CONTENTS

CBSE Examination Paper, 2020

[Delhi (Set-I, II, III)]

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

General Instructions:

Read the following instructions very carefully and strictly follow them:

(*i*) This question paper comprises **four** sections – A, B, C, and D.

(*ii*) There are **37** questions in the question paper. **All** questions are compulsory.

(*iii*) Section **A**: Q. no. **1** to **20** are very short-answer type questions carrying **1** mark each.

(*iv*) Section **B**: Q. no. **21** to **27** are short-answer type questions carrying **2** marks each.

(*v*) Section **C**: Q. no. **28** to **34** are long-answer type questions carrying **3** marks each.

(*vi*) Section **D**: Q. no. **35** to **37** are also long answer type questions carrying **5** marks each.

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

(*viii*) However, separate instructions are given with each section and question, wherever necessary.

(*ix*) Use of calculators and log tables is not permitted.

(*x*) You may use the following values of physical constants wherever necessary..

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

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

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

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

$$e_0 = 8.854 \times 10^{-12} \text{ C}^2 \text{ N}^{-1} \text{ m}^{-2}$$

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

Mass of electron (m_e) = 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}

Set-I

SECTION A

1. **The relationship between Brewester angle 'θ' and the speed of light 'v' in the denser medium is–** **1**

   (*a*) $v \tan\theta = c$ (*b*) $c \tan\theta = v$

   (*c*) $v \sin\theta = c$ (*d*) $c \sin\theta = v$

Ans. (*a*) $v \tan\theta = c$

According to Brewester's law

$\mu = \tan\theta$; and $\mu = \frac{c}{v}$, Where c is velocity of light in vacuum and v is the velocity of light in the denser medium

$\therefore v \tan\theta = c$

2. **Photo diodes are used to detect** **1**

   (*a*) radio waves (*b*) gamma rays

   (*c*) IR rays (*d*) optical signals

Ans. (*d*) Optical signals

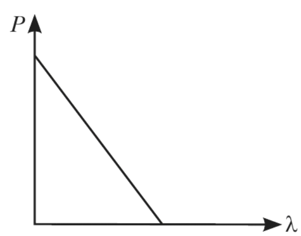
3. **The selectivity of a series *LCR* a.c. circuit is large, when** **1**

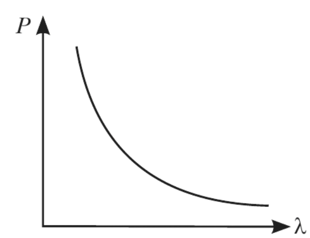
   (*a*) *L* is large and *R* is large (*b*) *L* is small and *R* is small

   (*c*) *L* is large and *R* is small (*d*) $L = R$

Ans. (*c*) *L* is large and *R* is small; $Q = \frac{1}{R}\sqrt{\frac{L}{C}}$

4. **The graph showing the correct variation of linear momentum (p) of a charged particle with its de-Broglie wavelength (λ) is –** **1**

(*a*)


(*b*)


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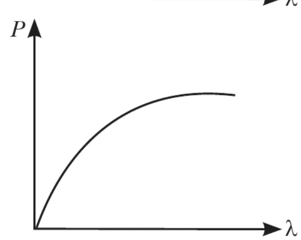
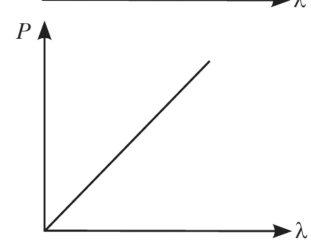


(*d*)


Ans. (*b*) $p = \frac{h}{\lambda}$; $p \propto \frac{1}{\lambda}$

5. **The wavelength and intensity of light emitted by a LED depend upon** **1**

(*a*) forward bias and energy gap of the semiconductor

(*b*) energy gap of the semiconductor and reverse bias

(*c*) energy gap only

(*d*) forward bias only

Ans. (*a*); $\lambda = \frac{c}{\nu} = \frac{c}{\frac{E_g}{h}} = \frac{hc}{E_g}$, and a heavily droped and strongly forward biased p-n junction provides lots of majority carriers and lots of photons.

6. **A charged particle after being accelerated through a potential difference '*V*' enters in a uniform magnetic field and moves in a circle of radius *r*. If *V* is doubled, the radius of the circle will become** **1**

(*a*) $2r$ **(*b*) $\sqrt{2r}$**

(*c*) $4r$ **(*d*) $\frac{r}{\sqrt{2}}$**

Ans. (*b*) $\sqrt{2r}$

As $r \propto \sqrt{v}$

$r' \propto \sqrt{2v}$ $(\because v' = 2v)$

$\therefore$ $\frac{r'}{r} = \sqrt{2}$

7. **The electric flux through a closed Gaussian surface depends upon** **1**

(*a*) Net charge enclosed and permittivity of the medium

(*b*) Net charge enclosed, permittivity of the medium and the size of the Gaussian surface

(*c*) Net charge enclosed only

(*d*) Permittivity of the medium only

Ans. (*a*) Net charge enclosed and permittivity of the medium

$$\phi_E = \oint \vec{E} . \vec{ds}$$

and $\vec{E} = \frac{1}{4\pi\varepsilon} \frac{q}{r^2}$

Where ε is the permittivity of the medium.

8. If photons of frequency ν are incident on the surfaces of metals A & B of threshold frequencies ν/2 and ν/3 respectively, the ratio of the maximum kinetic energy of electrons emitted from A to that from B is **1**

(*a*) 2 : 3 **(*b*) 3 : 4**

(*c*) 1 : 3 **(*d*) $\sqrt{3} : \sqrt{2}$**

Ans. (*b*) 3 : 4

$$h\nu = K + h\nu_0$$

where ν_0 is the threshold frequency of a metal.

(Using this equation)

$$h\nu = K_A + h\frac{\nu}{2}$$

$$K_A = h\left(\nu - \frac{\nu}{2}\right) = \frac{h\nu}{2}$$

and

$$h\nu = K_B + h\frac{\nu}{3}$$

$$K_B = h\left(\nu - \frac{\nu}{3}\right) = h\frac{2\nu}{3}$$

$$\therefore \quad \frac{K_A}{K_B} = \frac{h\nu}{2} \times \frac{3}{2h\nu} = \frac{3}{4}$$

9. The power factor of a series *LCR* circuit at resonance will be **1**

(*a*) 1 **(*b*) 0**

(*c*) $\frac{1}{2}$ **(*d*) $\frac{1}{\sqrt{2}}$**

Ans. (*a*) 1

Use $\cos\phi = \frac{R}{Z}$

At resonance Z = R

$\therefore \quad \cos\phi = 1$

10. A biconcave lens of power *P* vertically splits into two identical plano concave parts. The power of each part will be **1**

(*a*) 2*P* **(*b*) $\frac{P}{2}$**

(*c*) *P* **(*d*) $\frac{P}{\sqrt{2}}$**

Ans. (*b*) $\frac{P}{2}$

$$P = \frac{1}{f} = (\mu - 1)\frac{2}{R} \text{ for biconcave lens}$$

$$P' = \frac{1}{f'} = (\mu - 1)\left(\frac{1}{R} - \frac{1}{\infty}\right) = \frac{(\mu - 1)}{R}$$

$$P' = \frac{P}{2}$$

Note : Fill in the blanks with appropriate answer.

11. The physical quantity having SI unit NC^{-1} m is ________. **1**

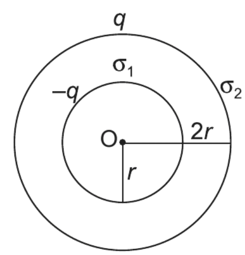
Ans. electric potential

12. A copper wire of non-uniform area of cross-section is connected to a d.c. battery. The physical quantity which remains constant along the wire is ________. **1**

Ans. electric current/resistivity

13. A point charge is placed at the centre of a hollow conducting sphere of internal radius '*r*' and outer radius '2*r*'. The ratio of the surface charge density of the inner surface to that of the outer surface will be ________.1

Ans. –4 : 1 or 4 : 1



$$\sigma_1 = \frac{-q}{4\pi r^2}$$

$$\sigma_2 = \frac{q}{4\pi (2r)^2}$$

$$\therefore \quad \frac{\sigma_1}{\sigma_2} = -4$$

14. The ________, a property of materials C, Si and Ge depends upon the energy gap between their conduction and valence bands. **1**

Ans. conductivity/resistivity.

15. The ability of a junction diode to ________ an alternating voltage, is based on the fact that it allows current to pass only when it is forward biased. **1**

Ans. rectify/convert in d.c.

Note : Answer the following:

16. Define the term 'current sensitivity' of a moving coil galvanometer. **1**

Ans. The current sensitivity of a moving coil galvanometer, $I_s = \frac{\text{deflection}, \phi}{\text{current}, i} = \frac{NBA}{C}$

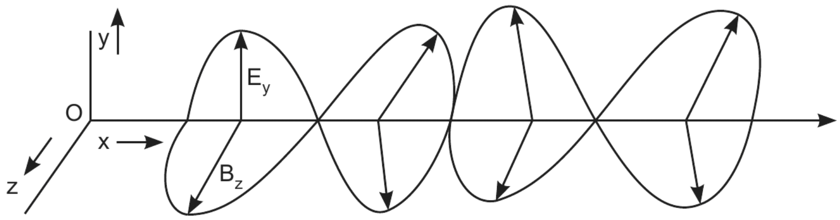
where, N is the number of wires of the coil, A the area of the coil B is the field induction and C is the torsional constant of suspension. Here, ϕ is in radians and i in Ampere. The unit of I_s is 'rad A^{-1}.

Or

It is also defined as the deflection produced when unit current flows, through the galvanometer.

17. Depict the fields diagram of an electromagnetic wave propagating along positive X-axis with its electric field along Y-axis. 1

Ans.



Along x-axis is the direction of propagation of e.m. wave.

18. Write the conditions on path difference under which (*i*) constructive (*ii*) destructive interference occur in Young's double slit experiment. 1

Ans. (*i*) For constructive interference, the path difference $\Delta x = n\lambda$, where $n = 0$, 1, 2, 3..... *i.e.* integer multiple of wave length.

(*ii*) For destructive interference, the path difference

$$\Delta x = (2n + 1)\frac{\lambda}{2}$$

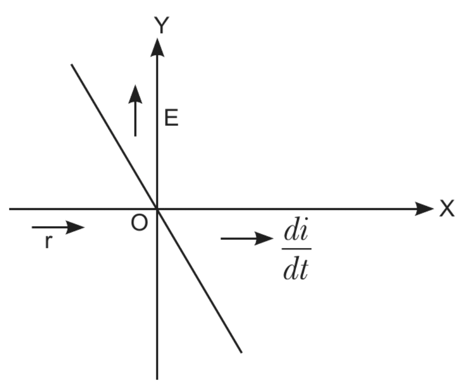
Where $n = 1, 2, 3....$ and $n \neq 0$ *i.e.*, odd multiple of half wavelength.

19. Plot a graph showing variation of induced e.m.f. with the rate of change of current flowing through a coil. 1

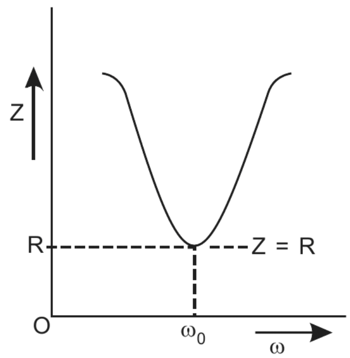
Or

A series combination of an inductor (*L*), capacitor (*C*) and a resistor (*R*) is connected across an ac source of emf of peak value E_0 and angular frequency (ω). Plot a graph to show variation of impedance of the circuit with angular frequency (ω). 1

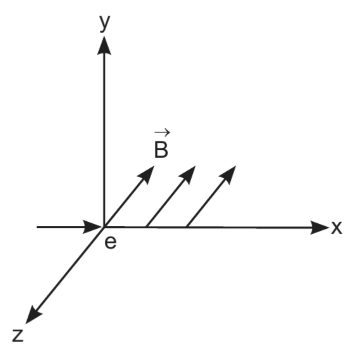
Ans. As $E = -L\frac{di}{dt}$



Or

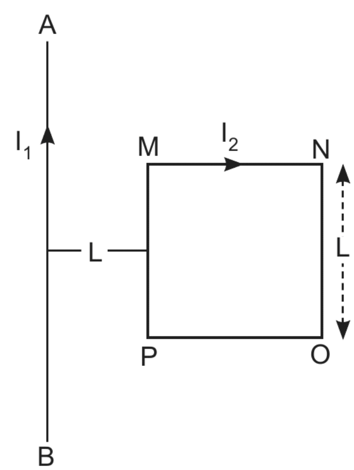


20. **An electron moves along +x direction. It enters into a region of uniform magnetic field $\vec{B}$ directed along –z direction as shown in fig. Draw the shape of trajectory followed by the electron after entering the field.** **1**



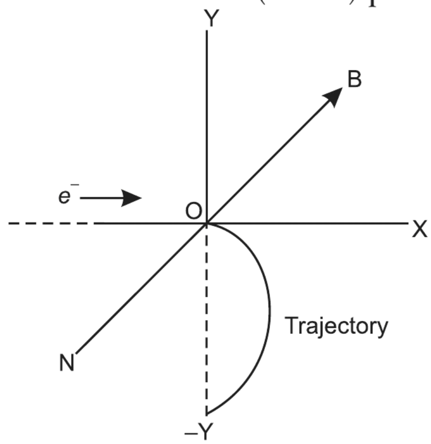
Or

A square shaped current carrying loop MNOP is placed near a straight long current carrying wire AB as shown in the fig. The wire and the loop lie in the same plane. If the loop experiences a net force *F* towards the wire, find the magnitude of the force on the side 'NO' of the loop. **1**

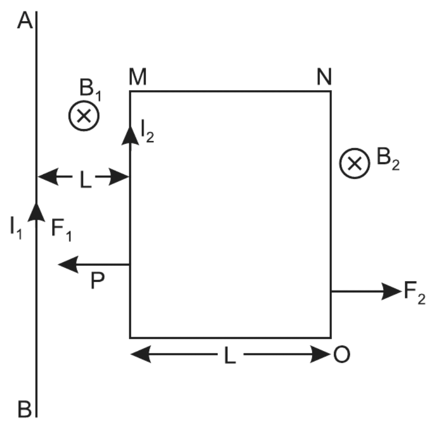


Ans. Using Fleming's LH Rule, F will act in –ve Y axis direction.

The trajectory will be semi circular in (X – Y) plane as shown below.



Or



Let F_1 be the force on MP arm of the square MNOP

L is the side of square MNOP

Then for MP side,

$$B_1 = \frac{\mu_0 I_1}{2\pi L} \otimes$$

$$F_1 = I_2 B_1 L = \frac{\mu_0 I_1 I_2 L}{2\pi L}$$

$$F_1 = \frac{\mu_0 I_1 I_2}{2\pi} \leftarrow$$

For side NO

$$B_2 = \frac{\mu_0 I_1}{2\pi(L+L)} = \frac{\mu_0 I_1}{4\pi L} \otimes$$

$$F_2 = I_2 B_2 L = \frac{\mu_0 I_1 I_2 L}{2\pi(L+L)} = \frac{\mu_0 I_1 I_2}{4\pi} \quad \rightarrow$$

The net force F towards wire AB = F = $F_1 - F_2$

$$F = \frac{\mu_0 I_1 I_2}{2\pi}\left[1 - \frac{1}{2}\right]$$

$$= \frac{\mu_0 I_1 I_2}{4\pi}$$

$\therefore$ Force on side NO $= \frac{F_1}{2} = F$

Where, $F = \frac{\mu_0 I_1 I_2}{4\pi}$

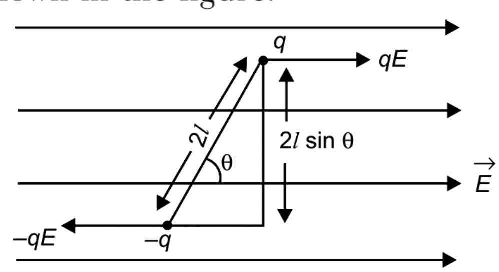
SECTION B

21. Derive the expression for the torque acting on an electric dipole, when it is held in a uniform electric field. Identify the orientation of the dipole in the electric field, in which it attains a stable equilibrium. 2

Or

Obtain the expression for the energy stored in a capacitor connected across a dc battery. Hence define energy density of the capacitor. 2

Ans. 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

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

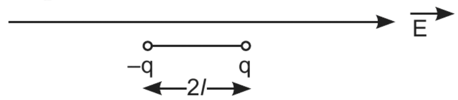
$$\tau = pE \sin\theta$$

Vectorially, 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.

The orientation of the dipole parallel to the direction of electric field brings the dipole in stable equilibrium.



For stable equilibrium, $\theta = 0°$

$$\vec{\tau} = \vec{p} \times \vec{E} = \vec{0} \text{ as } \vec{p} \text{ and } \vec{E} \text{ are parallel}$$

The potential energy of an electric dipole

$$U_\theta = \int \tau \, d\theta$$

$$= \int pE \sin\theta \, d\theta$$

$$U_\theta = -pE \cos\theta$$

The potential energy when $\theta = 0$ is

$$U_0 = -pE$$

As this value is minimum, the dipole is in stable equilibrium position.

Or

Suppose a charge dq is brought from infinity to the capacitor. The work done required will be

$$dW = Vdq = \frac{q}{C}dq \qquad (\because VC = q)$$

$$\therefore \quad W = \int dW$$

$$\Rightarrow \quad \frac{1}{C}\int q \, dq = \frac{1}{C}\left[\frac{q^2}{2}\right] = \frac{1}{2}CV^2 \qquad \text{(by putting } q = CV\text{)}$$

For a parallel plate capacitor $C = \frac{A\varepsilon_0}{d}$, Where A is the overlapping area of the plates and d is their separation.

Substituting

$$U = \frac{1}{2}\left(\frac{A\varepsilon_0}{d}\right) V^2 \times \frac{d}{d}$$

$$= \frac{1}{2}(Ad)\, \varepsilon_0 \left(\frac{V}{d}\right)^2$$

$$= \frac{1}{2}(\text{Volume})\varepsilon_0 \, E^2$$

$$\left[\because Ad = \text{Volume between plates and } \frac{V}{d} = E\right]$$

$\therefore \quad U_E = \dfrac{U}{vol}$ is called energy density (electric)

$$\therefore \quad U_E = \frac{1}{2}\varepsilon_0 E^2 \text{ J/m}^3$$

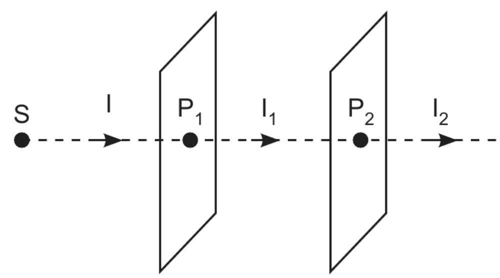
U_E is called the energy density of the capacitor.

22. Gamma rays and radio waves travel with the same velocity in free space. Distinguish between them in terms of their origin and the main application. 2

Ans. (*i*) Gamma rays are produced by disintegration of atomic nuclei, while radio waves are produced by oscillating electric circuits.

(*ii*) γ-rays are used to provide information about the structure of atomic nuclei, while radio waves are generally used in Radio and TV communication.

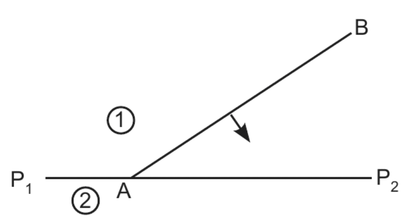
23. Light from a sodium lamp (S) passes through two polaroid sheets P_1 and P_2 as shown in fig. What will be the effect on the intensity of the light transmitted (*i*) by P_1 and (*ii*) by P_2 on rotating polaroid P_1 about the direction of propagation of light? Justify your answer in both cases. 2



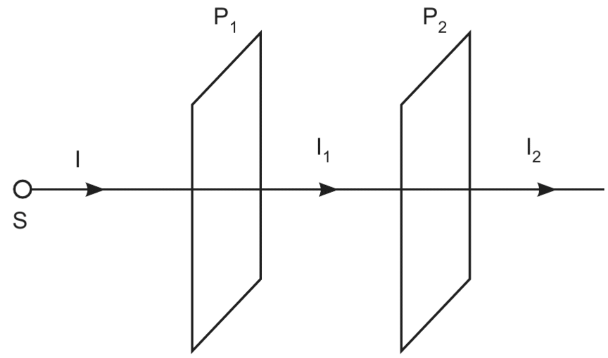
Or

Define the term 'wave front of light'. A plane wave front AB propagating from denser medium (1) into a rarer medium (2) is incident on the surface P_1P_2 separating the two media as shown in fig.

Using Huygen's principle, draw the secondary wavelets and obtain the refracted wave front in the diagram. 2



Ans.



The intensity of light remains unaffected because intensity does not depend on the orientation of polaroid with respect to the direction of propagation.

Sheet P_1 is called polariser and P_2 is called analyser. Let the intensity of unpolarised light be I.

The intensity of polarised light I_1 is defined as

$$I_1 = \frac{\int_0^{2\pi} I_x d\theta}{\int_0^{2\pi} d\theta},$$

where $I_x = I\cos^2\theta$ (using Malus Law)

$$\therefore \quad I_1 = \frac{I}{2\pi}\int_0^{2\pi}\cos^2\theta\, d\theta = \frac{I}{2\pi}\int_0^{2\pi}\left(\frac{1-\cos 2\theta}{2}\right)d\theta$$

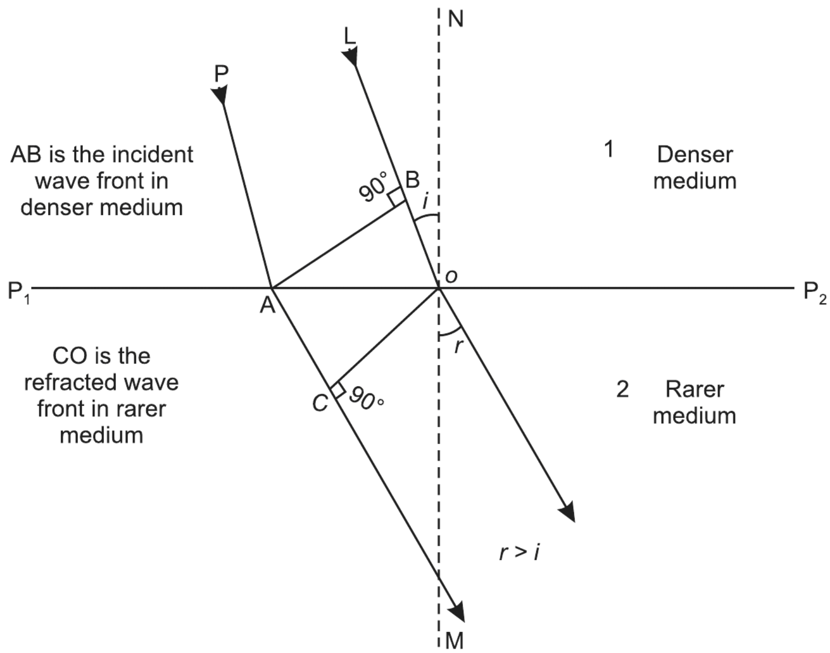
$$= \frac{I}{2\pi}\int_0^{2\pi}\frac{1}{2}d\theta = \frac{I}{2\pi}\left[\frac{1}{2}\times 2\pi\right] = \frac{I}{2}$$

Hence, after passing through P_1, the intensity of polarised light I_1 will be half of the intensity of unpolarised light. Further, when light passes through P_2, the analysor, then $I_2 = I_1\cos^2\phi$ where ϕ is the angle between P_1 and P_2. The intensity of transmitted light by P_2 will vary from I_1 to zero. (θ varies from 0 to $\frac{\pi}{2}$)

or $$I_2 = \frac{I}{2}\cos^2\phi$$

Or

The wave front at any instant is defined as the locus of all the particles in the medium which are being disturbed at the same instant of time and are in the same phase of vibration.

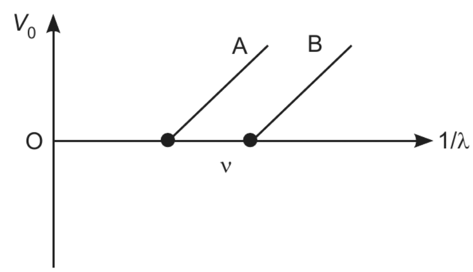


24. A heavy nucleus P of mass number 240 and binding energy 7.6 MeV per nucleon splits into two nuclei Q and R of mass numbers 110, 130 and binding energies per nucleons 8.5 MeV and 8.4 MeV, respectively. Calculate the energy released in the fission. **2**

Ans. The energy released in the fission reaction

$$= \{(110 \times 8.5 + 130 \times 8.4) - 240 \times 7.6\}\text{MeV}$$
$$= \{(935 + 1092) - 1824\}$$
$$= \{(2027) - 1824\} = 203 \text{ MeV}.$$

25. Figure shows the stopping potential (V_0) for the photo electron versus ($1/\lambda$) graph, for two metals A and B, λ being the wavelength of incident light.



(*a*) How is the value of Planck's constant determined from the graph?

(*b*) If the distance between the light source and the surface of metal A is increased, how will the stopping potential for the electrons emitted from it be effected? Justify your answer. **2**

Ans. (*a*) Planck's constant is determined by the slope of the straight lines.

Using Einstein equation

$$K = h\nu - \phi,$$

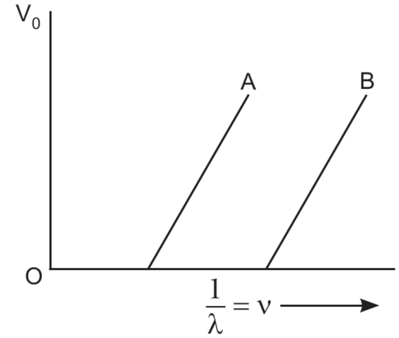
Where K is the K.E. of photoelectrons and ϕ is the work function

As $K = eV_0$

$$eV_0 = h\nu - \phi$$

and
$$V_0 = \frac{h}{e}\nu - \frac{\phi}{e}$$

$$= \frac{hc}{e\lambda} - \frac{\phi}{e}$$



comparing with equ^n of a st. line $y = mx + c$

m = slope of line = $\frac{hc}{e}$, $h = \frac{me}{c}$

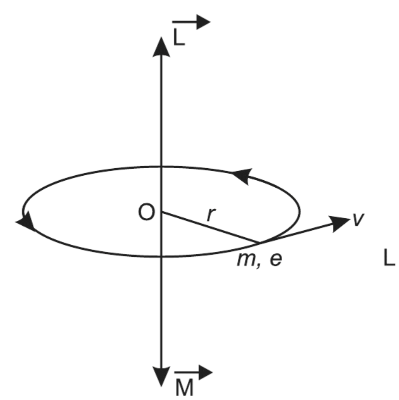
$\therefore$ $h = \frac{e}{c} \times$ slope of the line.

(*b*) By increasing the distance between the light source and the surface of metal A, the intensity of the incident light will decrease [I $\propto \frac{1}{r^2}$(Inverse sq. law)]. The decrease in intensity will decrease the photo electric current. The stopping potential depends on the frequency of incident light.

Here ν is constant, so V_0 will remain constant, as it depends on the frequency of incident radiation.

26. Use Bohr's model of hydrogen atom to obtain the relationship between the angular momentum and the magnetic moment of the revolving electron. 2

Ans. Let T be the time period of rotation of an electron of mass '*m*' and charge '*e*'.



$$T = \frac{2\pi r}{v}$$

As
$$i = \frac{e}{T} = \frac{ev}{2\pi r}$$

The area of orbit is πr^2

So the magnetic dipole moment, $M = iA$

$$\therefore \quad M = \frac{ev}{2\pi r} \times \pi r^2 = \frac{evr}{2}$$

Further the angular momentum $L = mvr$ and is directed upwards for the given direction of electron.

$$vr = \frac{L}{m}$$

$$\therefore \quad M = \frac{e}{2m}L$$

In vector form $\vec{M} = -\left(\frac{e}{2m}\right)\vec{L}$, as electrons are negatively charged particles.

In Bohr's theory of H like atoms

$$L = \frac{nh}{2\pi}$$

$$\therefore \qquad |\vec{M}| = \left(\frac{e}{2m}\right)\frac{nh}{2\pi} = n\left(\frac{eh}{4\pi m}\right)$$

The least value of M is called Bohr's Magneton for $n = 1$

$$\therefore \qquad \mu_B = \frac{eh}{4\pi m}.$$

27. In a single slit diffraction experiment, the width of the slit is increased. How will the (*i*) size and (*ii*) intensity of central bright band be affected? Justify your answer. **2**

Ans. (*a*) As the angular width of central max $2\theta = \frac{2\lambda}{a}$, where a is the width of slit we see that if a is increased, the width of central maximum will decrease.

(b) In a single slit diffraction experiment if the width of the slit is made double the original width, then the size of the central diffraction band is reduced to half and the intensity of central diffraction band increases up to four times. (The amplitude is proportional to slit width).

SECTION C

28. (*a*) Differentiate between electrical resistance and resistivity of a conductor.

(*b*) Two metallic rods, each of length L, area of cross A_1 and A_2, having resistivities ρ_1 and ρ_2 are connected in parallel across a d.c. battery. Obtain the expression for the effective resistivity of this combination. **3**

Ans. (*a*) Electrical resistance of a conductor R, depends directly as the length l, of the wire and inversely on its area of cross section A *i.e.*

$R \propto l$ and $R \propto \frac{1}{A}$

$\therefore\ R \propto \frac{l}{A}$ or $R = \rho\frac{l}{A}$,

Where ρ is the constant of proportionality that depends only on temperature and the nature of the material, called specific resistance or resistivity. Resistivity is the resistance of a conductor of unit length and unit area of cross section and depends on the nature of the material and its temperature.

(*b*) As $R_1 = \rho_1 \frac{L}{A_1}$ and $R_2 = \rho_2 \frac{L}{A_2}$

The effective resistance in parallel be R then $R = \rho\frac{L}{A}$, where ρ is effective resistivity of the combination and $A = A_1 + A_2$ will be the effective area of cross section.

In parallel $$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2}$$

or $$\frac{A}{\rho L} = \frac{A_1}{\rho_1 L} + \frac{A_2}{\rho_2 L}$$

or $$\frac{A}{\rho} = \frac{A_1}{\rho_1} + \frac{A_2}{\rho_2}$$

or $$\frac{A_1 + A_2}{\rho} = \frac{A_1\rho_2 + A_2\rho_1}{\rho_1\rho_2}$$

∴ $$\rho = \frac{(A_1 + A_2)\rho_1\rho_2}{A_1\rho_2 + A_2\rho_1}$$

29. Calculate the de-Broglie wavelength associated with the electron revolving in the first excited state of hydrogen atom. The ground state energy of the hydrogen atom is –13.6 eV. 3

Ans. The KE of electron in first excited state ($n = 2$)

will be, $$K = +\frac{13.6}{4} = 3.4 \text{ ev}$$

The de Broglie wavelength

$$\lambda = \frac{h}{p} = \frac{h}{\sqrt{2mK}}$$

$$\lambda = \frac{6.6 \times 10^{-34}}{\sqrt{2 \times 9.1 \times 10^{-31} \times 3.4 \times 1.6 \times 10^{-19}}}$$

$$= 0.663 \times 10^{-9} = 6.63 \text{ Å}$$

30. (*a*) Define the term decay constant of a radioactive substance.

(*b*) The half life of $^{238}_{92}U$ undergoing α decay is 4.5×10^9 years. Calculate the activity of 10 g sample of $^{238}_{92}U$. 3

Ans. (*a*) Let $\tau = \frac{1}{\lambda}$, then $\frac{N}{N_0} = e^{-\lambda\tau} = e^{-1} = \frac{1}{e}$

Hence the radioactive decay constant λ is the reciprocal of the time during which the original number of radioactive atoms falls to $1/e$ times of its value.

(*b*) Given that $T = 4.5 \times 10^9$ yrs $= 4.5 \times 10^9 \times 3.154 \times 10^7$s

$$\lambda = \frac{0.693}{T} \text{ and } \left|\frac{dN}{dt}\right| = \lambda N$$

$\because$ 238 gm of Uranium have atoms $= 6.023 \times 10^{23}$

$\therefore$ 1 gm of Uranium have atoms $= \dfrac{6.023 \times 10^{23}}{238}$

$\therefore$ 10 gm of Uranium have atoms $= \dfrac{6.023}{238} \times 10^{24} = N$

$$\therefore \left|\frac{dN}{dt}\right| = \frac{0.693}{4.5 \times 3.154 \times 10^{16}} \times \frac{6.023}{238} \times 10^{24}$$

$$= \frac{4.174}{3.3779} \times 10^5$$

$$= 1.235 \times 10^5 \text{B}q$$

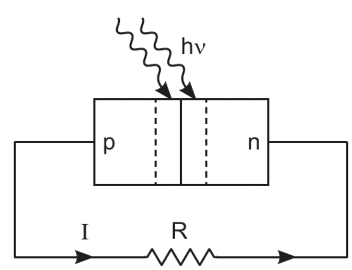
31. What is a solar cell? Draw its *V–I* characteristics. Explain the three processes involved in its working. 3

Or

Draw the circuit diagram of a full wave rectifier. Explain its working showing its input and output waveforms. 3

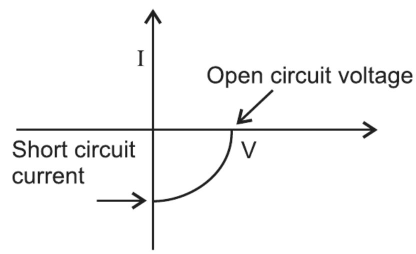
Ans. *Solar Cell* is a shallow *p-n* junction which is formed a small distance below the surface of silicon crystal. It converts solar energy directly into electric energy and is based on photo-voltaic effect.

It is due to the following three basic processes: generation, separation and collection— (*i*) generation of electron-hole 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*.



A voltage develops across the diode, similar to what happens in a battery, and a solar current flows in the circuit connected to the diode.

The above graph gives the I, V characteristic of the solar cell.



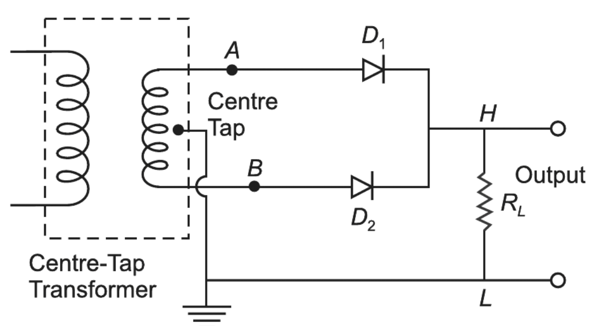
The open circuit voltage is regulated by the illumination of the incident light. Hence, the photo current is also proportional to the illumination intensity.

The important criteria required for the selection of a material for solar cell are as under.

1. The semiconductors having forbidden energy gap in range of 1.5 eV are ideal for the fabrication of solar cell. So, Si, GaAs, CdTe and $CuInSe_2$ are a few examples of suitable materials for solar cell.
2. The material should have high optical absorption so that sufficient photo voltage is developed across the junction.

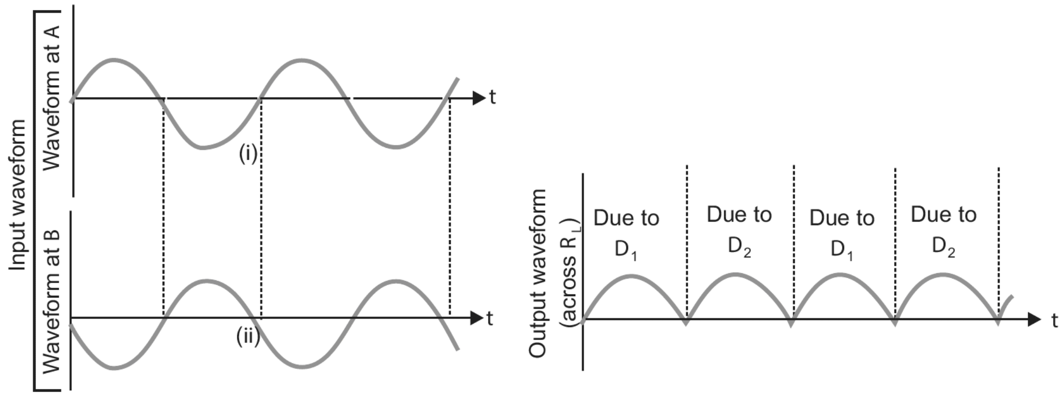
Or

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.



32. An optical instrument uses a lens of power 100 D for objective lens and 50 D for its eyepiece. When the tube length is kept at 25 cm. The final image is formed at infinity.

(*a*) Identify the optical instrument

(*b*) Calculate the magnification produced by the instrument. **3**

Ans. (*a*)

$$f_0 = \frac{1}{100} \text{ m} = 1 \text{ cm}$$

$$f_e = \frac{1}{50} \text{ m} = 2 \text{ cm}$$

Since the objective has a smaller focal length than the eyepiece, the instrument is a compound microscope.

(*b*) Also, $V_0 + f_e = 25\text{cm}$ (given)

$\therefore$ $V_0 = 25 - 2 = 23$ cm

As $\frac{1}{f_0} = \frac{1}{V_0} + \frac{1}{40}$

$$1 = \frac{1}{23} + \frac{1}{40}$$

$\therefore$ $\frac{1}{40} = 1 - \frac{1}{23} = \frac{23-1}{23} = \frac{22}{23}$

$\therefore$ $U_0 = \frac{23}{22}$ cm

Also $m = -\frac{V_0}{40}\left(\frac{D}{f_e}\right)$ when final image is formed at infinity substituting, we get

$$m = -\frac{23}{23} \times 22\left(\frac{25}{2}\right) = -11 \times 25 = -275$$

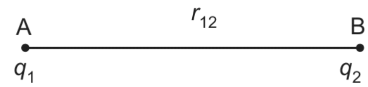
Alternately, the approximate value can be calculated by using

$$m = \frac{L \times D}{f_0 \times f_e} = \frac{25 \times 25}{1 \times 2} = 312.5$$

33. (*a*) **Two point charges q_1 and q_2 are kept at a distance of r_{12} in air. Deduce the expression for the electrostatic potential energy of this system.**

(*b*) **If an external electric field (E) is applied on the system, write the expression for the total energy of this system.** **3**

Ans. (*a*)



Consider a system AB of two charges q_1 and q_2 separated by a distance r_{12}. Imagine that charge q_2 at B is removed to infinity. The potential at B due to charge q_1 will be

$$V = \frac{1}{4\pi\varepsilon_0}\frac{q_1}{r_{12}}$$

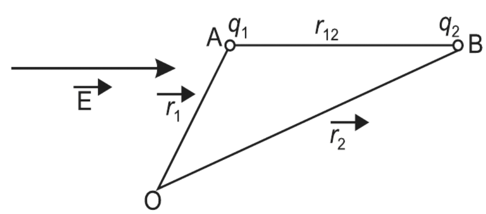
By definition, this is the work required to be done in order to bring a unit charge from infinity to the point B. Therefore the work done in bringing the charge q_2 from infinity to the point will be

$$W = q_2 V = \frac{1}{4\pi\varepsilon_0}\frac{q_1 q_2}{r_{12}}$$

Therefore the electrostatic potential energy U of the system of charges q_1 and q_2 is

$$U = \frac{1}{4\pi\varepsilon_0}\frac{q_1 q_2}{r_{12}}$$

(*b*) If we want to find potential energy of the system of two charges q_1 and q_2, situated at point A and B having radius vectors $\vec{r_1}$ and $\vec{r_2}$ with respect to origin O, under the influence of an external field $\vec{E}$, then first we calculate the work done in bringing the charge q_1 from infinity to $\vec{r_1}$ so the work done in this step is $q_1 V(\vec{r_1})$. Next we find the work done in bringing q_2 to r_2. Now work is done not only against the external field $\vec{E}$ but also against the field due to q_1.



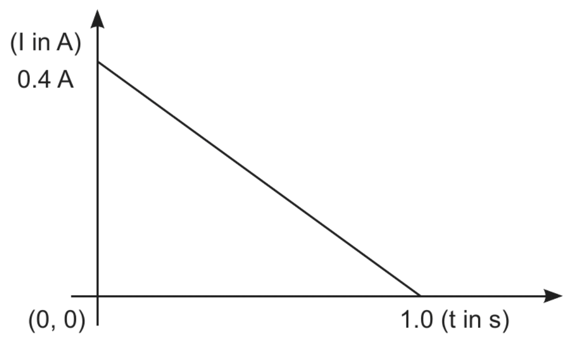
Hence, work done in bringing q_2 to $\vec{r_2}$

$$= q_2 V(\vec{r_2}) + \frac{q_1 q_2}{4\pi\varepsilon_0 r_{12}}$$

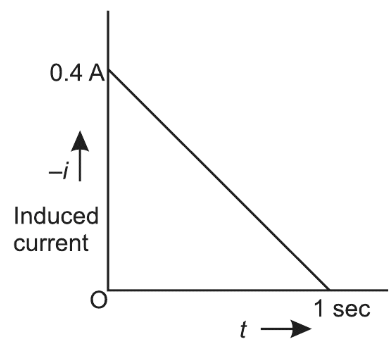
Therefore, the total potential energy of the system

$$U = q_1 V(\vec{r_1}) + q_1 V(\vec{r_2}) + \frac{q_1 q_2}{4\pi\varepsilon_0 r_{12}}$$

34. When a conducting loop of resistance 10 Ω and area 10 cm^2 is removed from an external magnetic field acting normally, the variation of induced current in the loop with time is shown in the figure.
Find the
(*i*) total charge passed through the loop.
(*ii*) change in magnetic flux through the loop.
(*iii*) magnitude of the magnetic field applied. **3**



Ans. (*i*) The slope of the graph $= \frac{0-0.4}{1-0} = -0.4$



$\therefore$ equation of current vs time is $-i = -0.4$ t

or $$i = 0.4\,t$$

or $$\frac{dq}{dt} = 0.4\,t$$

$$dq = 0.4\,tdt$$

integrating on both sides

$$q = 0.4\left[\frac{t^2}{2}\right]_0^1 = 0.2\text{ C}$$

or

Total charge passed through the loop

Q = Area under I – t graph

$$= \frac{1}{2} \times 0.4 \times 1 = 0.2\text{ C}$$

(*ii*) $$e = -\frac{d\phi}{dt}$$

or $$iR = \frac{d\phi}{dt}$$

$$\Rightarrow \qquad d\phi = iRdt$$

$$\text{or} \qquad \phi = iRt$$

$$= \qquad qR = 0.2 \times 10 = 2 \text{ W}b$$

$$\text{Change in magnetic flux} = q\text{R}$$

$$= 10 \times 0.2 = 2 \text{ W}b.$$

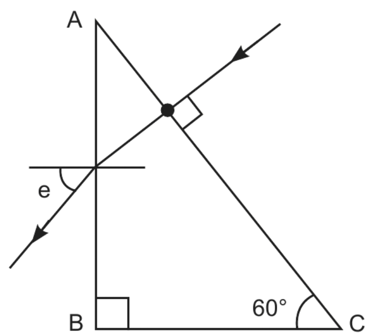
(*iii*) $\therefore \text{BA} = 2 \qquad (\because \Delta\phi = \text{BA})$

$$\text{B} = \frac{2}{10 \times 10^{-4}} = 2 \times 10^{3} \text{ T}$$

SECTION D

35. (*a*) Define the term 'focal length of a mirror'. With the help of a ray diagram, obtain the relation between its focal length and radius of curvature.

(*b*) Calculate the angle of emergence (e) of the ray of light incident normally on the face AC of a glass prism ABC of refractive index $\sqrt{3}$. How will the angle of emergence change qualitatively, if the ray of light emerges from the prism into a liquid of refractive index 1.3 instead of air? **5**



Or

(*a*) Define the term 'resolving power of a telescope'. How will the resolving power be effected with the increase in

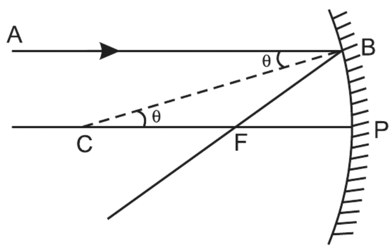
(*i*) Wavelength of light used.

(*ii*) Diameter of the objective lens.

Justify your answers.

(*b*) A screen is placed 80 cm from an object. The image of the object on the screen is formed by a convex lens placed between them at two different locations separated by a distance 20 cm. Determine the focal length of the lens. **5**

Ans. (*a*) The focal length of a spherical mirror is equal to the distance between the focus and the pole of the mirror. The focus of a spherical mirror is a point on the principal axis where a narrow beam of light parallel to the principal axis either converges to or diverges from, after reflection from the mirror. Pole is the mid point of the curved surface of the mirror. The focal length is positive for convex mirror and negative for concave mirror as per cartesian sign conventions.



Let the ray AB, Parallel to principal axis of a concave mirror, is incident at the point B of the mirror and after reflection passes through the focus F. Joining B with the centre of curvature of the mirror, C makes the normal at point B.

Angle of incidence ABC = (θ) is equal to the angle of reflection CBF.

Also $\angle ABC = \angle BCP$

as $AB \parallel CP$

Hence $\angle CBF = \angle BCP$

$\Rightarrow$ $FC = FB$

If aperture of the mirror is very small them the point B will be very close to the pole P.

Hence $FC = FB = PF$

Further $PC = PF + FC = 2PF$

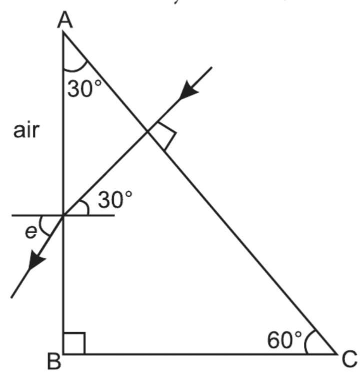
or $PF = \frac{PC}{2}$

Now $PF = -f$, the focal length of the mirror

and $PC = -R$, the radius of curvature of the mirror

Hence $f = \frac{R}{2}$

(*b*) The angle of incidence when ray moves, out of glass surface AB into air is 30°.



$$\text{Given that} \quad {}_a\mu_g = \sqrt{3}$$

$$\therefore \quad {}_g\mu_a = \frac{1}{\sqrt{3}}$$

$$\therefore \quad \frac{1}{\sqrt{3}} = \frac{\sin 30°}{\sin e}$$

$$\text{or} \quad \sin e = \sqrt{3}\ \sin 30°$$

$$\text{or} \quad \frac{\sqrt{3}}{2} = \sin e$$

$$\therefore \quad e = 60°$$

The angle of emergence will decrease.

If length goes from glass to a liquid qualitatively instead of air then

$${}_g\mu_l = {}_g\mu_a \times {}_a\mu_l$$

$$= \frac{1}{\sqrt{3}} \times 1.3$$

$$\therefore \quad \frac{1.3}{\sqrt{3}} = \frac{\sin 30°}{\sin e'}$$

$$\therefore \quad \sin e' = \frac{\sqrt{3}}{2 \times 1.3} = 0.666$$

$$\therefore \quad e' = \sin^{-1} 0.666 = 41.76°$$

Hence $e' < e$.

So, the angle of emergence reduces to 41.83° from 60°.

Or

(*a*) The resolving power of a telescope is its ability to show two distant closely lying objects as just separate

$$\text{R.P.} = \frac{D}{1.22\,\lambda}$$

Where D is the diameter of objective lens and λ is the wavelength of the light used.

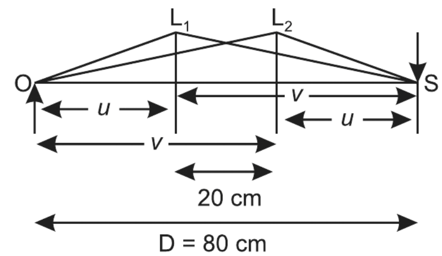
(*i*) If λ is increased, the resolving power will decrease

(*ii*) If D is increased, the resolving power of the telescope will increase.

(*b*) In position L_1 of the lens $OL_1 = u$ and $L_1S = v$

In position L_2 of the lens $OL_2 = u' = v$ and $L_2S = v' = u$

$$u + v = 80$$
$$v - u = 20$$
$$2v = 100$$
$$v = 50 \text{ cm}$$
$$u = 30 \text{ cm}$$



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

we get, $\frac{1}{f} = \frac{1}{50} + \frac{1}{30} = \frac{3+5}{150} = \frac{8}{150}$

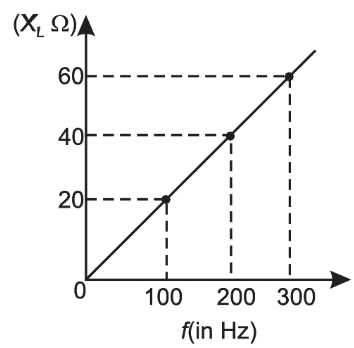
∴ $f = \frac{150}{8} \text{cm} = 18.75 \text{ cm}$

or using $f = \frac{D^2 - d^2}{4D} = \frac{6400 - 400}{4 \times 80}$

$$= \frac{600\not{0}}{32\not{0}} = \frac{300}{16} = \frac{150}{8} = 18.75 \text{ cm}$$

36. (*a*) Show that an ideal inductor does not dissipate power in an ac circuit.

(*b*) The variation of inductive reactance (X_L) of an inductor with the frequency (*f*) of the ac source of 100 V and variable frequency is shown in the fig.



(*i*) Calculate the self-inductance of the inductor.

(*ii*) When this inductor is used in series with a capacitor of unknown value and a resistor of 10 Ω at 300 s^{-1}, maximum power dissipation occurs in the circuit. Calculate the capacitance of the capacitor. **5**

Or

(*a*) A conductor of length '*l*' is rotated about one of its ends at a constant angular speed '*w*' in a plane perpendicular to a uniform magnetic field B. Plot graphs to show variations of the *emf* induced across the ends of the conductor with (*i*) angular speed *w* and (*ii*) length of the conductor *l*.

(*b*) Two concentric circular loops of radius 1 cm and 20 cm are placed coaxially.

(*i*) Find mutual inductance of the arrangement.

(*ii*) If the current passed through the outer loop is changed at a rate of 5 A/ms, find the emf induced in the inner loop. Assume the magnetic field on the inner loop to be uniform. 5

Ans. (*a*) For an ideal inductor

$$i = i_0 \sin wt$$

and $$V = V_0 \sin\left(wt + \frac{\pi}{2}\right) \text{ as}$$

V leads i by phase $\frac{\pi}{2}$.

The instantaneous power $P = Vi$

or $$P = Vi = V_0 \cos wt \times i_0 \sin wt$$

$$= V_0 i_0 \sin wt \cos wt \times \frac{2}{2}$$

$$P = \frac{V_0 i_0}{2} \sin 2wt$$

The average power dissipated over the whole cycle will be

$$P = \frac{\int_0^T P dt}{\int_0^T dt} = \frac{1}{T}\int_0^T P dt = \frac{V_0 i_0}{2T}\int_0^T \sin 2wt\, dt$$

$$= \frac{V_0 i_0}{2T}\left[-\frac{\cos 2wt}{2w}\right]_0^T$$

$$= \frac{V_0 i_0 \times T}{2T \times 2 \times 2\pi}\left[-\cos\frac{4\pi}{T}T + \cos 0\right]$$

$$= \frac{V_0 i_0}{8\pi}[-1+1] = 0$$

Hence ideal inductor does not dissipate power in an a.c. circuit.

(*b*) Given that $V = 100$ V; $X_L = 2\pi fL$

$$\therefore \quad \frac{X_L}{f} = 2\pi L = \text{slope of the graph}$$

$$= \frac{60-20}{300-100} = \frac{40}{200} = \frac{1}{5}$$

(*i*) $$L = \frac{1}{5\times 2\pi} = \frac{1}{10\pi}H = 0.032\text{H}$$

(*ii*) As maximum power dissipates, it should be the condition of electrical resonance

$$\therefore \quad Z = R$$

or $$X_L = X_C$$

At $$f = 300 \text{ s}^{-1}$$

$$X_L = 60\ \Omega \text{ from the graph}$$

$$\therefore \quad X_C = \frac{1}{2\pi fC} = 60\ \Omega$$

or $$C = \frac{1}{2\pi f\times 60} = \frac{1}{2\times 3.14\times 300\times 60}$$

$$= \frac{1}{113040} = 0.0000088464$$

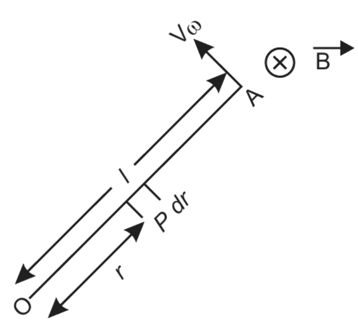
$$C = 8.85 \times 10^{-6} \text{ F}$$

or $$f = \frac{1}{2\pi\sqrt{LC}}$$

$$\therefore \quad C = \frac{1}{L\times 300^2\times 4\pi^2} = 8.85\ \mu f$$

Or

(*a*) Let us take a small elementary length dr (OP = r) at a distance r away from end O of the rod of length l. The elemenntary emf developed in element dr will be



$$de = -Bvdr$$

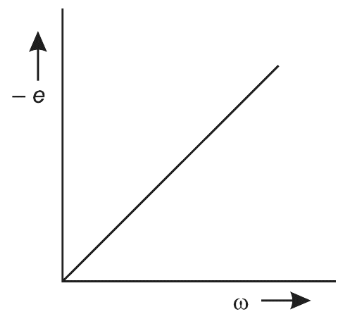
As $$v = rw$$

at point P $$de = -Bwrdr$$

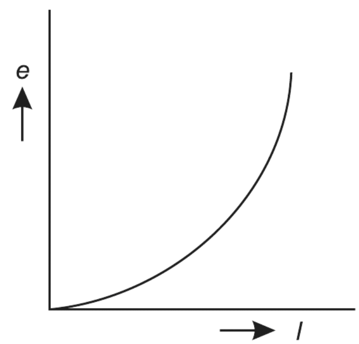
$$\therefore \qquad e = -Bw\int_0^l r\,dr = -Bw\left[\frac{r^2}{2}\right]_0^l$$

$$\text{or} \qquad e = \frac{-Bwl^2}{2}$$

(*i*) As $|e| \propto \omega$



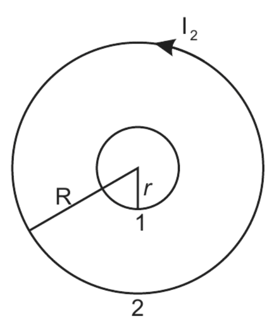
(*ii*) As $|e| \propto l^2$



(*b*) Let two concentric coils 1 and 2 of radii r and R respectively are placed co-axially. Magnetic field at the centre due to outer coil, 2.

$$B_2 = \frac{\mu_0 I_2}{2R}$$

As $r << R$, B_2 is almost uniform over the first coil, 1.



$\therefore$ flux linked with inner coil.

$$\phi_1 = B_2A_1$$

$$= \frac{\mu_0 I_2}{2R} . \pi r^2$$

By def^n. $\phi_1 = MI_2$

where M is the mutual inductance,

Then $M = \frac{\mu_0}{2R}(\pi r^2)$

(*i*) Given that $r = 1 \text{ cm} = 10^{-2} \text{ m}$

and $R = 20 \text{ cm} = 20 \times 10^{-2} \text{ m}$

$$M = \frac{4\pi \times 10^{-7} \times \pi \times (10^{-2})^2}{2 \times 20 \times 10^{-2}}$$

$$= 9.9 \times 10^{-10} \text{ H} \cong 10^{-9} \text{ H}$$

(*ii*) Given that $\frac{dI_2}{dt} = 5 \text{ A/ms} = 5 \times 10^3 \text{ A/s}$

and $e_1 = -M\frac{dI_2}{dt}$

The emf produced in the inner loop by substituting the values, we get

$$e_1 = 10^{-9} \times 5 \times 10^3 \text{ volt}$$

$$= -5 \times 10^{-6} \text{ volt}$$

37. (*a*) **Write two important characteristics of equipotential surfaces.**

(*b*) **A thin circular ring of radius *r* is charged uniformly so that its linear charge density becomes λ. Derive an expression for the electric field at a point P at a distance *x* from it along the axis of the ring. Hence, prove that at large distances (*x* >> *r*), the ring behaves as a point charge.** **5**

Or

(*a*) **State Gauss's law on electrostatics and derive an expression for the electric field due to a long straight thin uniformly charged wire (linear charge density λ) at a point lying at a distance *r* from the wire.**

(*b*) **The magnitude of electric field (in NC^{-1}) in a region varies with the distance *r*(in *m*) as**

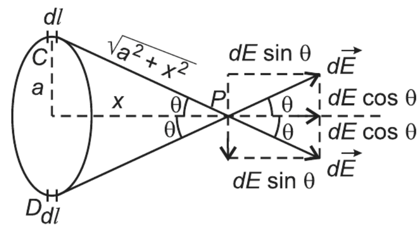
$\boldsymbol{E = 10\,r + 5}$

By how much does the electric potential increase in moving from point at *r* = 1 m to a point at *r* = 10 m. **5**

Ans. (*a*) If all points on a surface are at the same electric potential then the surface is called an equipotential surface.

1. If a test charge is moved between any two points on an equipotential surface through any path, the work done is zero.
2. The equipotential surface is always as right angles to the lines of force *i.e.* at right angles to the electric field intensity, $\vec{E}$.

(*b*) Let a charge Q is distributed uniformly all over the ring of radius a, such that linear charge density $\lambda = \frac{Q}{2\pi a}$. Now, consider two small charge elements of length 'dl' at C and D, having the charge $dQ = \lambda dl$ each. Then, at the point P and distance x apart from the centre of ring; electric field due to each charge element will be $d\vec{E}$. Resolving $d\vec{E}$ into components along x-axis and perpendicular to x-axis. We see that the perpendicular components ($dE \sin\theta$) get cancelled out and only $dE \cos\theta$ components contribute to the net electric field.



$$\therefore \quad E_{net} = \int dE\cos\theta = \int \frac{1}{4\pi\varepsilon_0}\cdot\frac{\lambda dl}{(x^2+a^2)}\times\frac{x}{(x^2+a^2)^{1/2}} = \frac{\lambda x}{4\pi\varepsilon_0(a^2+x^2)^{3/2}}\int_{l=0}^{2\pi R} dl$$

$$\therefore \quad E_{net} = \frac{Qx}{4\pi\varepsilon_0(x^2+a^2)^{3/2}}$$

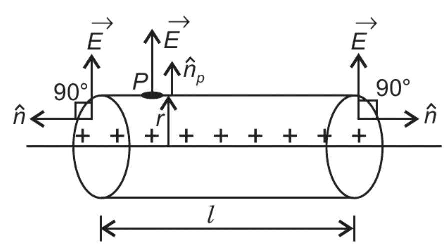
At large distances $x >> a$, a^2 can be neglected and

$$E = \frac{Q}{4\pi\varepsilon_0 x^2}$$

i.e. ring will behave like a point change.

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.

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

Electric flux through the curved surface is given by

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

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

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

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

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*) Given that $E = 10r + 5$

As $$E = -\frac{dV}{dr}(def^n)$$

$$dV = -E\,dr$$

$\therefore$ $$V = -\int_{r=1}^{10}(10r+5)\,dr = 10\int_1^{10} r dr - 5\int_1^{10} dr$$

$$= -10\left[\frac{r^2}{2}\right]_1^{10} - 5[r]_1^{10}$$

$$= -5[100 - 1] - 5[10 - 1]$$

$$= -5 \times 99 - 5 \times 9$$

$$= -495 - 45 = -540 \text{ volt.}$$

Set-II (Uncommon Questions to Set-I)

SECTION A

6. A biconvex lens of focal length f is cut into two identical plano convex lenses. The focal length of each part will be **1**

(*a*) f **(*b*) $f/2$**

(*c*) $2f$ **(*d*) $4f$**

Ans. (*c*) $2f$

Focal length of a bifocal convex lens of focal length f is

$$\frac{1}{f} = (\mu - 1)\frac{2}{R} \quad \text{...}(i)$$

Focal length of a plano convex lens, f' is

$$\frac{1}{f'} = (\mu - 1)\frac{1}{R} \quad \text{...}(ii)$$

$\therefore$ Dividing (i) by (ii)

$$\frac{f'}{f} = (\mu - 1)\frac{2}{R} \times \frac{R}{(\mu - 1)} = 2$$

$\therefore$ $f' = 2f$.

7. The phase difference between the current and the voltage in series LCR circuit at resonance is **1**

(*a*) π (*b*) $\pi/2$

(*c*) $\pi/3$ (*d*) **zero**

Ans. (*d*) As Z = R at resonance, $i = i_0 \sin wt$ and $V = V_0 \sin wt$, both i and V are in the same phase.

8. Photons of frequency ν are incident on the surfaces of two metals A and B of threshold frequencies 3/4 ν and 2/3 ν, respectively. The ratio of maximum kinetic energy of electrons emitted from A to that from B is **1**

(*a*) **2 : 3** (*b*) **4 : 3**

(*c*) **3 : 4** (*d*) **3 : 2**

Ans. (*c*); Using $h\nu = K + h\nu_0$, we have

$$h\nu = K_A + h\frac{3\nu}{4}$$

$\therefore$ $$K_A = h\nu\left(1 - \frac{3}{4}\right) = \frac{1}{4}h\nu$$

and $$h\nu = K_B + h\frac{2\nu}{3}$$

$\therefore$ $$K_B = h\nu\left(1 - \frac{2}{3}\right) = \frac{1}{3}h\nu$$

$\therefore$ $$\frac{K_A}{K_B} = \frac{1}{4}h\nu \times \frac{3}{h\nu} = \frac{3}{4}$$

SECTION B

21. (*a*) Define one Becquerel.

(*b*) A radioactive substance disintegrates into two types of daughter nuclei, one type with disintegration constant λ_1 and the other type with disintegration constant λ_2. Determine the half-life of the radioactive substance. **2**

Ans. (*a*) One Becquerel is defined as radioactivity of one disintegration per second.

(*b*) Let T_1 and T_2 be the half lives in first and second processes respectively.

$$\lambda_1 = \frac{\ln 2}{T_1}$$

and $$\lambda_2 = \frac{\ln 2}{T_2} \quad \text{(By } def^n\text{)}$$

The probability that an active nucleus decays by the first process in a time interval dt is $\lambda_1\, dt$ and for second process is $\lambda_2\, dt$

If the effective decay constant is λ, the final probability is $\lambda\, dt$.

Thus $$\lambda dt = \lambda_1 dt + \lambda_2 dt$$

$\therefore$ $$\lambda = \lambda_1 + \lambda_2$$

or $$\frac{1}{T} = \frac{1}{T_1} + \frac{1}{T_2} \quad \text{[When } T \text{ is true]}$$

effective half life,

$$\text{Half life} = \frac{\ln 2}{\lambda} = \frac{0.693}{\lambda_1 + \lambda_2}$$

23. In case of photoelectric effect experiment, explain the following facts, give reasons.

(*a*) The wave theory of light could not explain the existence of the threshold frequency.

(*b*) The photo electric current increases with increase of intensity of incident light. **2**

Ans. (*a*) There is no concept of threshold frequency in wave theory. No matter what the frequency of radiation is a sufficiently intense beam of radiation should be able to impart enough energy to the electrons, so that they exceed the minimum energy needed to escape from the metal surface.

(*b*) The maximum K.E. of photoelectrons is expected to increase with increase in intensity. Greater the intensity greater is the amplitude of electric and magnetic fields. Greater the intensity, greater is the energy absorbed by electron as the radiant energy is absorbed by metal continously.

The observations in Lenard and Hertz's experiment could not be explained on the basis of above classical wave theroy which failed to explain the photoelectric effect.

SECTION C

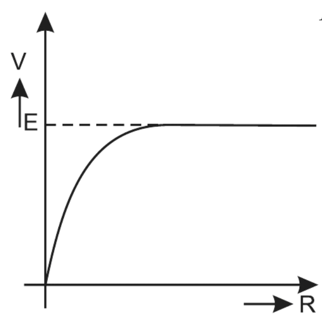
30. (*a*) Define internal resistance of a cell.

(*b*) A cell of emf *E* and internal resistance *r* is connected across a variable resistor *R*. Plot the shape of graphs showing variation of terminal voltage *V* with (*i*) *R* and (*ii*) circuit current *I*. 3

Ans. (*a*) The resistance offered by the electrolyte of the cell to the flow of current made up to lots of ions through it, is called the internal resistance of a cell, The internal resistance of a cell increases slowly as the cell is being used.

(*b*) (*i*)

$$V = \frac{ER}{R+r} = \frac{E}{1+\frac{r}{R}}$$



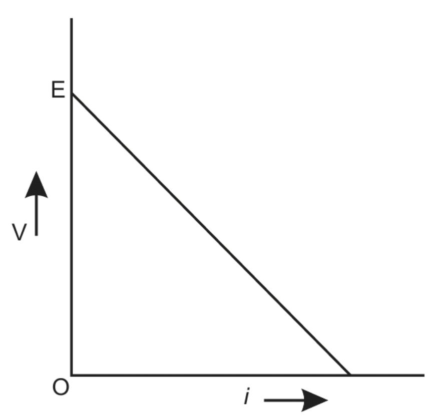
(*ii*)

$$E = V - ir$$

$\therefore$ $$V = -ir + E$$

$$V = E$$

if $$i = 0$$

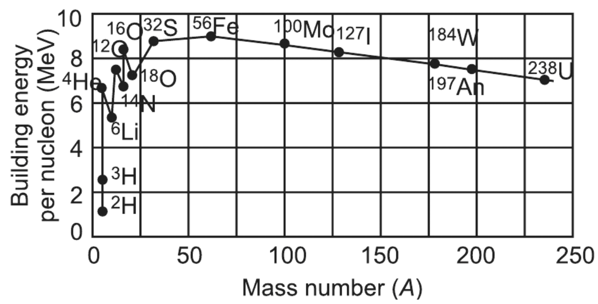


33. Draw the curve showing the variation of binding energy per nucleon with the mass number of nuclei. Using it explain the fusion of nuclei lying on ascending part and fission of nuclei lying on descending part of this curve. 3

Ans. Important conclusion regarding the nature of nuclear force:

(*a*) The forces is attractive and sufficiently strong to produce a binding energy of a few MeV per nucleon.

(*b*) The constancy of the binding energy in the wide range of mass number $30 < A < 170$ indicates that nuclear force is short range force.



The binding energy per nucleon as a function of mass number

(*a*) According to binding energy curve, a very heavy nucleus ($A > 170$), has lower binding energy per nucleon compared to nuclei of middle mass number ($30 < A < 170$).

Thus, if a heavy nucleus breaks into two nuclei of mass number between 30 and 170, nucleons get more tightly bound. This implies energy would be released in the process (nuclear fission).

(*b*) When two light nuclei ($A \leq 10$) join to form a heavier nucleus, the binding energy per nucleon of fused heavier nucleus increases. Again it indicates that energy would be released in the process (nuclear fusion).

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

SECTION B

21. Write shortcomings of Rutherford atomic model. Explain how these were overcome by the postulates of Bohr's atomic model. 2

Ans. The Rutherford's model suffers from several difficulties. The revolving electrons which are constantly accelerated towards the centre, must continuously emit electromagnetic radiation according to classical theory. Hence they should describe paths of less and less radii and ultimately fall into the nucleus. Further in the Rutherford's model the electrons can revolve in orbits of all possible radii and so they should emit continuous radiation of all frequencies. But the experimental fact is that atoms like hydrogen emit line spectra of only certain fixed frequencies.

Bohr suggested that the stability of the atom and the emission of sharp spectral lines could both be explained by applying planck's quantum theory of the atom. He proposed that

(*i*) An electron can move only in those orbits for which the angular momentum is an integral multiple of $h/2\pi$ $\left(mvr = \frac{nh}{2\pi}\right)$.

(ii) The electron does not emit radiation while moving an the orbit in spite of its accelerated motion. Hence atom is stable.

(*iii*) A quantum of energy called photon is emitted when an electron jumps from an orbit of higher energy to an orbit of lower energy. Hence the emitted spectrum has fixed frequencies.

Bohr′s postulates though successful, were arbitrary without physical interpretation.

24. Calculate for how many years will the fusion of 2.0 kg deuterium keep 800 W electric lamp glowing. Take the fusion reaction as **2**

$$^{2}_{1}\mathrm{H} + ^{2}_{1}\mathrm{H} \rightarrow ^{3}_{2}\mathrm{He} + ^{1}_{0}n + 3.27 \text{ MeV}$$

Ans. We know that in 2 g of deuterium the number of atoms present are 6.023×10^{23} (Avogadro's Number). So in 2 kg or 2000 g of deuterium the number of atoms present will be 6.023×10^{26}.

The energy released in the fusion of 2 deuterium atoms is given equal to 3.27 MeV.

Therefore, total energy released in the fusion of

$$2 \text{ kg atoms} = \frac{3.27}{2} \times 6.023 \times 10^{26} = 9.84 \times 10^{26} \text{ MeV}$$

$$= 9.84 \times 10^{26} \times 1.6 \times 10^{-13} \text{ J}$$

$$= 15.756 \times 10^{13} \text{ J}$$

Energy consumed by the bulb per second

$$= 800 \text{ J}$$

The time for which the bulb continues of glow

$$= \frac{15.756 \times 10^{13}}{800} \text{ second} = 1.969 \times 10^{11} \text{ s}$$

$$= \frac{1.969 \times 10^{11}}{3.15 \times 10^{7}} \text{ years}$$

$$= 0.622 \times 10^{4} \text{ years}$$

$$= 6.22 \times 10^{3} \text{ years}$$

SECTION C

28. (*a*) Define the term 'half-life' of a radioactive substance.

(*b*) The half-life of $^{238}_{92}U$ undergoing alpha decay is 4.5×10^9 years. Calculate the activity of 5 g sample of $^{238}_{92}U$. **3**

Ans. (*a*) The half life T of a radioactive substance is defined as the time taken for half the atoms to disintegrate. In this time, the radioactivity of the element diminishes to half of its value.

(*b*) Given that $T_{1/2} = 4.5 \times 10^9$ years

$$= 4.5 \times 10^9 \times 3.15 \times 10^7 \text{ s}$$

Mass of sample $m = 5$ g

Mass number $A = 238$

Number of atoms in 5 g uranium $= N = \frac{m}{A} \times$ Avogadro's Number

$$\therefore \quad N = \frac{5 \times 6.023 \times 10^{23}}{238} \text{ atoms}$$

The activity of the sample

$$R = \lambda N = \frac{0.693}{T_{1/2}} \times N$$

$$= \frac{0.693 \times 5 \times 6.023 \times 10^{23}}{238 \times 4.5 \times 10^9 \times 3.15 \times 10^7} \text{ s}^{-1}$$

$$= \frac{20.869 \times 10^{23}}{3373.65 \times 10^{16}}$$

$$= 0.006185 \times 10^7$$

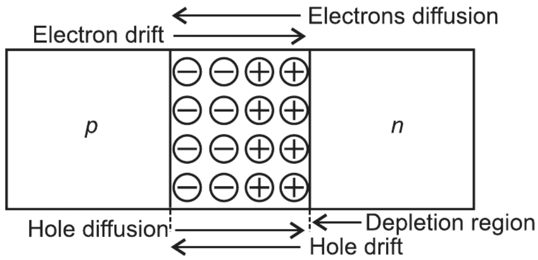
$$= 6.185 \times 10^4 \text{ Bq}$$

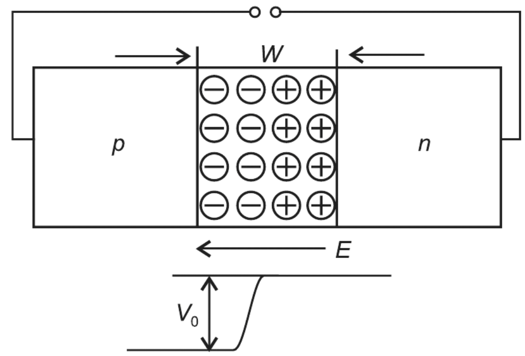
29. Explain the formation of potential barrier and depletion region in a p-n junction diode. What is effect of applying forward bias on the width of depletion region? **3**

Or

What is photo diode? Briefly explain its working and draw its V-I characteristics. **3**

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.

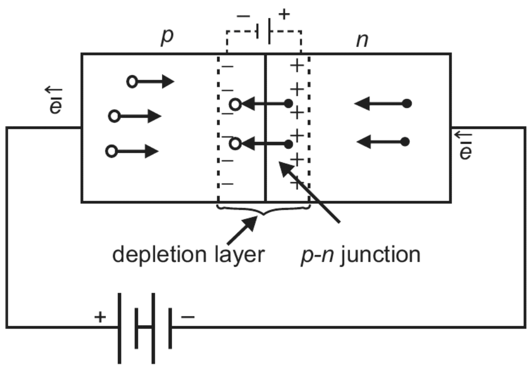
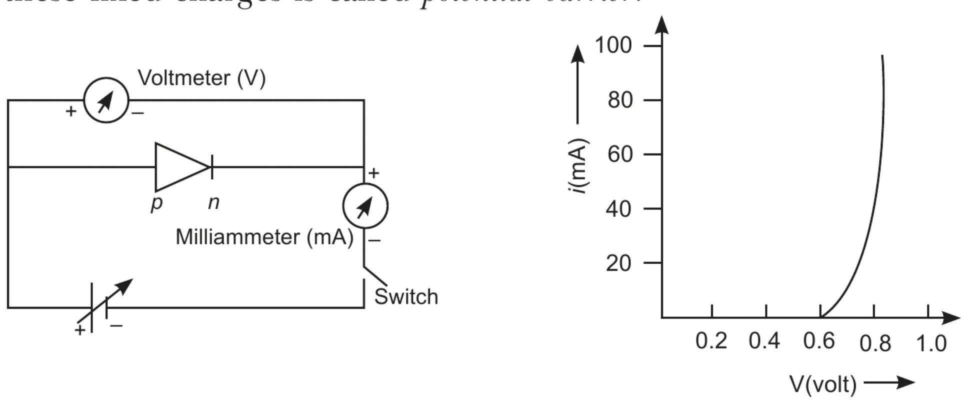


Fig. (*a*)

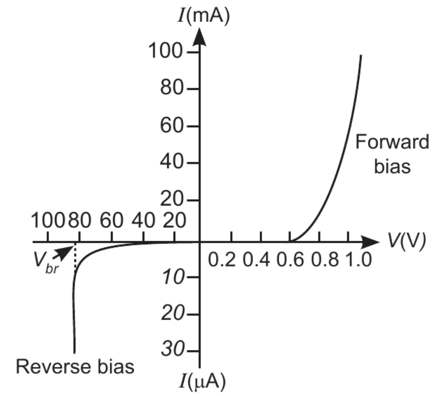
Fig. (*b*)

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*.



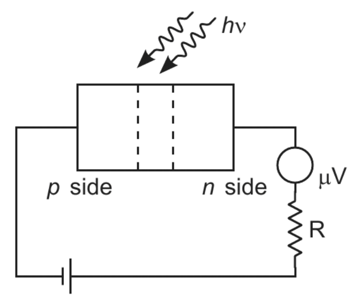
Forward bias

Explanation: 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).



Or

In a photodiode a *p-n* junction is made from a photo sensitive semiconducting material in such a way that light can fall on its junction. Below is shown the circuit diagram of reversed biased photo diode.



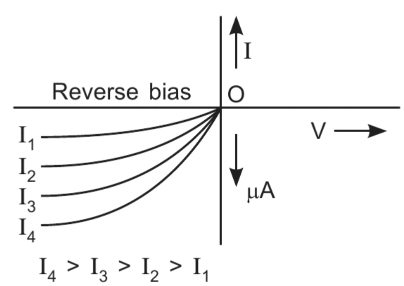
The voltage is kept slightly less than the break down voltage. When no light is incident on the junction, a small reverse saturation current flows through the junction. This current is due to thermally generated radiations of frequency ν, such that the energy of its photons is more than the band gap of the semiconductor (i.e. $h\nu > E_g$). Additional electron hole pairs are created due to excitation of electrons from valence band to the conduction band. The photo generated charge carrier increase the conductivity of the semiconductor. When a photo-diode is illuminated with light photons of energy $h\nu > E_g$, with increasing intensities of incident light, the value of reverse saturation current increases in the same proportion. Hence, a measurement of the change in the reverse saturation current can give the values of the corresponding values of varying light intensities.

In the given problem $E_g = 1.2$ eV

The wavelength of incident light = 400 nm

$$\lambda = 4 \times 10^{-7} \text{ m}$$

The energy of incident photon $= h\nu = \dfrac{hc}{\lambda}$



or $$E = \frac{6.63 \times 10^{-34} \times 3 \times 10^{8}}{4 \times 10^{-7}}$$

$$= \frac{6.63 \times 3}{4} \times 10^{-19} = 4.9725 \times 10^{-19} \text{ J}$$

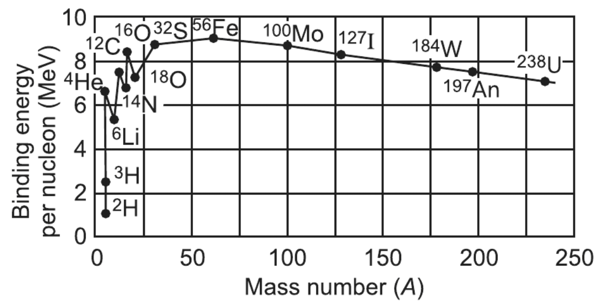
or $$E = \frac{4.9725 \times 10^{-19}}{1.6 \times 10^{-19}} \text{ eV} = 3.1078 \text{ eV}$$

As $E > E_g$ (3.1078 eV > 1.2 eV)

The diode can detect the light of wave length 4×10^{-7} m.

30. Draw the curve showing the variation of binding energy per nucleon with the mass number of nuclei. Using it explain the fusion of nuclei lying on ascending part. 3

Ans.



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.

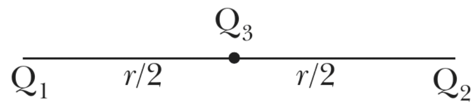
(*ii*) During nuclear fission light nuclei (for A < 30) fuse together to form a bigger nucleus having higher B.E./nucleon. Hence, energy gets released.

The rising part of the graph shows that elements with low mass number can produce energy by fusion. Since, the curve rises from ${}_1H^2$ to ${}_2He^4$, whose B.E./ Nucleon is greater than that for deuterium, ${}_1H^2$.

32. (*a*) Two point charges + Q_1 and – Q_2 are placed r distance apart. Obtain the expression for the amount of work done to place a third charge Q_3 at the midpoint of the line joining the two charges.

(*b*) At what distance from charge + Q_1 on the line joining the two charges (in terms of Q_1, Q_2 and *r*) will this work done be zero. 3

Ans. (*a*)



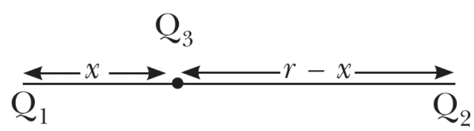
The amount of work done to place a third charge Q_3 at the midpoint of the line joining the two charges will be

$$W = \frac{kQ_1Q_3}{r/2} - \frac{kQ_2Q_3}{r/2}$$

$$= \frac{2k}{r}[Q_1Q_3 - Q_2Q_3]$$

$$W = \frac{2Q_3}{4\pi\varepsilon_0 r}[Q_1 - Q_2]$$

(*b*)



Let at distance x from charge $+Q_1$ as the line joining the two chages the work done be zero. Then

$$W = \frac{kQ_1Q_3}{x} - \frac{kQ_2Q_3}{r - x} = 0 \qquad \text{(given)}$$

$\therefore$ $$\frac{\not{k}Q_1\not{Q_3}}{x} = \frac{\not{k}Q_2\not{Q_3}}{r - x}$$

$\Rightarrow$ $$\frac{Q_1}{x} = \frac{Q_2}{r - x}$$

Cross multiplying, we get

$$Q_1r - Q_1x = Q_2x$$

or $$x(Q_1 + Q_2) = Q_1r$$

$\therefore$ $$x = \left[\frac{Q_1}{(Q_1 + Q_2)}\right]r$$

33. An optical instrument uses an objective lens of power 100 D and an eyepiece of power 40 D. The final image is formed at infinity, when the tube length of the instrument is kept at 20 cm.

(*a*) Identify the optical instrument.

(*b*) Calculate the angular magnification produced by the instrument. **3**

Ans. (*a*) Given that Power of objective lens = 100 D

$$\therefore \qquad f_o = \frac{100}{P_o} = \frac{100}{100} = 1 \text{ cm}$$

Power of an eye piece = 40 D

$$\therefore \qquad f_e = \frac{100}{Pe} = \frac{100}{40} = 2.5 \text{ cm}$$

As both focal lengths are small and $f_o < f_e$ the optical instrument is a microscope.

(*b*) We know that the angular magnification

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

Given that L = 20 cm and D = 25 cm for normal human eye.

$$\therefore \qquad m = -\frac{20}{1} \times \frac{25}{2.5} = -20 \times 10 = -200$$

Negative sign is to show that final image is inverted.

Examination Papers 2019
Delhi [Set I, II, III]

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

General Instructions:

(*i*) **All** questions are **compulsory**. There are **27** questions in all.

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

(*iii*) Section **A** contains **five** questions of **one** mark each, Section **B** contains **seven** questions of **two** marks each, Section **C** contains **twelve** questions of **three** marks each and Section **D** 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

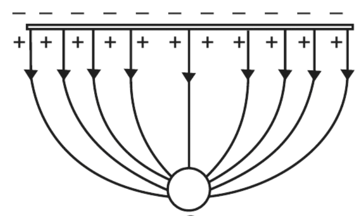
Avogadro's number $= 6.023 \times 10^{23}$ per gram mole

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

SECTION A

1. Draw the pattern of electric field lines, when a point charge $-Q$ is kept near an uncharged conducting plate. **1**

Ans.



2. How does the mobility of electrons in a conductor change, if the potential difference applied across the conductor is double, keeping the length and temperature of the conductor constant? **1**

Ans. Mobility is defined as the positive value of drift velocity per unit electric field applied.

$$\therefore \quad \mu_e = \frac{v_d}{E} = \frac{e}{m}t$$

Therefore, the mobility increases with the decrease in temperature and remains same when p.d. applied across the conductor is doubled.

3. Define the term "threshold frequency", in the context of photoelectric emission. **1**

Or

Define the term "Intensity" in photon picture of electromagnetic radiation.

Ans. **Threshold frequency:** For a given photosensitive surface, the minimum value of frequency of the incident radiation for which no photoelectric emission takes place is known as threshold frequency.

Or

Intensity of light

The intensity of light is defined as the number of photons falling per unit area per second

$$\text{Intensity} = \frac{N}{A \times t}$$

N = Number of photons, A = surface area and t = time for which photons are incident on the surface.

4. What is the speed of light in a denser medium of polarising angle 30°? **1**

Ans. $\because$ Polarising angle $= i_B = 30°$;

$\therefore$ Refractive index $= n = \tan i_B = \tan 30°$

$$= \frac{1}{\sqrt{3}} = 0.8$$

5. In sky wave mode of propagation, why is the frequency range of transmitting signals restricted to less than 30 MHz? **1**

Or

On what factors does the range of coverage in ground wave propagation depend? **1**

Ans. Out of syllabus

Or

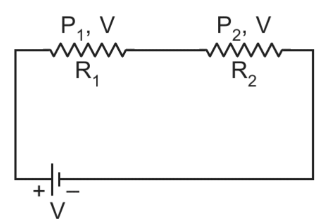
Out of syllabus

SECTION B

6. Two bulbs are rated (P_1, V) and (P_2, V). If they are connected (*i*) in series and (*ii*) in parallel across a supply V, find the power dissipated in the two combinations in terms of P_1 and P_2. **2**

Ans. (*i*) $\because$ In series current remains same i.e. $I = \frac{P_1}{V} = \frac{P_2}{V}$ and $R_1 = \frac{V}{I} = \frac{V^2}{P_1}$; $R_2 = \frac{V^2}{P_2}$

$\therefore$ Equivalent resistance in series; $R_S = R_1 + R_2$

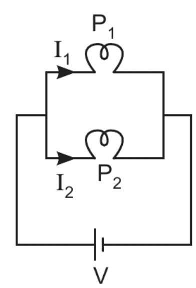


$$\therefore \quad R_S = V^2\left[\frac{1}{P_1} + \frac{1}{P_2}\right]$$

$$= V^2\left[\frac{P_1 + P_2}{P_1.P_2}\right]$$

$\therefore$ Power dissipated in series $= P_S = I^2R_S = \frac{V^2}{R_S} = \frac{V^2}{V^2}\left[\frac{P_1P_2}{P_1 + P_2}\right]$

$$\therefore \quad P_S = \frac{P_1.P_2}{P_1 + P_2}$$



(*ii*) In Parallel combination

$$I = I_1 + I_2$$

$$\frac{P}{V} = \frac{P_1}{V} + \frac{P_2}{V}$$

$$\Rightarrow \quad P = P_1 + P_2$$

Net power consumed $= P_P = P_1 + P_2$

7. Calculate the radius of curvature of an equi-concave lens of refractive index 1.5, when it is kept in a medium of refractive index 1.4, to have a power of –5D? **2**

Or

An equilateral glass prism has a refractive index 1.6 in air. Calculate the angle of minimum deviation of the prism, when kept in a medium of refractive index $4\sqrt{2/5}$. **2**

Ans. For equi-convex lens R.I. $= n_2 = 1.5$ (glass); $n_1 =$ R.I. of medium $= 1.4$

Power $= P = -5\text{D}$;

$$\therefore \quad P = \frac{1}{f} = \left(\frac{n_2}{n_1} - 1\right)\left(\frac{2}{-R}\right)$$

$$\Rightarrow \quad 5 = \left(\frac{1.5}{1.4} - 1\right)\frac{2}{R}$$

$$R = \left(\frac{1.5 - 1.4}{1.4}\right)\left(\frac{2}{5}\right) = \frac{0.1}{1.4} \times \frac{2}{5}$$

$$R = \frac{100}{35}\text{ cm} = \frac{20}{7}\text{ cm} = 2.85\text{ cm}$$

Or

$A = 60°$, R.I. $= n_g = 1.6$; $\delta_m = ?$, $n_m = ?$

$$\because \quad n_{gw} = \frac{n_g}{n_w} = \frac{\sin\left(\dfrac{A + \delta_m}{2}\right)}{\sin\dfrac{A}{2}} = \frac{\sin\left(\dfrac{60° + \sin\delta_m}{2}\right)}{\sin\dfrac{60°}{2}}$$

$$\frac{1.6}{4\sqrt{2}/5} = \frac{\sin\left(\dfrac{60° + \delta_m}{2}\right)}{\sin 30°} \qquad [\because \sin 30° = \frac{1}{2}]$$

$$\therefore \quad \sin\left(\frac{60° + \delta_m}{2}\right) = \frac{1.6 \times 5}{4\sqrt{2}} \times \frac{1}{2} = \frac{1}{\sqrt{2}} = \sin 45°$$

$$\therefore \quad \frac{60° + \delta_m}{2} = 45°$$

$$\Rightarrow \quad \delta_m = 30°$$

8. An α-particle and a proton of the same kinetic energy are in turn allowed to pass through a magnetic field $\vec{B}$, acting normal to the direction of motion of the particles. Calculate the ratio of radii of the circular paths described by them. 2

Ans. If mass of proton $= m$, then mass of α-particle $= 4$ m

Then, $$\frac{r_\alpha}{r_P} = \frac{\sqrt{2m_\alpha K_\alpha}}{\sqrt{2m_P K_P}} \quad [\because \text{radius} = r = \sqrt{2mK} \text{ and } (\text{K.E.})_\alpha = (\text{K.E.})_P]$$

$$\frac{r_\alpha}{r_P} = \frac{\sqrt{4\text{ m}}}{\sqrt{\text{m}}} = \frac{2}{1}$$

9. State Bohr's quantization condition of angular momentum. Calculate the shortest wavelength of the Bracket series and state to which part of the electromagnetic spectrum does it belong. 2

Or

Calculate the orbital period of the electron in the first excited state of hydrogen atom. 2

Ans. An electron revolves around the nucleus only in those orbits for which angular momentum is an integral multiple of $h/2\pi$, where h is the Planck's constant.

i.e. $$L = \frac{nh}{2\pi}$$

and $$h = 6.6 \times 10^{-34} \text{ Js}$$

Shortest wavelength is emitted when electron jumps from $n_1 = \infty$ to $n_2 = 4$

$$\therefore \quad \frac{1}{\lambda_{\text{shortest}}} = R\left(\frac{1}{4^2} - \frac{1}{\infty^2}\right) \qquad \left[\because \frac{1}{\lambda} = R\left(\frac{1}{n_2^2} - \frac{1}{n_1^2}\right)\right]$$

$$\therefore \quad \lambda_{\text{shortest}} = \frac{16}{R} \text{ m} = 1458.5 \text{ nm}$$

This wavelength belongs to far Infrared region.

Or

Orbital period of electron in the first excited state of H-atom

$$T_2 = \frac{2\pi r_2}{v_2} = 2\pi\left(\frac{n^2h^2}{4\pi^2 mke^2}\right).\frac{nh}{2\pi ke^2} \qquad ...(i)$$

Here in first excited state $n = 2$, $h = 6.6 \times 10^{-34}$ Js, $k = 9 \times 10^9$ Nm^{2}c^{-2}, $e = 1.6 \times 10^{-19}$ C

Substituting values in eq. (i) and calculating, we get

$$T_1 = \frac{2\pi \times 0.53 \times 10^{-10} \times 8}{2.19 \times 10^6} = 1.216 \times 10^{-15} \text{ sec} = 1.22 \times 10^{-15} \text{ sec}$$

10. Why a signal transmitted from a TV tower cannot be received beyond a certain distance? Write the expression for the optimum separation between the receiving and the transmitting antenna. 2

Ans. Out of syllabus

11. Why is wave theory of electromagnetic radiation not able to explain photo electric effect? How does photon picture resolve this problem? 2

Ans. The electromagnetic wave theory of radiation does not agree with the following experimental observations.

(i) Instantaneous emission of electron from the metal surface.

(ii) Maximum K.E. of emitted photoelectrons is independent of intensity.

(iii) Existence of threshold frequency.

But, according to wave theory, the free electrons at the surface of the metal continuously absorb the incident radiant energy which contradicts the observations.

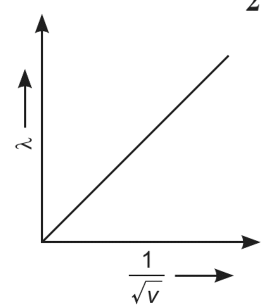
According to the Einstein's photoelectric equation (i.e. photon picture)

$$K_{\text{max}} = h\nu - \phi_0 \qquad ...(i)$$

According to eq. (i), K.E. will be zero for minimum frequency ν_0 (threshold frequency), emission is possible only for $\nu > \nu_0$ and K_{max} depends only on frequency not intensity of incident radiation.

12. Plot a graph showing variation of de Broglie wavelength (*l*) associated with a charged particle of mass *m*, versus $\frac{1}{\sqrt{V}}$, where *V* is the potential difference through which the particle is accelerated. How does this graph give us the information regarding the magnitude of the charge of the particle? 2

Ans. ∵ de Broglie wavelength, $\lambda = \frac{h}{\sqrt{2\,mqV}}$



For a particle of mass '*m*' accelerated through a P.D. of *V* volt, electric charge

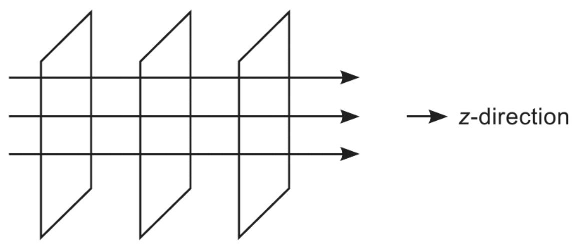
$$q = \left(\frac{h}{\sqrt{2\,m} \times \text{slope of graph}}\right)^2$$

SECTION C

13. (*a*) Draw the equipotential surfaces corresponding to a uniform electric field in the *z*-direction.

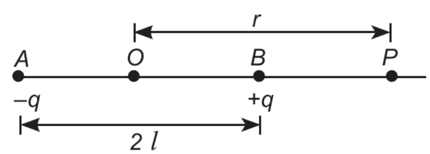
(*b*) Derive an expression for the electric potential at any point along the axial line of an electric dipole. 3

Ans. (*a*)



Equipotential Surfaces

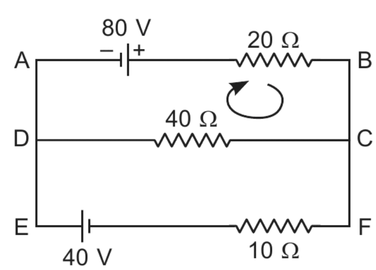
(*b*) Potential at *P* due to dipole is given by



$$V_p = V_{PA} + V_{PB} = \frac{q}{4\pi\varepsilon_0}\left[\frac{1}{r-l} - \frac{1}{r+l}\right]$$

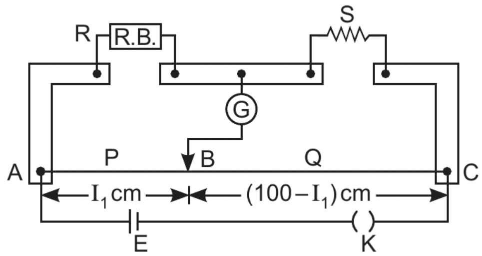
$$= \frac{1}{4\pi\varepsilon_0}\frac{q.2l}{(r^2-l^2)} = \frac{1}{4\pi\varepsilon_0}\frac{p}{(r^2-l^2)}$$

14. Using Kirchhoff's rules, calculate the current through the 40 W and 20 W resistors in the following circuit: 3



Or

What is end error in a metre bridge? How is it overcome? The resistances in the two arms of the metre bridge are R = 5 Ω and S respectively.



3

Ans. Consider loop ABCDA using KV law

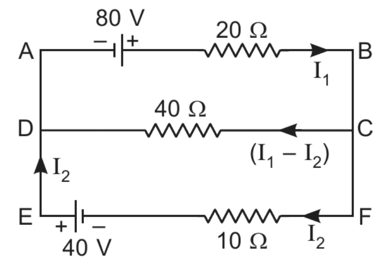
$$80 - 20I_1 - 40(I_1 - I_2) = 0$$

$$3I_1 - 2I_2 = 4 \qquad ...(i)$$

Applying Kirchoff's loop rule along ABCFEDA

$$80 - 20I_1 - 10I_2 + 40 = 0$$

$$2I_1 + I_2 = 12 \qquad ...(ii)$$



Solving equation (*i*) and (*ii*), we get

$$I_1 = 4 \text{ A}; \quad I_2 = 4 \text{ A}$$

∴ Current through 40 Ω resistor = $I_1 - I_2 = 0$ A

Or

The end error, in a meter bridge, is the error arising due to (*i*) Ends of the wire not coinciding with $\frac{0 \text{ cm}}{100 \text{ cm}}$ marks on the metre scale. (*ii*) Presence of contact resistance at the joints of the metre bridge wire with the metallic strips.

It can be reduced by finding balance length by inter-changing the positions of *R* and *S* and then taking the average value of '*S*' for two readings.

15. (*a*) Identify the part of the electromagnetic spectrum used in (*i*) radar and (*ii*) eye surgery. Write their frequency range.

(*b*) Prove that the average energy density of the oscillating electric field is equal to that of the oscillating magnetic field. **3**

Ans. (*a*) Part of electromagnetic spectrum used in

(*i*) Radar — Microwaves, (10^{10} Hz to 10^{12} Hz)

(*ii*) Eye surgery — UV rays (10^{15} Hz to 10^{17} Hz)

(*b*) $$u_E = \frac{1}{2}\varepsilon_0 E_{rms}^2, \; u_B = \frac{B_{rms}^2}{2\mu_0}, \quad \left[\because \; E_{rms} = \frac{E_0}{\sqrt{2}}, B_{rms} = \frac{B_0}{\sqrt{2}}\right]$$

or $$u_E = \frac{1}{4}\varepsilon_0 E_0^2 \text{ and } u_B = \frac{B_0^2}{4\mu_0}$$

Moreover $E_0 = cB_0$ and $c^2 = \frac{1}{\mu_0 \varepsilon_0}$

$$u_E = \frac{1}{4}\varepsilon_0(cB_0)^2 = \frac{1}{4}\varepsilon_0\frac{B_0^2}{\mu_0\varepsilon_0} = u_B.$$

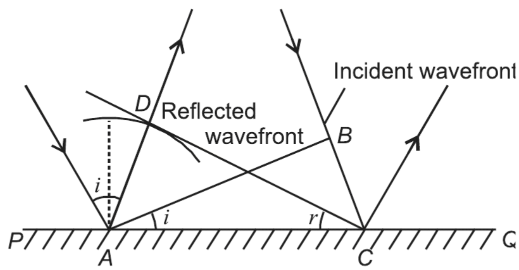
16. Define the wavefront. Using Huygen's wave theory, verify the law of reflection. 3

Or

Define the term, "refractive index" of a medium. Verify Snell's law of refraction when a plane wavefront is propagating from a denser to a rarer medium. 3

Ans. Wavefront: A wavefront is the locus of all points oscillating in same phase.

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

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

Or

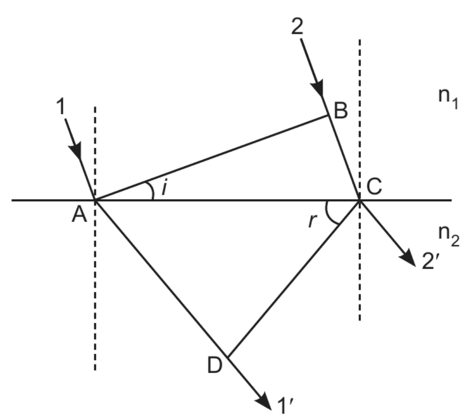
Refractive Index: The refractive index of a medium is defined as the ratio of velocity of light in vacuum (or air) to the velocity of light in that medium. It is designated by n or μ.

$$_an_m = \frac{v_{\text{air}}}{v_{\text{med}}}$$

Verification of Snell's law of Refraction:

Let AB is a plane wavefront incident at an angle i in denser medium of refractive index n_2.

When part of wavefront spreads from B to C with speed v_2 in time t; then from A it moves to D with speed v_1 in rarer medium of refractive index n_1. If r is the angle by which refracted wavefront bend then



$$= \frac{\sin i}{\sin r} = \frac{BC}{AC} \times \frac{AC}{AD} = \frac{v_2\tau}{v_1\tau}$$

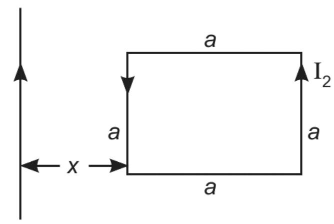
$$= \frac{v_2}{v_1} = \text{constant} = n_{12}$$

Refractive index of medium 1 w.r.t. 2, n_{12}.

$\therefore \qquad n_{12} = \frac{v_2}{v_1} = \frac{\sin i}{\sin r}$ [Snell's law]

17. (*a*) Define mutual inductance and write its S.I. unit.

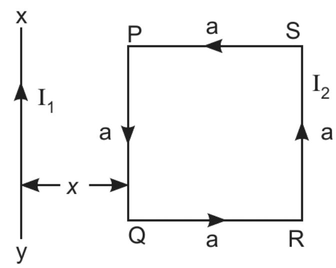
(*b*) A square loop of side '*a*' carrying a current I_2 is kept at distance *x* from an infinitely long straight wire carrying a current I_1 as shown in the figure. Obtain the expression for the resultant force acting on the loop. 3



Ans. (*a*) Mutual inductance of two coils is equal to the magnetic flux linked with one coil when a unit current is passing through the other coil.

i.e. $\phi = MI$

Its SI unit is henry (H) or WbA^{-1}.



(*b*) Force experienced by arm *PQ*

$$F_1 = \frac{\mu_0}{4\pi}.\frac{2I_1I_2a}{x}, \text{ away from conductor } XY$$

Force experienced by arm *RS*

$$F_2 = \frac{\mu_o}{4\pi}.\frac{2I_1I_2}{(x+a)}.a, \text{ towards } XY$$

Force experienced by arms *PS* and *QR* are equal and opposite, therefore will cancel out as $F_1 > F_2$

$\therefore$ Net force experienced by loop $= F_1 - F_2$

$$F = \frac{\mu_0}{4\pi}.2I_1I_2a\left[\frac{1}{x} - \frac{1}{x+a}\right]$$

$$F = \frac{\mu_o}{4\pi}.\frac{2I_1I_2a^2}{x(x+a)}; \quad \text{away from long straight wire } XY.$$

18. (*a*) Derive the expression for the torque acting on a current carrying loop placed in a magnetic field.

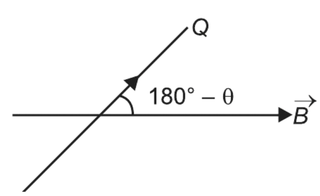
(*b*) Explain the significance of a radial magnetic field when a current carrying coil is kept in it. 3

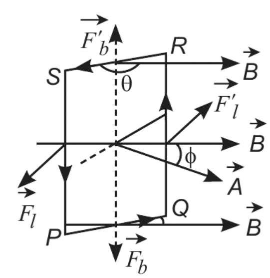
Ans. (*a*) **Torque acting on current carrying loop**

Forces experienced by the sides *PQ* and *RS* of the loop are

$F_b = IlB \sin\theta$

$F'_b = IlB \sin(180 - \theta) = IbB\sin\theta$



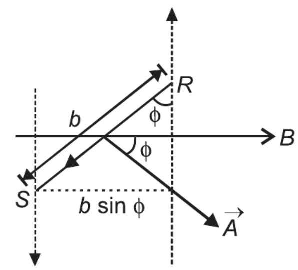


We observe that $\vec{F_b} = -\vec{F_b}$

(acting along the axis of the loop)

These forces do not provide torque because their lines of action coincide.

Forces acting on the sides *QR* and *SP* of the loop are



$$F_l = IlB, \text{ perpendicular outwards}$$

and $$F_l' = IlB, \text{ perpendicular inwards}$$

These forces provide a torque because $-\vec{F_l} = \vec{F_l'}$

and the lines of action of the forces do not coincide Now, the torque experienced by the loop is given as

τ = Magnitude of either force × Perpendicular distance between the forces $\tau = BIl \times ST$, where $ST = b \sin \phi$,

$\tau = IlB\,(b \sin \phi) \;\Rightarrow\; \tau = IAB \sin \phi \quad (\because lb = A)$

$\therefore\ \tau = mB \sin \phi \qquad (\because IA = m)$

here ϕ is the angle between normal to the coil and magnetic field.

$$\vec{\tau} = \vec{m} \times \vec{B}$$

(*b*) Significance of radial magnetic field:

(*i*) Maximum torque is experienced.

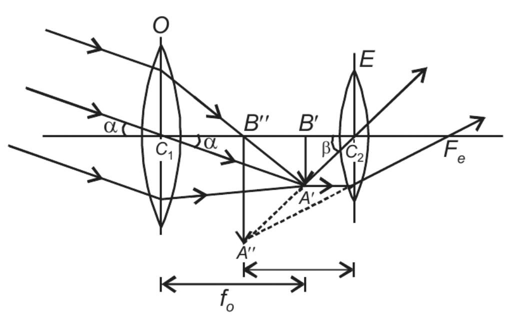
(*ii*) Current is directly proportional to the deflection.

(*iii*) The plane of the coil is parallel to the direction of magnetic field.

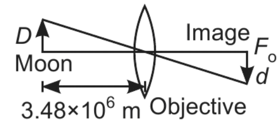
19. Draw a labelled ray diagram of an astronomical telescope in the near point adjustment position.

A giant refracting telescope at an observatory has an objective lens of focal length 15 m and an eyepiece of focal length 1.0 cm. If this telescope is used to view the Moon, find the diameter of the image of the Moon formed by the objective lens. The diameter of the Moon is 3.48 × 10⁶ m, and the radius of lunar orbit is 3.8 × 10⁸ m. **3**

Ans.



Given: $f_o = 15 \times 10^2$ cm, $f_e = 1$ cm



(*a*) Angular magnification of the telescope, $m = \dfrac{f_o}{f_e} = 1500$

(*b*) Angle subtended by image $= \frac{d}{f_o}$ ...(*i*)

where d is the diameter of the image.

Angle substended by diameter of moon $= \frac{3.48 \times 10^6 \text{m}}{3.8 \times 10^8 \text{ m}}$ ...(*ii*)

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

$$\frac{d}{1500} = \frac{3.48 \times 10^6 \text{m}}{3.8 \times 10^8 \text{ m}} \Rightarrow d = 13.73 \text{ cm}$$

20. (*a*) State Gauss's law for magnetism. Explain its significance.

(*b*) Write the four important properties of the magnetic field lines due to a bar magnet. 3

Or

Write three points of differences between para-, dia- and ferro- magnetic materials, giving one example for each. 3

Ans. (*a*) Gauss's law of magnetism states that the flux of B through any closed surface is always zero $\int_s B \,.\, ds = 0$. If the monopole existed, then Gauss's law would have been $\oint \vec{B} \,.\, \vec{ds}$ $= \mu_0 q_m$ where q_m is magnetic charge (monopole) enclosed by the surface.

(*b*) **Properties of Magnets**

(*i*) Attractive property: A magnet can attract the magnetic substances like iron, steel, cobalt, etc.

(*ii*) Directive property.

(*iii*) Unlike poles attract and like poles repel.

(*iv*) Magnetic poles exist in pairs.

(*v*) Force between two magnetic poles obeys inverse square law.

Or

Classification of Magnetic Materials

Different materials are known to behave differently in external magnetic field called the magnetising field and accordingly they are categorised as diamagnetic, paramagnetic and ferromagnetic materials.

Diamagnetic Materials**:** Such materials get magnetised in a direction opposite to the direction of the magnetising field. Hence, their susceptibility and intensity of magnetisation are negative and their relative permeability is less than 1 ($\mu_r < 1$). For example, Bismuth, Antimony, Water, etc.

Paramagnetic Materials**:** Such materials get magnetised in the direction of the magnetising field, though feebly. So, their relative permeability, susceptibility and intensity of magnetisation are positive (> 1, but close to it). For example, Platinum, Aluminium, Manganese, etc.

Ferromagnetic Materials**:** Such materials get strongly magnetised in the direction of the magnetising field. So, their relative permeability, susceptibility and intensity of magnetisation are positive (much greater than 1). For example, Iron, Nickel, Cobalt, etc.

21. Define the term 'decay constant' of a radioactive sample. The rate of disintegration of a given radioactive nucleus is 10000 disintegrations/s and 5,000 disintegrations/s after 20 hr and 30 hr respectively from start. Calculate the half life and initial number of nuclei at $t = 0$. **3**

Ans. **Definition of decay constant:**

$$N = N_0 e^{-\lambda t} \quad \text{if} \quad t = \frac{1}{\lambda}; \quad N = \frac{N_0}{e}$$

Thus, $\lambda = \frac{1}{t}$, i.e. the reciprocal of the time for which number of atoms left (N) is $\frac{1}{e}$ times N_0.

Given: $R_1 = R_o e^{-\lambda t_1} = 10{,}000$ dist./sec, at $t_1 = 20$ hr

$R_2 = R_o e^{-\lambda t_2} = 5{,}000$ dist./sec, at $t_2 = 30$ hr

$$\therefore \quad \frac{R_1}{R_2} = \frac{10{,}000}{5{,}000} = e^{-\lambda t_1 + \lambda t_2} \Rightarrow 2 = e^{\lambda(-20 + 30)}$$

or $\quad 2 = e^{-10\lambda}$,

Taking log $\quad \log_e 2 = -10\lambda \Rightarrow 2.3036 \times 0.3010 = -10 \times \frac{0.693}{T_{1/2}}$

$\Rightarrow \quad T_{1/2} = 10$ hr; Now, $t_1 = 20$ hr, i.e. 2 half lives

$\therefore$ No. of nuclei in 20 hr $= N_1 = \frac{N_0}{4}$, $\lambda = \frac{0.693}{10 \times 3600}$ per sec.

as $\quad R_1 = \lambda N_1 \Rightarrow 10{,}000 = \frac{0.693 \times N_0}{10 \times 3600 \times 4}$

$$N_0 = \frac{144 \times 10^7}{0.693} = 2.1 \times 10^9 \text{ nuclei}$$

22. (*a*) Three photo diodes D_1, D_2 and D_3 are made of semiconductors having band gaps of 2.5 eV, 2 eV and 3 eV respectively. Which of them will not be able to detect light of wavelength 600 nm?

(*b*) Why photodiodes are required to operate in reverse bias? Explain. **3**

Ans. (*a*) Energy of incident photon, $E = \frac{hc}{\lambda e}$ eV

$$E = \frac{6.6 \times 10^{-34} \times 3 \times 10^8}{6000 \times 10^{-10} \times 1.6 \times 10^{-19}} \text{eV} = \frac{12.42 \times 10^{-9}}{600 \times 10^{-9}} \text{ eV} = 2.07 \text{ eV}$$

For detection, $\frac{hc}{\lambda} \geq E_g$

$\therefore$ Diode D_2 will detect the light of wavelength 6000 Å.

(*b*) The fractional change in the minority charge carriers is more than the fractional change in the majority charge carriers, that is why, the change in current in reverse bias is more observable than the change in current in the forward bias.

23. **(*a*) Describe briefly the functions of the three segments of *n-p-n* transistor.**

(*c*) Draw the circuit arrangement for studying the output characteristics of *n-p-n* transistor in CE configuration. Explain how the output characteristics is obtained. **3**

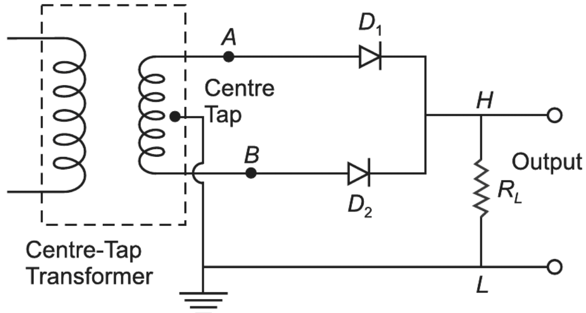
Or

Draw the circuit diagram of a full wave rectifier and explain its working. Also, give the input and output waveforms. **4**

Ans. Out of syllabus

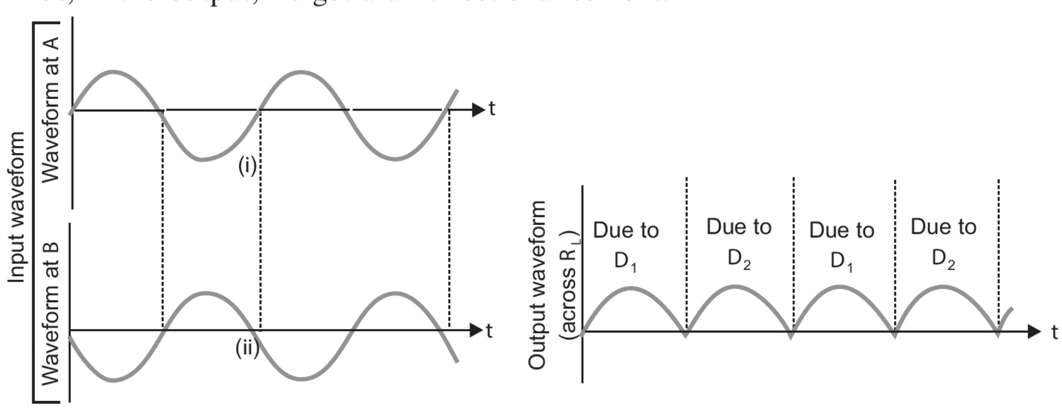
Or

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.



24. **(*a*) If A and B represent the maximum and minimum amplitudes of an amplitude modulated wave, write the expression for the modulation index in terms of A and B.**

(*b*) A message signal of frequency 20 kHz and peak voltage 10 V is used to modulate and carrier of frequency 2 MHz and peak voltage of 15 V. Calculate the modulation index. Why the modulation index is generally kept less than one? **3**

Ans. Out of syllabus

SECTION D

25. (*a*) **In a series LCR circuit connected across an a.c. source of variable frequency, obtain the expression for its impedance and draw a plot showing its variation with frequency of the a.c. source.**

(*b*) **What is the phase difference between the voltages across inductor and the capacitor at resonance in the LCR circuit?**

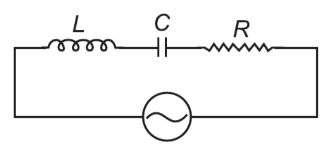
(*c*) **When an inductor is connected to a 200 V dc voltage, a current of 1 A flows through it. When the same inductor is connected to a 200 V, 50 Hz a.c. source, only 0.5 A current flows. Explain, why? Also, calculate the self inductance of the inductor.** **5**

Or

(*a*) **Draw the diagram of a device which is used to decrease high a.c. voltage into a low a.c. voltage and state its working principle. Write four sources of energy loss in this device.**

(*b*) **A small town with a demand of 1200 kW of electric power at 220 V is situated 20 km away from an electric plant generating power at 440 V. The resistance of the two wire line carrying power is 0.5 W per km. The town gets the power from the line through a 4000-220 V step-down transformer at a sub-station in the town. Estimate the line power loss in the form of heat.** **5**

Ans. (*a*) Take the voltage of source



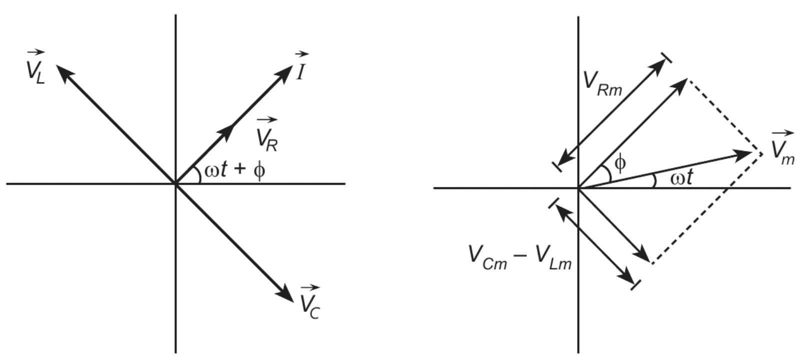
$$V = V_m \sin \omega t \qquad ...(i)$$

To determine the phase relation between current and voltage at any instant of time, we use a phasor technique.

As all the three components are in series, the same amount of current flows through them at any instant of time. Let it be

$$I = I_m \sin (\omega t + \phi) \qquad ...(ii)$$

where ϕ is the phase difference between the voltage across the source and current. We construct a phasor diagram.



On applying Pythagoras theorem, we get

$$V_m^2 = V_{Rm}^2 + (V_{Cm} - V_{Lm})^2$$

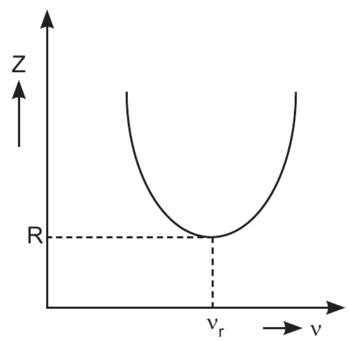
Here $V_{Rm} = I_m R$, $V_{Cm} = I_m X_C$, $V_{Lm} = I_m X_L$

$$V_m = I_m \sqrt{R^2 + (X_C - X_L)^2}$$

$$V_m = I_m Z$$

where, $$Z = \sqrt{R^2 + (X_C - X_L)^2}$$

Variation of impedance with frequency of a.c. source



(*b*) Phase difference between voltage across an inductor and a capacitor is $\pi(180°)$ at resonance. [Always]

(*c*) $V = 200$ V (d.c.), $I = 1$ A (d.c.)

$\therefore$ $$R = \frac{V}{I} = \frac{200}{1} = 200\ \Omega$$

When, $V_{rms} = 200$ V, $I_{rms} = 0.5$ A

$\therefore$ Impedance, $$Z = \frac{V_{rms}}{I_{rms}} = \frac{200}{0.5} = 400\ \Omega$$

i.e. more resistance is offered to the flow of alternating current by an inductor.

$\because$ $$Z = \sqrt{R^2 + X_L^2}$$

$\Rightarrow$ $$X_L = \sqrt{Z^2 - R^2} = \sqrt{(400)^2 - (200)^2} = 200\sqrt{3}\ \Omega$$

$$2\pi\nu L = 200\sqrt{3}, \quad \because \nu = 50 \text{ Hz}$$

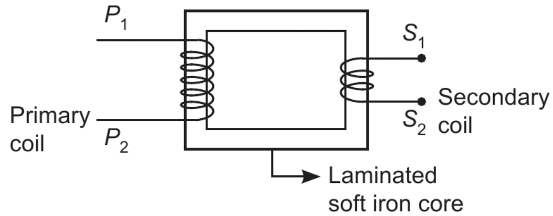
$$\therefore\ 2 \times \pi \times 50 \times L = 200\sqrt{3}$$

$$L = \frac{2\sqrt{3}}{\pi} \text{ H}$$

$$L = \frac{2 \times 1.732}{3.14} \text{ H} = 1.1 \text{ H}$$

Or

(*a*) Step down transformer :



Principle: 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.

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

Energy Losses:

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

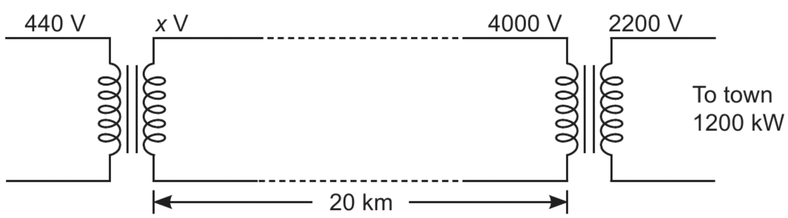
(*i*) Joule's heating of the primary and secondary windings

(*ii*) Heating of the core due to eddy currents.

(*iii*) Hysteresis loss.

(*iv*) Flux leakage or incomplete flux linkage.

(*b*)



$$\text{Resistance of two wire line 20 km long} = R = \frac{2 \times 0.5\,\Omega}{\text{km}} \times 20\text{ km} = 20\,\Omega$$

$$\therefore \quad \text{Electric current in the wire} = I = \frac{4000\text{ V}}{20\,\Omega} = 200\text{ A}$$

$$\therefore \quad \text{Power lost in the form of heat} = P = I^2R = (200)^2 \times 20$$

$$P = 8 \times 10^5\text{ W} = 800\text{ kW}$$

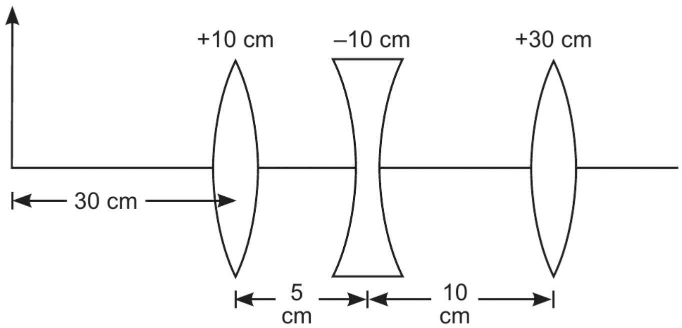
26. (*a*) Describe any two characteristic features which distinguish between interference and diffraction phenomena. Derive the expression for the intensity at a point of the interference pattern Young's double slit experiment.

(*b*) In the diffraction due to a single slit experiment, the aperture of the slit is 3 mm. If monochromatic light of wavelength 620 nm is incident normally on the slit, calculate the separation between the first order minima and the 3rd order maxima on one side of the screen. The distance between the slit and the screen is 1.5 m. 5

Or

(*a*) Under what conditions is the phenomenon of total internal reflection of light observed? Obtain the relation between the critical angle of incidence and the refractive index of the medium.

(*b*) Three lenses of focal lengths + 10 cm, – 10 cm and + 30 cm are arranged coaxially as in the figure given below. Find the position of the final image formed by the combination. **5**



Ans. (*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.

Consider two coherent sources S_1 and S_2. Suppose waves from these two sources meet at a point on the screen with a phase difference ϕ between their displacements.

If the displacement produced by S_1 is $y_1 = a \cos \omega t$ and displacement produced by S_2 is $y_2 = \text{a} \cos (\omega t + \phi)$ then, the resultant displacement will be

$$y = y_1 + y_2$$

$$\therefore \quad y = a[\cos \omega t + \cos (\omega t + \phi)] = 2a \cos \phi/2 \cos (\omega t + \phi/2)$$

From the above equation, we find that the amplitude of resultant displacement is

$$A = 2\,a \cos (\phi/2).$$

$\therefore$ Intensity at the point, $I = kA^2$

$$I = k4a^2 \cos^2 \phi/2 = 4\,I_0 \cos^2 \phi/2 \qquad [\because\ I_0 = ka^2]$$

(*b*) $a = 3 \text{ mm} = 3 \times 10^{-3}$ m, $\lambda = 620$ nm $= 620 \times 10^{-9}$ m, D = 1.5 m

Position of first order minima $= Y_1 = 1.\dfrac{\lambda D}{a} = \dfrac{620 \times 10^{-9} \times 1.5}{3 \times 10^{-3}}$ m

$= 310.0 \times 10^{-6}$ m $= 310 \times 10^{-6} = 0.31$ mm

Position of 3rd order maxima $= Y_3 = (2 \times 3 + 1)\dfrac{\lambda D}{2a}$

$= 3.5 \times 310 \times 10^{-6}$ m $\qquad \left[\text{Using } Y_3 = (2n+1)\dfrac{\lambda D}{2a}\right]$

$\therefore \quad Y_3 - Y_1 = (1.085 - 0.310)$ mm $= 0.775$ mm

Or

(*a*) When the angle of incidence is increased then for some angle of incidence i_c called the critical angle, the angle of refraction will be 90°. If the angle of incidence is increased beyond i_c, the incident ray is reflected back in the denser medium and obeys the laws of reflection. This is known as total internal reflection. The following are the necessary conditions for total internal reflection to take place:

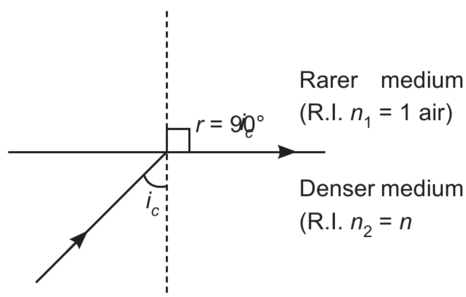
(*i*) Light must travel from denser medium to rarer medium.

(*ii*) The angle of incidence (in the denser medium) must be greater than the critical angle i_c, where

$$\sin i_c = \frac{1}{n}$$

The critical angle of diamond is 24° and for glass is 42°.

Relation between critical angle of incidence and refractive index



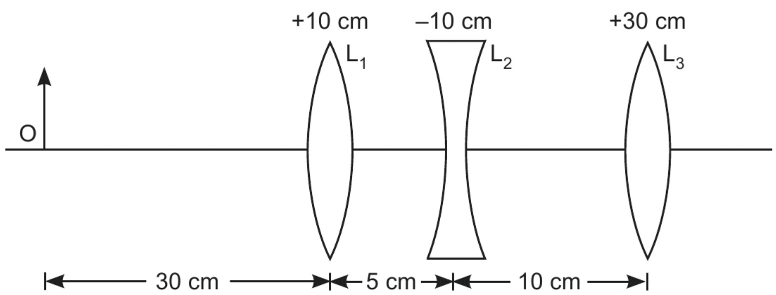
When angle of incidence in denser medium is i_c then angle of refraction r = 90° in rarer medium

$\therefore$ Using Snell's law $\quad n_2 \sin i_c = n_1 \sin r$

$$n \sin i_c = 1.\ \sin 90°, \qquad [\because\ \sin 90° = 1]$$

$$n = \frac{1}{\sin i_c}$$

(*b*)



$u_1 = -30$ cm, $f_1 = +10$ cm

$$\therefore \qquad v = \frac{uf}{u+f} = \frac{-30 \times 10}{-30 + 10} = 15 \text{ cm}$$

Image formed from first lens will act as object for second bus with object distance $u_2 = 15 - 5 = 10$ cm

$\because\ f = -10$ cm

$\therefore \qquad v_2 = \dfrac{10 \times -10}{10 - 10} = \infty$

For third lens (L_3); $u_3 = \infty, f_3 = +30$cm

$\therefore \qquad v_3 = f_3 = +30$ cm

$\therefore$ Final image will be formed at 30 cm on the right of lens (L_3) of focal length 30 cm.

27. (*a*) Describe briefly the process of transferring the charge between the two plates of a parallel plate capacitor when connected to a battery. Derive an expression for the energy stored in a capacitor.

(*b*) A parallel plate capacitor is charged by a battery to a potential difference *V*. It is disconnected from battery and then connected to another uncharged capacitor of the same capacitance. Calculate the ratio of the energy stored in the combination to the initial energy on the single capacitor. 5

Or

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

(*b*) Two identical point charges, *q* each, are kept 2 m apart in air. A third point charge *Q* of unknown magnitude and sign ins placed on the line joining the charges such that the system remains in equilibrium. Find the position and nature of *Q*. 5

Ans. (*a*) As soon as we connect a capacitor with a dc battery, one of its plates attains a higher potential and the other one at lower potential. An electric field is developed between the plates. As $V = Ed$, the field grows in magnitude till the potential difference between the plates is equal to the potential applied. Charge of opposite polarity is transferred to other place by induction process.

Energy stored in a capacitor

Let a capacitor of capacity C be charged to a potential V by a charge Q. Work has to be done in charging a capacitor. This work is stored in the capacitor in the form of potential energy. It exists in the electric field between the plates of the capacitor. Let q be the charge on the capacitor at any stage and V the potential difference across the plates then $V = \dfrac{q}{C}$

Then small amount of work done dW in giving a further small charge dq to the capacitor is

$$dW = Vdq = \frac{q}{C}dq$$

$\therefore$ Work done in charging the capacitor to a charge Q is

$$W = \int_0^Q \frac{q}{C}dq = \frac{1}{2}\left[\frac{q^2}{C}\right]_0^Q = \frac{1}{2C}[Q^2 - 0] = \frac{1}{2}\frac{Q^2}{C} \quad \text{Also, } Q = CV$$

$$\therefore \qquad W = \frac{1}{2}\frac{C^2V^2}{C} = \frac{1}{2}CV^2$$

Initial potential difference on charged capacitor = V

$\therefore$ Initial charge on the capacitor = $Q = C.V.$

When charged capacitor is disconnected from the battery and connected to another uncharged capacitor then, electric charge 'Q' is shared between the two.

$$\therefore \qquad \text{Common potential} = V' = \frac{Q \text{ (total charge)}}{2C \text{ (Total capacitance)}} = \frac{V}{2}$$

$$\text{Initial energy stored} = U_i = \frac{1}{2}CV^2 \qquad ...(i)$$

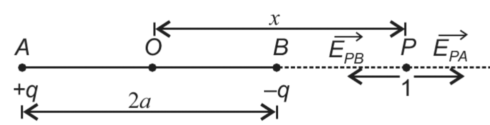
$$U_f = \frac{1}{2}\times(2C)\times\left(\frac{V}{2}\right)^2 = \frac{1}{4}CV^2$$

$$\therefore \qquad \frac{U_f}{U_i} = \frac{1}{4}$$

Or

(*a*) Electric field intensity at a point on the axis of an electric dipole.

Electric field at P due to charge at A



$$\vec{E}_{PA} = \frac{kq}{(x+a)^2}\hat{i}$$

Electric field at P due to charge at B

$$\vec{E}_{PB} = -\frac{kq}{(x-a)^2}\hat{i}$$

Net electric field at P,

$$\vec{E}_{ax} = \vec{E}_{PA} + \vec{E}_{PB} = kq\left[\frac{1}{(x+a)^2} - \frac{1}{(x-a)^2}\right]$$

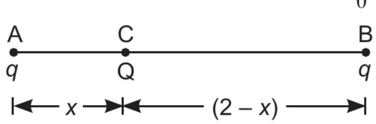
$$\vec{E}_{ax} = kq\left[\frac{x^2+a^2-2xa-x^2-a^2-2xa}{(x^2-a^2)^2}\right] = \frac{-2k(q2x)a}{(x^2-a^2)^2}$$

$$= \frac{-2kpx}{(x^2-a^2)^2} = \frac{-2kx\vec{p}}{(x^2-a^2)^2}$$

In the limiting case when $x >> a$, $(x^2 - a^2) \simeq x^4$

$$\vec{E}_{ax} = \frac{-2\vec{p}}{4\pi\varepsilon_0 x^3}$$

(*b*)



Let third charge Q is placed at C, at a distance $AC = x$ from $+q$ charge at A.

$\because$ System is at equilibrium

$\because \quad \Sigma\vec{F}_A = \Sigma\vec{F}_B = \Sigma\vec{F}_C = 0$

$\therefore \quad \vec{F}_{CA} + \vec{F}_{CB} = 0$ [net force on Q at C]

$\Rightarrow \quad \vec{F}_{CA} = -\vec{F}_{CB}$

$$\therefore \quad \frac{1}{4\pi\varepsilon_0}\frac{|qQ|}{x^2} = \frac{1}{4\pi\varepsilon_0}\frac{|qQ|}{(2-x)^2} \Rightarrow x = 2 - x \Rightarrow x = 1 \text{ m}$$

$\Rightarrow \quad AC = \text{BC} = 1 \text{ m}$

Now, net force on charge at A must also be zero.

$\therefore \quad \vec{F}_{AC} + \vec{F}_{AB} = 0$

$\Rightarrow \quad \vec{F}_{AC} = -\vec{F}_{AB}$

Which is possible when nature of charge Q is negative

$$\therefore \quad \frac{1}{4\pi\varepsilon_0}\frac{|q.Q|}{1^2} = \frac{1}{4\pi\varepsilon_0}\frac{|q.q|}{(2)^2}$$

$$|Q| = \frac{q}{4}, \quad \therefore \quad Q = -\frac{q}{4}$$

SET II [Uncommon Questions To Set-I]

SECTION A

2. When unpolarised light is incident on the interface separating the rarer medium and the denser medium, Brewster angle is found to be 60°. Determine the refractive index of the denser medium. 1

Ans. $i_B = 60°$, R.I. $= n = \tan i_B = \tan 60° = \sqrt{3}$

3. In sky wave mode of propagation, why is the frequency range of transmitting signals restricted to less than 30 MHz? 1

Or

On what factors does the range of coverage in ground wave propagation depend?

Ans. Out of syllabus

Or

Out of syllabus

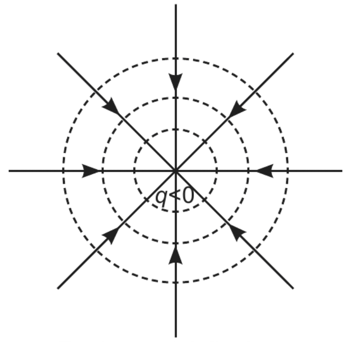
4. When a potential difference is applied across the ends of a conductor, how is the drift velocity of the electrons related to the relaxation time? 1

Ans.
$$\vec{v}_d = \frac{-e\vec{E}}{m}\tau$$

where m is the mass of the electron, $\vec{E}$ is the applied external electric field, and τ is the relaxation time.

5. Draw the equipotential surfaces due to an isolated point charge. **1**

Ans. Single point charge $q < 0$.



Equipotential Surfaces

SECTION B

7. A deuteron and an alpha particle having same momentum are in turn allowed to pass through a magnetic field $\vec{B}$, acting normal to the direction of motion of the particles. Calculate the ratio of the radii of the circular paths described by them. **2**

Ans. If electric charge of deuteron $q_d = +e$

then electric charge of α-particle $q_\alpha = +2e$

$\because \quad p_d = p_\alpha = p \text{ (momentum)}$

and $\quad r = \dfrac{p}{Bq} \Rightarrow r \propto \dfrac{1}{q}$

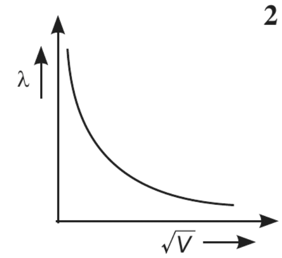
$\therefore \quad \dfrac{r_d}{r_\alpha} = \dfrac{q_\alpha}{q_d} = \dfrac{2e}{e} = \dfrac{2}{1}$

11. (*a*) Plot a graph showing variation of de-Broglie wavelength (λ) associated with a charged particle of mass *m*, versus $\sqrt{V}$, where *V* is the accelerating potential.

(*b*) An electron, a proton and an alpha particle have the same kinetic energy. Which one has the shortest wavelength? **2**

Ans. (*a*) $\lambda = \dfrac{h}{\sqrt{2mqV}}$

$\Rightarrow \lambda \propto \dfrac{1}{\sqrt{V}}$



(*b*) $K_e = K_P = K_\alpha$

$e \rightarrow$ electron; $p \rightarrow$ proton, $\alpha \rightarrow$ α-particle

$\because \lambda = \dfrac{h}{\sqrt{2mK}}$ and $m_\alpha > m_P >> m_e$

$\therefore$ α-particle has shortest wavelength.

12. Why a signal transmitted from a TV tower cannot be received beyond a certain distance? Write the expression for the optimum separation between the receiving and the transmitting antenna. **2**

Ans. Out of syllabus

SECTION C

13. (*a*) State the underlying principle of a moving coil galvanometer.

(*b*) Give two reasons to explain why a galvanometer cannot as such be used to measure the value of the current in a given circuit.

(*c*) Define the terms: (*i*) voltage sensitivity and (*ii*) current sensitivity of a galvanometer. **3**

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

Working: A coil free to rotate in a uniform magnetic field about a fixed axis experiences a torque when current is passed through it.

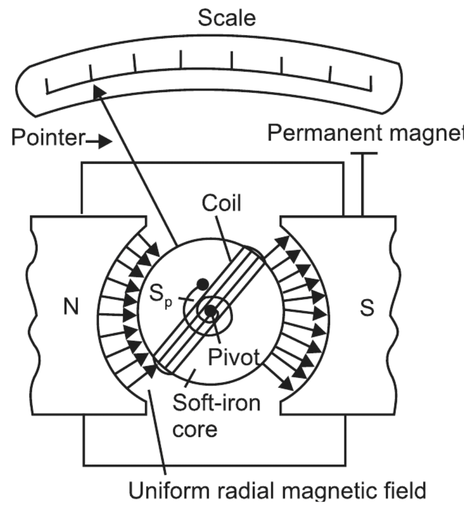
$$\tau = NIAB$$

A spring S_p provides a counter torque $k\phi$ that balances the magnetic torque. For a steady angular deflection ϕ and in equilibrium,

$$k\phi = NIBA$$

where, k is torsional constant of the spring. The deflection ϕ is taken on a scale by a pointer attached to the spring.

$$\phi = \left(\frac{NAB}{k}\right)I$$



A moving coil galvanometer

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

(*ii*) A galvanometer has larger resistance than an ammeter. Therefore, when it is connected in series with the circuit, the current in the circuit decreases.

(*c*) **Sensitivity of a Galvanometer**

(*i*) ***Current Sensitivity*:** It is defined as the deflection produced in a coil per unit current passed through it.

$$I_s = \frac{\phi}{I} = \frac{NBA}{k}$$

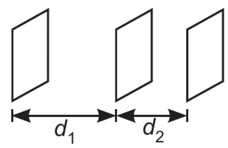
(*ii*) ***Voltage Sensitivity***: It is defined as the coil deflection per unit potential difference applied across its ends.

$$V_s = \frac{\phi}{V} = \frac{\phi}{IR} = \frac{NBA}{kR}$$

15. **(*a*) Draw equipotential surfaces corresponding to the electric field that uniformly increases in magnitude along with the *z*-directions.**

(*b*) Two charges $-q$ and $+q$ are located at points (0, 0, $-a$) and (0, 0, a). What is the electrostatic potential at the points (0, 0, $\pm z$) and (x, y, 0)? **3**

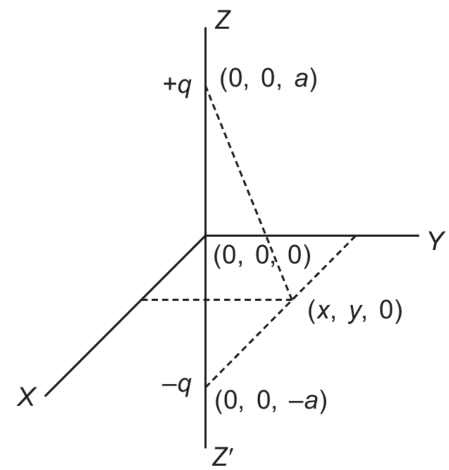
Ans. (*a*)



$d_2 < d_1$ for increasing field and $d_2 = d_1$ for uniform field.

(*b*) The separation between the charges is $l = 2a$.

Electric dipole moment is $p = q(2a)$



(*i*) • **Point (0, 0, +*z*)** lies on the axial line of the electric dipole. In case the point lies near the charge $+q$ potential at the point due to charge $+q$ is

$$V_1 = \frac{1}{4\pi\varepsilon_0}\frac{q}{(z-a)}$$

Potential at the point due to charge $-q$ is

$$V_2 = -\frac{1}{4\pi\varepsilon_0}\frac{q}{(z+a)}$$

Net potential at the point, $V = V_1 + V_2$

$$\therefore \quad V = \frac{q}{4\pi\varepsilon_0}\left[\frac{1}{z-a} - \frac{1}{z+a}\right] = \frac{p}{4\pi\varepsilon_0(z^2-a^2)} \qquad (\because p = q \times 2a)$$

If the point lies near the charge $-q$, then the net potential would be

$$V = -\frac{p}{4\pi\varepsilon_0(z^2-a^2)}$$

At point (0, 0, –*z*)

Net electric potential, $$V = \frac{1}{4\pi\varepsilon_0}\left[\frac{-q}{(z-a)} + \frac{q}{(z+a)}\right]$$

$$= \frac{q}{4\pi\varepsilon_0}\left[\frac{-z-a+z-a}{z^2-a^2}\right] = \frac{-2aq}{4\pi\varepsilon_0(z^2-a^2)} = \frac{-p}{4\pi(z^2-a^2)}$$

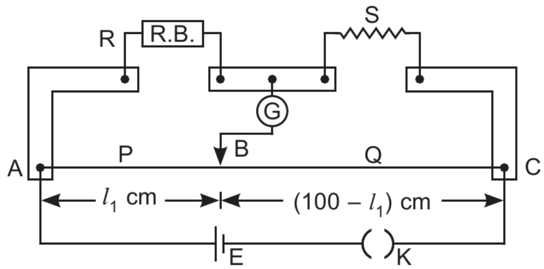
$$\therefore \quad V = \frac{-p}{4\pi(z^2-a^2)} \text{ at point } (0, 0, -z)$$

(*ii*) Both the points being on the equipotential surface, the work done would be zero because work done is independent of the path.

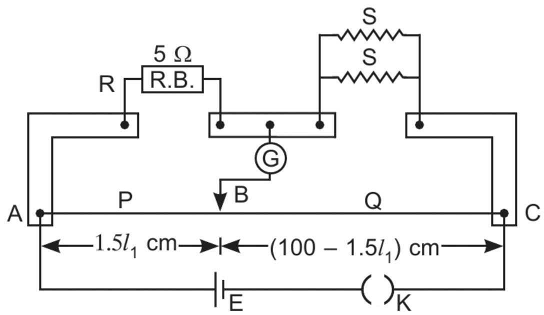
Point (x, y, 0) lies on the equitorial plane of the dipole. This point is equidistant from both the charges (i.e. $S = \sqrt{x^2+y^2+a^2}$). So, the potential at the point is zero.

16. What is end error in a metre bridge? How is it overcome? The resistances in the two arms of the metre bridge are $R = 5\ \Omega$ and S respectively.

When the resistances S is shunted with an equal resistance, the new balance length found to be $1.5l_1$, where l_1 is the initial balancing length. Calculate the value of S. **3**



Ans.



$$\frac{5}{S} = \frac{l_1}{100 - l_1} \quad ...(i)$$

$$\frac{1.5l_1}{100 - 1.5l_1} = \frac{5}{S/2} = \frac{10}{S} \quad ...(ii)$$

$$\frac{1.5l_1}{100 - 1.5l_1} = \frac{2l}{100 - l_1}$$

$$1.5l_1 = 200 - 3l_1$$

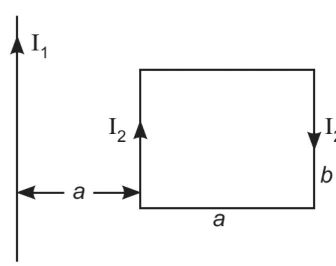
$$l_1 = \frac{500}{15} = \frac{100}{3} \text{ cm}$$

$$S = \frac{5\left(100 - \frac{100}{3}\right)}{\frac{100}{3}} = \frac{5 \times 2}{3 \times \frac{1}{3}} = 10\ \Omega$$

Hence $S = 10\ \Omega$

19. (*a*) Define the term 'self inductance' of a coil. Write its SI unit.

(*b*) A rectangular loop of sides *a* and *b* carrying current I_2 is kept at a distance '*a*' from an infinitely long straight wire carrying current I_1 as shown in the figure. Obtain an expression for the resultant force acting on the loop. **3**



Ans. (*a*) **Self-Inductance**

For a coil, if ϕ is the magnetic flux linked with it due to a current I in it, then

$\phi \propto I$

or $\phi = L I$

It follows from here that $\phi = L$ if $I = 1$ A

In other words, self-inductance L of a coil is numerically equal to the magnetic flux linked with the coil due to a unit current in the coil itself.

Also, since magnitude of induced emf, $|\varepsilon| = \frac{d\phi}{dt}$

Therefore, $|\varepsilon| = L\frac{dI}{dt} \Rightarrow L = \frac{|\varepsilon|}{dI/dt}$

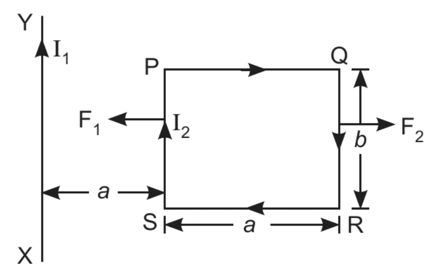
From here, it follows that $L = |\varepsilon|$ if $\frac{dI}{dt} = 1$.

In other words, the self-inductance of a coil is numerically equal to the magnitude of the induced emf sets up in the coil due to a current in it changing at the rate of unity.

***SI Unit of Self-Inductance*:** In the SI system, self-inductance is also measured in henry (H).

1 henry = 1 volt-sec/ampere.

(*b*) Forces experienced by arms *PQ* and *RS* are equal and opposite, therefore, will cancel out.



Force on arm PS

$$F_1 = \frac{f_1}{b} = \frac{\mu_0}{4\pi}\frac{2I_1I_2}{a}$$

Force on arm QR,

$$F_2 = \frac{f_2}{b} = \frac{\mu_0}{4\pi}\frac{2I_1I_2}{2a}$$

$$\therefore \quad F = F_1 - F_2 = \frac{\mu_0}{4\pi}.\frac{2I_1I_2}{a}\left[1 - \frac{1}{2}\right]$$

$$F = \frac{\mu_0}{4\pi}.\frac{2I_1I_2}{2}$$, towards straight conductor *XY*

SET III [Uncommon Questions To Set-I & Set-II]

SECTION A

1. Distinguish between unpolarized and linearly polarized light. **1**

Ans. An unpolarized light is a beam of light in which the plane of oscillation of an optical vector keeps on changing rapidly and randomly. In a linearly polarized light, an optical vector is made to oscillate in a fixed plane.

3. How is the drift velocity in a conductor affected with the rise in temperature? **1**

Ans. Mobility is defined as the positive value of drift velocity per unit electric field applied.

$$\therefore \qquad \mu = \frac{v_d}{E} = \frac{e}{m}\tau$$

Therefore, the mobility (*i*) increases with the decrease in temperature.

4. In sky wave mode of propagation, why is the frequency range of transmitting signals restricted to less than 30 MHz? **1**

Or

On what factors does the range of coverage in ground wave propagation depend?

Ans. Out of syllabus

SECTION B

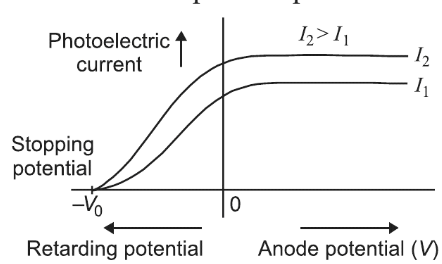
6. (*a*) Define the terms, (*i*) threshold frequency and (*ii*) stopping potential in photoelectric effect.

(*b*) Plot a graph of photocurrent versus anode potential for a radiation of frequency ν and intensities I_1 and $I_2 (I_1 < I_2)$. **2**

Ans. (*a*) (*i*) For every metal surface, there is a minimum frequency of incident radiation, below which the photoelectric emission does not take place no matter what the intensity of incident radiation is and for how long the radiations are allowed to fall on the metal. This frequency is called threshold frequency.

(*ii*) It is the minimum retarding potential which should be applied across a photoelectric tube in order to make photoelectric current zero. The photoelectrons of maximum kinetic energy 2 eV can thus, be completely stopped by a potential difference of –2V (or by a stopping potential of 2V).

(*b*) Stopping potential remains same. It depends upon the frequency of incident radiation.



11. Obtain the expression for the ratio of the de-Broglie wavelengths associated with the electron orbiting in the second and third excited states of hydrogen atom. **2**

Ans. In an orbit of radius r_n, the de Broglie wavelength associated with the revolving electron λ_n, is given by

$$2\pi r_n = n\lambda_n$$

$$\Rightarrow \qquad \lambda_n = \frac{2\pi r_n}{n}$$

here $r_n = n^2 r_1$, $n = 1, 2, 3, \ldots\ldots$ = Principal quantum number.

$$\therefore \qquad \lambda_n = \frac{2\pi n^2 r_1}{n} = (2\pi r_1)n$$

In, second excited state, $n = 3$, $\quad \therefore \; \lambda_3 = (2\pi r_1) \times 3$

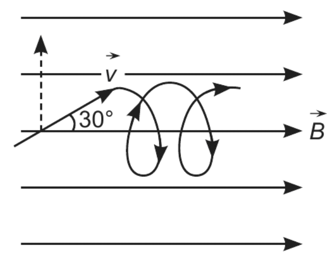
In, third excited state, $n = 4$ $\quad \therefore \; \lambda_4 = (2\pi r_1) \times 4$

$$\therefore \qquad \frac{\lambda_3}{\lambda_4} = \frac{3(2\pi r_1)}{4(2\pi r_1)} = \frac{3}{4}$$

$$\frac{\lambda_3}{\lambda_4} = \frac{3}{4}$$

12. A charged particle *q* is moving in the presence of a magnetic field B which is inclined to an angle 30° with the direction of the motion of the particle. Draw the trajectory followed by the particle in the presence of the field and explain how the particle describes this path. 2

Ans. Resolving $\vec{v}$ (velocity) into two components



(*i*) along magnetic field $\vec{B}$, $v_{\parallel} = v \cos 30°$, and

(*ii*) perpendicular to $\vec{B}$, $v_{\perp} = v \sin 30°$

Magnetic Lorentz Force experienced by charged particle $\vec{F} = q(\vec{v_{\perp}} \times \vec{B})$ is in a perpendicular direction to $\vec{B}$ and $\vec{v}$, therefore charge will follow circular path. But no force will be experienced in a direction of $v_{\parallel}$, and $\vec{B}$, hence, charge in this direction will move uniformly. Therefore, due to combined effect of two kinds of motion, charge will follow helical path.

SECTION C

13. (*a*) Explain briefly how Rutherford scattering of α-particle by a target nucleus can provide information on the size of the nucleus.

(*b*) Show that density of nucleus is independent of its mass number A. 3

Ans. (*a*) In Rutherford's α-particle scattering experiment, the energised α-particles were bombarded on gold foil, K.E. of α-particle is changed into P.E. of α-particle and a gold nucleus, due to nuclear repulsion. During this scattering process, mechanical energy of the system remains constant.

$$(\text{K.E.})_{\text{initial}} = (\text{P.E.})_{\text{final}}$$

$$K_\alpha = \frac{1}{4\pi\varepsilon_0} \cdot \frac{(2e)(ze)}{r_0}$$

or
$$r_0 = \frac{1}{4\pi\varepsilon_0} \cdot \frac{2ze^2}{k_\alpha}$$

$\therefore$ By knowing r_0, the size of the nucleus can be ascertained.

(*b*) If nuclear radius = $R = R_0 A^{1/3}$, where $R_0 = 1.2 \times 10^{-15}$ m,

m = mass of each nucleon = 1.6×10^{-27} kg

Density of a nucleus of mass number A and radius R is given by

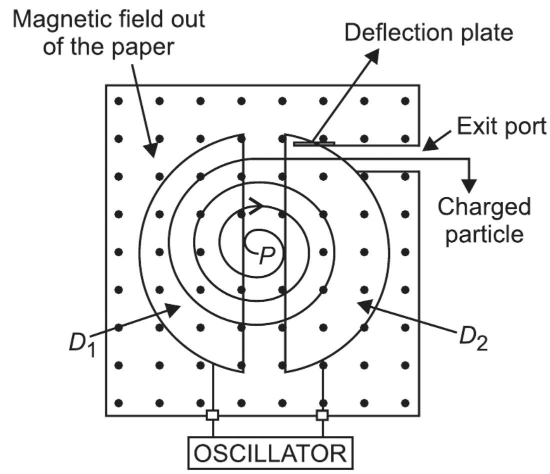
$$d = \frac{M}{V} = \frac{mA}{\frac{4}{3}\pi R_0^3 A} = \frac{3m}{4\pi R_0^3}$$

which is independent of the mass number.

14. State the underlying principle of a cyclotron. Explain its working with the help of a schematic diagram. Obtain the expression for cyclotron frequency. 3

Ans. Principle: The energy of charged particles or ions can be made to increase by using the crossed electric and magnetic fields.

A schematic sketch of the cyclotron is shown in figure.



It consists of two D-shaped hollow metal discs D_1 and D_2 having a very small gap between them. A high frequency alternating potential difference is applied across the dees. These are evacuated and the whole appratus is placed between the poles of an electromagnet. The magnetic field is perpendicular to the dees.

Working: The heavy +ve ions to be accelerated are introduced in the space between the dees. The electric field between the dees accelerates the ions. The ions enter the dee and come out of it with the same speed. Just when they come out of a dee, the polarity of the dees is reversed and the ions are further accelerated. This goes on, till the ions acquire sufficient speed and are taken out with the help of the deflection plate. The time for which the ions remain inside the dee is constant and does not depend upon its speed and radius of the path.

Expression for cyclotron frequency: Time taken by a charged particle to complete half revolution is given by $t = \frac{\pi r}{v}$.

$\therefore$ Time period of a revolution, $T = 2t = \frac{2\pi r}{v}$ ...(*i*)

$\because$ $$\frac{mv^2}{r} = Bqv$$

$\Rightarrow$ $$\frac{r}{v} = \frac{m}{Bq}$$ ...(*ii*)

$\therefore$ Time period of revolution, $T = 2\pi \frac{m}{Bq}$

or Frequency revolution, $\nu = \frac{1}{2\pi} \cdot \frac{Bq}{m}$

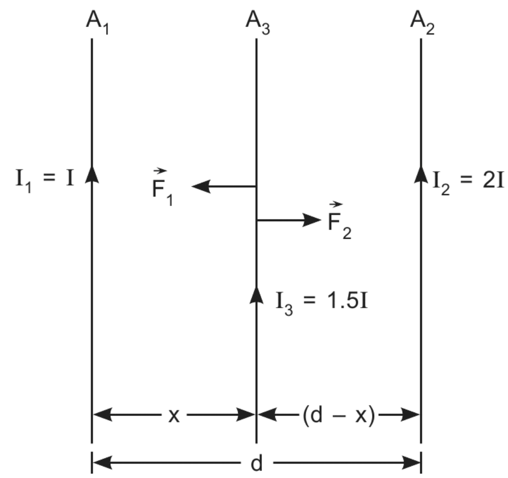
15. Two infinitely long straight wires A_1 and A_2 carrying currents I and 2I flowing in the same directions are kept '*d*' distance apart. Where should a third straight wire A_3 carrying current 1.5 I be placed between A_1 and A_2 so that it experiences no net force due to A_1 and A_2? Does the net force acting on A_3 depend on the current flowing through it? **3**

Ans. Force on wire A_3 due to wire A_1,

$$F_1 = \frac{\mu_0}{4\pi}.\frac{2I(1.5I)}{x} \text{ towards } A_1$$

Force on wire A_3 due to wire A_2

$$F_2 = \frac{\mu_0}{4\pi}.\frac{2(2I)(1.5I)}{(d-x)}, \text{ towards } A_2$$



$\because$ No net force is experienced by wire A_3

$\therefore$ $F_1 = F_2$

$$\frac{\mu_0}{4\pi}.\frac{2I(1.5I)}{x} = \frac{\mu_0}{4\pi}.\frac{2(2I)(1.5I)}{(d-x)}$$

$$\frac{1}{x} = \frac{2}{(d-x)}$$

$$\frac{1}{x} = \frac{2}{d-x}$$

$\Rightarrow$ $d - x = 2x \Rightarrow 3x = d$

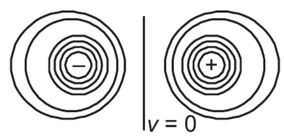
$$x = \frac{d}{3}$$

Net force acting on A_3 does not depend on current flowing through it.

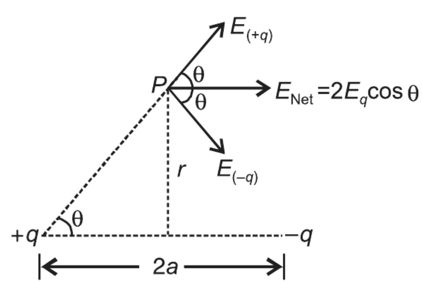
16. (*a*) Draw the equipotential surfaces due to an electric dipole.

(*b*) Derive an expression for the electric field due to a dipole of dipole moment *P* at a point on its perpendicular bisector. **3**

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



(*b*)



Let the dipole be made of two equal and opposite charges $+q$ and $-q$, separated by $2a$. Consider a point P at a distance r from the mid-point. Field at P due to each charge will be of equal magnitude $|\vec{E}_{\pm q}| = \frac{kq}{(r^2+a^2)}$ pointing as shown.

Resolving electric fields due to two charges. We can see that *Y*-axis components get cancelled out.

Net field at *P*, $E = 2E_q \cos\theta$

$$E = \frac{2kq}{(r^2+a^2)} \cdot \frac{a}{(r^2+a^2)^{1/2}}$$

$$= \frac{2aqk}{(r^2+a^2)^{3/2}} = \frac{kp}{(r^2+a^2)^{3/2}} \left[\because \cos\theta = \frac{a}{(r^2+a^2)^{1/2}}\right]$$

(pointing anti-parallel to dipole moment)

If $r >> a$, (i.e.) a^2 can be neglected in comparison to r^2.

$$\therefore E = \frac{kp}{r^3} \quad \text{(anti parallel to } \vec{p}\text{)}$$