval, 0 – 2 sec : $\Delta t = 2 - 0 = 2$ sec

$$\Delta B = 1 - 0 = 1\ \text{T}$$

$$\therefore \quad i = \frac{-A}{R}\frac{\Delta B}{\Delta t} = \frac{-0.045}{8.5} \times \frac{1}{2}\ \text{A}$$

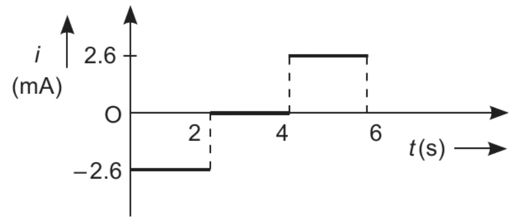
$$i = -2.6 \times 10^{-3}\ \text{A} = -2.6\ \text{mA}$$

From 2 – 4 sec, $\Delta B = 0$;

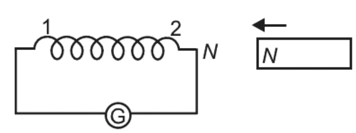
$\therefore \quad i = 0$

From 4 sec – 6 sec; $\Delta B = (0 - 1)\text{T} = -1$ T; $\Delta t = 6 - 4 = 2$ s

$$\therefore \quad i = \frac{-0.045}{8.5} \times \left(\frac{-1}{2}\right) = 2.6 \times 10^{-3}\ \text{A} = 2.6\ \text{mA}$$



(*c*) Lenz's law complies with the principle of conservation of energy. For example, when the N-pole of a bar magnet is pushed into a coil as shown, the direction of induced current in the coil will be such that the end 2 of the coil will act as N-pole. Thus, work has to be done against the magnetic repulsive force to push the magnet into the coil. The electrical energy produced in the coil is at the expense of this work done.

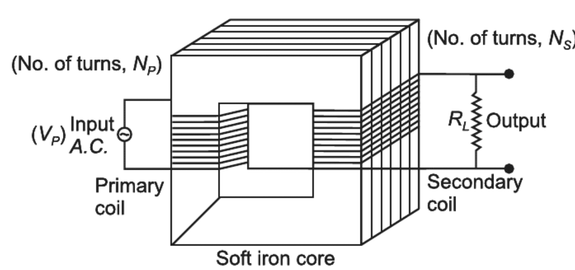


OR

(*a*) A step-up transformer is based on the principle of mutual induction.

An alternating potential (V_p) when applied to the primary coil is induced an emf in it.

$$\varepsilon_p = -N_p \frac{d\phi}{dt}$$



If resistance of primary coil is low, then $V_p = \varepsilon_p \Rightarrow V_p = -N_p \frac{d\phi}{dt}$

As same flux is linked with the secondary coil with the help of soft iron core due to the mutual induction, an emf is induced in it.

$$\varepsilon_s = -N_s \frac{d\phi}{dt}$$

If an output circuit is opened, $V_s = \varepsilon_s \Rightarrow V_s = -N_s \frac{d\phi}{dt}$

Thus, $$\frac{V_s}{V_p} = \frac{N_s}{N_p}$$

For step-up transformer, $\frac{N_s}{N_p} > 1$

In an ideal transformer

$$\text{Input power} = \text{Output power}$$

$$I_p V_p = I_s V_s$$

or $$\frac{V_s}{V_p} = \frac{I_p}{I_s} = \frac{N_s}{N_p}$$

(*b*) Given: $I_p = 15$ A; $V_p = 100$ V; $\eta = 90\% = \frac{90}{100} = \frac{9}{10}$,

$P_s = P_{\text{output}} = ?$, $V_s = ?$, $I_s = 3$ A

$\because$ $$\text{Efficiency} = \frac{\text{Output power}}{\text{Input power}} \times 100$$

$$\eta = \frac{P_{\text{out}}}{V_p I_p} \times 100$$

$$\frac{90}{100} = \frac{P_0}{100 \times 15} \Rightarrow P_0 = 1350 \text{ W}$$

$\because$ $$P_0 = V_s I_s$$

$\Rightarrow$ $$V_s = \frac{P_0}{I_s} = \frac{1350}{3} = 450 \text{ V}$$

26. **(*a*) A point object is placed on the principal axis of a convex spherical surface of radius of curvature R, which separates the two media of refractive indices n_1 and n_2 ($n_2 > n_1$). Draw the ray diagram and deduce the relation between the object distance (u), image distance (v) and the radius of curvature (R) for refraction to take place at the convex spherical surface from rarer to denser medium.**

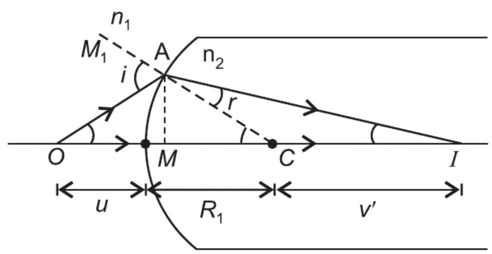
(*b*) A converging lens has a focal length of 20 cm in air. It is made of a material of refractive index 1.6. If it is immersed in a liquid of refractive index 1.3, find its new focal length.

OR

(*a*) Draw the ray diagram showing refraction of light through a glass prism and hence obtain the relation between the refractive index μ of the prism, angle of prism and angle of minimum deviation.

(*b*) Determine the value of the angle of incidence for a ray of light travelling from a medium of refractive index $\mu_1 = \sqrt{2}$ into the medium of refractive index $\mu_2 = 1$, so that it just grazes along the surface of separation.

Ans. (*a*)



For small angles, $\angle AOM \simeq \tan \angle AOM = \dfrac{AM}{MO}$

$$\angle ACM \simeq \tan \angle ACM = \frac{AM}{MC}$$

$$\angle AIM \simeq \tan \angle AIM = \frac{AM}{MI}$$

From ΔAOC, $\angle i = \angle AOM + \angle ACM$

$$\angle i = \frac{AM}{MO} + \frac{AM}{MC} \quad ...(i)$$

From ΔACI, $\angle r = \angle ACM - \angle AIM$

$$\angle r = \frac{AM}{MC} - \frac{AM}{MI} \quad ...(ii)$$

Using Snell's law, we get, $n_1 \sin i = n_2 \sin r$

For small angles, $n_1 i = n_2 r$

Substituting values of $\angle i$ and $\angle r$ from equation (*i*) and (*ii*), we get

$$\frac{n_1}{MO} + \frac{n_1}{MC} = \frac{n_2}{MC} - \frac{n_2}{MI}$$

$$\frac{n_1}{MO} + \frac{n_2}{MI} = \frac{n_2 - n_1}{MC}$$

As $MO = -u$, $MI = +v'$, $MC = +R_1$

$$\frac{n_1}{-u} + \frac{n_2}{v'} = \frac{n_2 - n_1}{R_1} \qquad ...(iii)$$

(*b*) $f = 20$ cm, $n_2 = 1.6$ (R.I. of material of lens), $n_1 = 1$ (R.I. of air)

$n_1' = 1.3$ (R.I of liquid)

Using lens Maker's formula

$$\frac{1}{f} = \left(\frac{n_2}{n_1} - 1\right)\left(\frac{1}{R_1} - \frac{1}{R_2}\right) \qquad ...(i)$$

$$\frac{1}{f'} = \left(\frac{n_2}{n_1'} - 1\right)\left(\frac{1}{R_1} - \frac{1}{R_2}\right) \qquad ...(ii)$$

Dividing equation (*i*) by equation (*ii*), we get

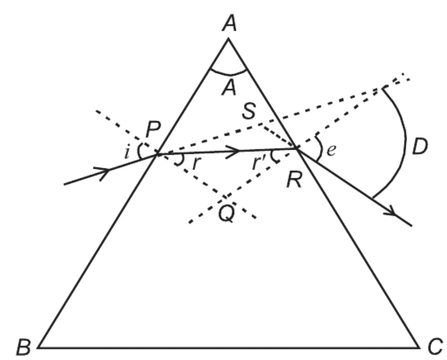
$$\frac{f'}{f} = \frac{(n_2 - n_1) \,.\, n_1'}{n_1(n_2 - n_1')}$$

$$\Rightarrow \qquad f' = 20 \times \frac{(1.6 - 1) \times 1.3}{1\,(1.6 - 1.3)}$$

$$f' = 52.0 \text{ cm}$$

OR

(*a*) The ray diagram showing the passage of a ray of light through a prism of refracting angle A.



Here $\angle BAC = \angle A$, $\angle SPQ = \angle i$, $\angle SRQ = \angle e$

In trapezium $APQR$,

$$\angle A + \angle PQR = 180° \qquad ...(i)$$

In ΔPQR,

$$\angle r + \angle PQR + \angle r' = 180° \qquad ...(ii)$$

In trapezium $PQRS$,

$\angle SPQ + \angle PQR + \angle SRQ + \angle PSR = 360°$

$\angle i + (180° - \angle A) + \angle e + \angle PSR = 360°$

Also $\qquad \angle PSR + \angle D = 180°$

$\therefore \; \angle i + (180° - \angle A) + \angle e + 180° - \angle D = 360°$

or $\qquad \angle i + \angle e = \angle A + \angle D \qquad ...(iii)$

From equations (*i*) and (*ii*), we get

$$\angle r + \angle r' = \angle A$$

At minimum deviation, $D = D_{\min}$

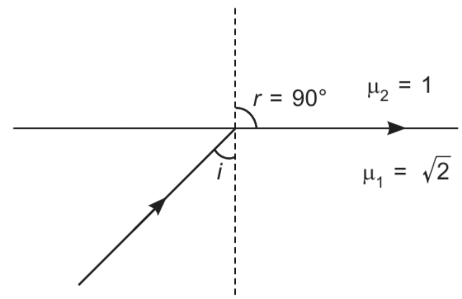
When $\angle r = \angle r'$, $2\angle r = \angle A$ or $\angle r = \dfrac{\angle A}{2}$ and $\angle i = \angle e$

$\therefore$ Equation (*iii*) becomes $2\angle i = \angle A + \angle D_{\min} \Rightarrow \angle i = \dfrac{\angle A + \angle D_{\min}}{2}$

$$\therefore \qquad \mu = \frac{\sin i}{\sin r} = \frac{\sin\left(\dfrac{A + D_{\min}}{2}\right)}{\sin \dfrac{A}{2}}$$

(*b*) According to Snell's law

$\mu_1 = \sqrt{2}$, $\mu_2 = 1$



$$\mu_1 \sin i = \mu_2 \sin r$$

$$\sqrt{2} \sin i = 1 \sin 90° = 1$$

$$\sin i = \frac{1}{\sqrt{2}} = \sin 45°$$

$$i = 45°$$

SECTION B

6. Two metallic wires *P* and *Q* of the same material and same length but different cross-sectional areas A_1 and A_2 are jointed together and then connected to a source of emf. Find the ratio of the drift velocities of free electrons in the wires *P* and *Q*, if the wires are connected (*i*) in series, and (*ii*) in parallel.

Ans. Refer to Q-24 Part (*b*) of Set I

10. Write two points of difference between *n*-type and *p*-type semiconductors.

Ans.

n-type semiconductor	***p-type semiconductor***
1. Dopants are pentavalent.	1. Dopants are trivalent (13^{th} group)
2. $n_e >>> n_h$, i.e. majority charge carriers are electrons.	2. $n_h >>> n_e$, i.e. majority charge carriers are holes.
3. Donor energy level lies below conduction band.	3. Acceptor energy level lies above valence band.

(*any two*)

SECTION C

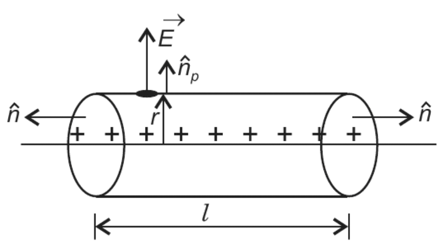
12. Define electric flux. Write its SI unit.

Using Gauss's law, deduce an expression for electric field intensity due to an infinitely long straight uniformly charged wire.

Ans. The total number of electric lines of force passing through a given area normally is called electric flux through that area.

$$\phi_E = \vec{E} . \vec{A}$$

Its SI unit is $\text{N m}^2\text{C}^{-1}$.



Consider a linear charge distribution with charge density λ. We imagine a symmetrical cylindrical Gaussian surface around length *l* of this distribution in such a way that the point *P* where we have to calculate electric field lies on it.

Electric flux through the circular faces of this Gaussian surface is zero.

$$\phi_s = \int \vec{E} \cdot \vec{ds} = 0 \qquad (\because \theta = 90°)$$

Electric flux through the curved surface is given by

$$\phi_{cs} = \oint \vec{E} \cdot \vec{ds} = \oint E \, . \, ds$$

$$\phi_{cs} = E \oint ds = E(2\pi rl) \qquad (\because \theta = 0°)$$

Net flux through the Gaussian surface is given by

$$\phi_E = \phi_s + \phi_{cs} = E(2\pi rl) \qquad \ldots(i)$$

According to the Gauss's theorem

$$\phi_E = \frac{q}{\varepsilon_0} = \frac{\lambda l}{\varepsilon_0} \qquad (\because q = \lambda l) \qquad \ldots(ii)$$

From equations (*i*) and (*ii*), we get

$$E = \frac{\lambda}{2\pi\varepsilon_0 r}$$

13. A proton and an α-particle move perpendicular to a magnetic field. Find the ratio of radii of the circular paths described by them when both (*i*) have equal momenta, and (*ii*) were accelerated through the same potential difference.

Ans. If mass of proton = $m_p = m$; then mass of α-particle $m_\alpha = 4$ m

Charge on proton = $q_p = e$, charge on α-particle $q_\alpha = 2e$

$$\frac{1}{2}mv^2 = qV$$

$$v = \sqrt{\frac{2qV}{m}}$$

$$\because \qquad r = \frac{mv}{qB} = \frac{1}{B}\sqrt{\frac{2mV}{q}}$$

(*i*) If momentum mv is same

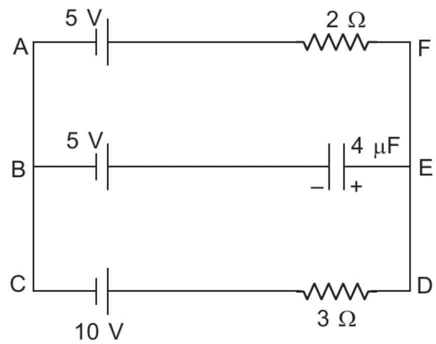
$$\frac{r_p}{r_\alpha} = \frac{q_\alpha}{q_p} = \frac{2e}{e} \Rightarrow r_p : r_\alpha : : 2 : 1$$

(*ii*) If V = Same

Then
$$\frac{r_p}{r_\alpha} = \sqrt{\frac{m_p \cdot q_\alpha}{q_p \, m_\alpha}}$$

$$= \sqrt{\frac{m}{e} \times \frac{2e}{4\,m}} = \sqrt{\frac{1}{2}}$$

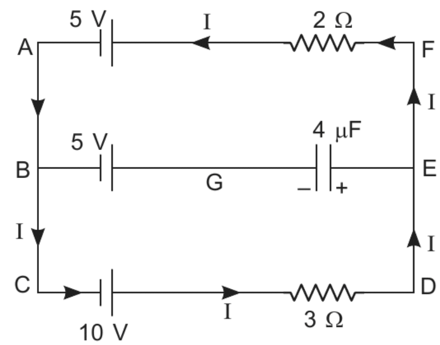
16. In the given circuit, with steady current, calculate the potential drop across the capacitor in terms of V.



Ans. Applying Kirchoff's voltage rule to the loop ABCDEFA

$$10 - 3I - 2I - 5 = 0$$

$$5I = 5 \Rightarrow I = 1 \text{ A}$$



Since P.D. across points B and E is same as P.D. across points C and D.

Therefore

$\because$ $V_{BE} = V_{CD} = 10 - 3I$

$= 10 - 3 \times 1 = 7$ V

$\therefore$ $V_{BE} = 5 + V$

Here V = P.D. across capacitor

$\therefore$ $7 = 5 + V \Rightarrow V = 2$ V

18. ***(a)*** **Write the process of β-decay. How can radioactive nuclei emit β-particles even though they do not contain them? Why do all electrons emitted during β-decay not have the same energy?**

(b) **A heavy nucleus splits into two lighter nuclei. Which one of the two — parent nucleus or the daughter nuclei has more binding energy per nucleon?**

Ans. (*a*) The basic nuclear process of neutron undergoing β-decay.

In β^- decay, one neutron inside the nucleus decays into one proton and one electron (β^-). The proton remains inside the nucleus and the electron is ejected out.

$${}^{A}_{Z}X \longrightarrow {}^{A}_{Z+1}Y + \beta^- + \bar{\nu} \qquad (\because {}^{0}_{1}n \longrightarrow 1p + \beta^- + {}^{0}_{0}\bar{\nu})$$

In β^+ decay, the conversion of proton into neutron and position (β^+) takes place.

$${}^{A}_{Z}X \longrightarrow {}^{A}_{Z-1}Y + \beta^+ + \nu \qquad (\because p \longrightarrow n + {}^{+}\beta + {}^{0}_{0}\nu)$$

All electrons emitted during β-decay do not have the same energy, because energy released during the process is shared by β-particle and antineutrino.

(*b*) Daughter nuclei will have more binding energy per nucleon. Parent nucleous having lesser binding energy is less stable, therefore it undergoes disintegrate into daughter nuclei to gain stability.

19. What is sky wave propagation? Which frequency range is suitable for sky wave propagation and why? Over which range of frequencies can communication through free space using radio waves take place?

Ans. The long distance communication in which the concept of ionospheric reflection of radiowaves back towards the earth is used, is called sky wave communication.

The ionospheric layer acts as a reflector for a particular range of frequencies (3 MHz to 40 MHz).

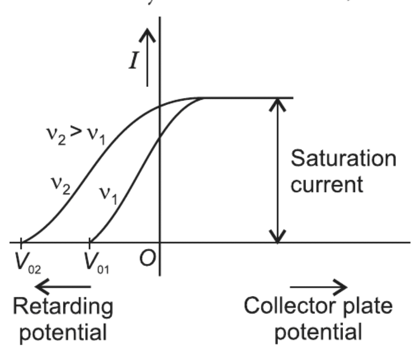
Hence, it is not applicable to all the frequencies.

Space wave communication can be used for frequencies above 40 MHz.

20. (*a*) Draw a graph showing variation of photocurrent with anode potential for a particular intensity of incident radiation. Mark saturation current and stopping potential.

(*b*) By how much would the stopping potential for a given photosensitive surface go up if the frequency of the incident radiations were to be increased from 4×10^{15} Hz to 8×10^{15} Hz?

Ans. (*a*) The energy of emitted photoelectrons depends on the frequency of incident radiation. Greater the frequency; greater is stopping potential. Saturation current depends on intensity of radiation, so it remains same.



(*b*)

$$eV_{o1} = h\nu_1 - \phi_0 \quad ...(i)$$

$$\nu_1 = 4 \times 10^{15} \text{ Hz}$$

$$eV_{o2} = h\nu_2 - \phi_0 \quad ...(ii)$$

$$\nu_2 = 8 \times 10^{15} \text{ Hz}$$

Equation (*ii*) – equation (*i*)

$$e(V_{o2} - V_{o1}) = h(\nu_2 - \nu_1)$$

$$V_{o2} - V_{o1} = \frac{6.63 \times 10^{-34} \times (8-4) \times 10^{15}}{1.6 \times 10^{-19}} \text{ V} = 16.6 \text{ V}$$

SECTION B

7. Find the intensity at a point on a screen in Young's double slit experiment where the interfering waves have a path difference of (*i*) λ/6, and (*ii*) λ/2.

Ans. (*i*) Path difference $= \frac{\lambda}{6}$

$\therefore$ Phase difference $= \frac{2\pi}{6} = \frac{\pi}{3} \Rightarrow \phi = \frac{\pi}{3}$

$\therefore$ Intensity $= I = 4I_0 \cos^2 \frac{\phi}{2}$

$$I = 4I_0 \cos^2 \frac{\pi}{2\times 3} = 4I_0 = \left(\frac{\sqrt{3}}{2}\right)^2$$

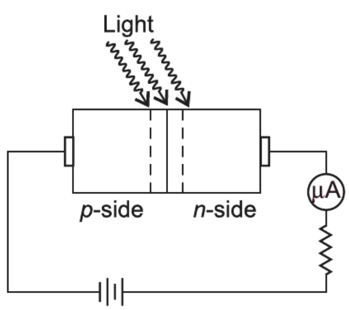
$$I = 3I_0$$

(*ii*) Path difference $= \frac{\lambda}{2}$; ϕ = Phase difference $= \frac{2\pi}{2} = \pi$

$\therefore$ $I = 4I_0 \cos^2 \frac{\pi}{2} = 0$

8. Describe, with the help of a circuit diagram, the working of a photodiode.

Ans.



When a photodiode is illuminated with light having photons of energy ($h\nu$) greater than energy gap (E_g) of semiconductor, the electron-hole pairs are generated in the depletion region. An electric field across the junction separates the holes and electrons. Thus, the electrons reach *n*-side and holes reach *p*-side. Hence, the accumulation of electrons on *n*-side and holes on *p*-side develops an emf.

When an external load is connected, current flows.

SECTION C

11. A proton and an α-particle move perpendicular to a magnetic field. Find the ratio of radii of circular paths described by them when both have (*i*) equal velocities, and (*ii*) equal kinetic energy.

Ans. $q_p = +e$, $q_\alpha = +2e$; $m_p = m$(let), $m_\alpha = 4$ m

$\because$ Radius of circular path $r = \frac{mv}{qB} = \frac{\sqrt{2mK}}{qB}$

$K \rightarrow$ Kinetic energy

(*i*) When $v_1 = v_2$ $\qquad r \propto \frac{m}{q} \Rightarrow \frac{r_p}{r_\alpha} = \frac{m_p\, q_\alpha}{m_\alpha\, q_p} = \frac{m \times 2e}{4m \times e} = \frac{1}{2}$

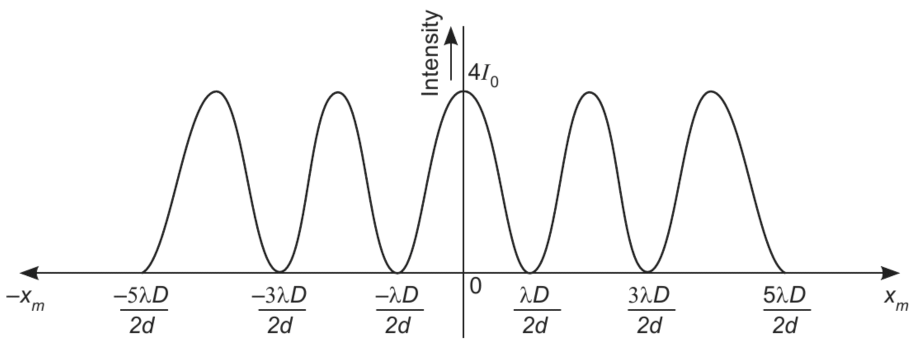
$r_p : r_\alpha :: 1 : 2$

(*ii*) When $K_1 = K_2$ $\qquad r \propto \frac{\sqrt{m}}{q} \Rightarrow \frac{r_p}{r_\alpha} = \sqrt{\frac{m_p}{m_\alpha}} \times \frac{q_\alpha}{q_p} = \sqrt{\frac{m}{4m}} \times \frac{2e}{e}$

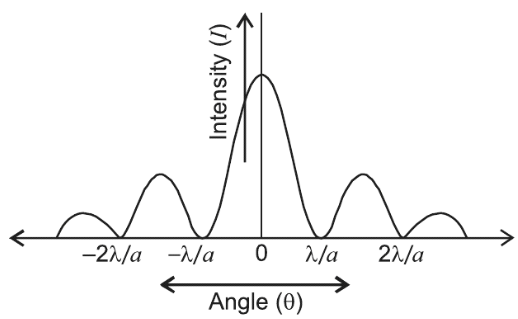
$\frac{r_p}{r_\alpha} = \frac{1}{1}$

12. Draw the intensity distributions for (*i*) the fringes produced in interference, and (*ii*) the diffraction bands produced due to single slit. Write two points of difference between the phenomena of interference and diffraction.

Ans.



(*i*) Interference fringes



(*ii*) Diffraction bands due to single slit

Differences between interference and diffraction

(*i*) Interference is the superposition of light waves from two different wavefronts originating from the same source, while the diffraction is the interaction of light waves from different parts of the same wavefront.

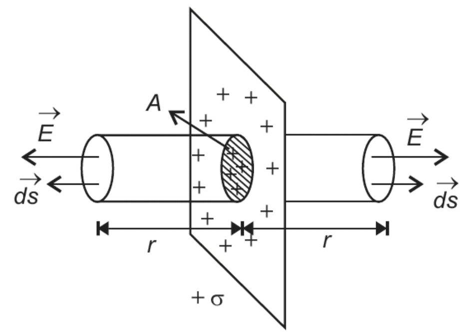
(*ii*) In an interference pattern, fringes may or may not be of the same width, while in diffraction pattern, they are never of the same width.

(*iii*) In an interference pattern, bright fringes are of uniform intensity, while in diffractions pattern, they are of varying intensity. (*any two*)

13. Using Gauss's law in electrostatics, deduce an expression for electric field intensity due to a uniformly charged infinite plane sheet. If another identical sheet is placed parallel to it, show that there is no electric field in the region between the two sheets.

Ans. Difference between interference and diffraction. *(any two)*

Consider a thin infinite sheet of charge with uniform surface charge density σ. To calculate electric field at a point *P* distant *r* from the sheet we imagine a symmetrical Gaussian surface in such a way that the point charge lies on it. Here we assume a cylinder of cross-sectional area *A* and length 2*r* with its axis perpendicular to the sheet.



Flux through the curved surface of the cylinder,

$$\phi_1 = \int \vec{E}.\vec{ds} = 0 \qquad (\because \theta = 90°)$$

Total flux through plane faces of the cylinder,

$$\phi_2 = 2\int \vec{E}.\vec{ds} = 2EA \qquad (\because \theta = 0°)$$

Net flux through the Gaussian surface is

$$\phi = \phi_1 + \phi_2 = 2EA \qquad ...(i)$$

Net charge enclosed by the Gaussian surface is

$$Q = \sigma A$$

According to the Gauss's theorem, $\phi = \dfrac{Q}{\varepsilon_0}$

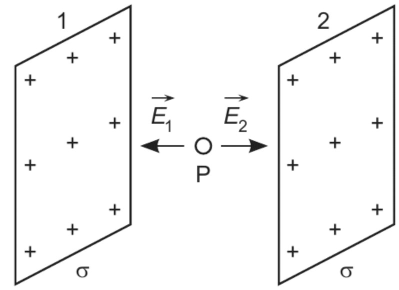
$$\therefore \qquad \phi = \frac{\sigma A}{\varepsilon_0} \qquad ...(ii)$$

From equations (*i*) and (*ii*), we get

$$2EA = \frac{\sigma A}{\varepsilon_0} \Rightarrow E = \frac{\sigma}{2\varepsilon_0}$$

Net electric field at P is given by

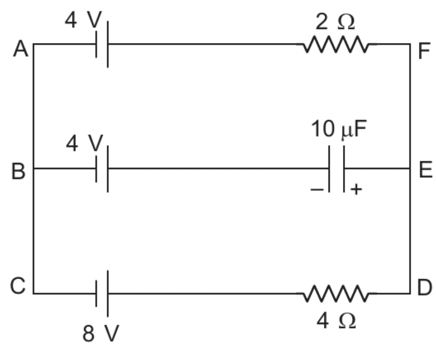
Superposition Principle as



$$\vec{E} = \vec{E_1} + \vec{E_2}$$

$$= \frac{\sigma}{2\varepsilon_0}\hat{i} - \frac{\sigma}{2\varepsilon_0}\hat{i} = 0$$

14. In the given circuit, with steady current, calculate the potential drop across the capacitor and the charge stored in it.



Ans. Consider loop ABCDEFA

$$8 - 4I - 2I - 4 = 0 \quad \text{[Using Kirchoff's voltage law]}$$

$$6I = 4$$

$$I = \frac{2}{3} \text{ A.}$$

$\therefore$ PD across CD $= 8 - 4I$

$$V_{CD} = 8 - \left(4 \times \frac{2}{3}\right) = \frac{16}{3} \text{ V}$$

$\because$ $V_{CD} = V_{BE} = 4 + V$ [V = PD across capacitor]

$$\frac{16}{3} = 4 + V$$

$\Rightarrow$ $V = \frac{4}{3}$ V

Charge stored, $Q = CV = 10 \times 10^{-6} \times \frac{4}{3} \text{ C} = 13.33 \ \mu\text{C}$

16. (*a*) Derive the relation between the decay constant and half life of a radioactive substance.

(*b*) A radioactive element reduces to 25% of its initial mass in 1000 years. Find its half life.

Ans. (*a*) Relationship between $T_{1/2}$ and λ

$\because$ $N = N_0 e^{-\lambda t}$ $\left\{\because \text{ At } t = T_{1/2}, N = \frac{N_0}{2}\right\}$

$\therefore$ $\frac{N_0}{2} = N_0 e^{-\lambda T_{1/2}} \Rightarrow e^{\lambda T_{1/2}} = 2$

Taking log on both sides

$$\lambda T_{1/2} = \ln 2 = 2.3036 \log_{10} 2 = 2.3036 \times 0.3010$$

$$T_{1/2} = \frac{0.6931}{\lambda}$$

(*b*) $\because \quad \frac{N}{N_0} = \frac{25}{100} = \frac{1}{4} = \left(\frac{1}{2}\right)^2; \quad t = 1000 \text{ years}$

and $\quad t = n T_{½}$; where $n = 2$ (no. of half lives)

then $\quad T_{½} = \frac{1000}{2} = 500$ years