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**2017**

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Question: 1 – 30

ii-xxviii

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**Question 1**

Define the term 'threshold frequency' in relation to photoelectric effect.

[1]

**Answer:**

Threshold frequency is defined as the minimum frequency of incident radiation which can cause Photoelectric emission. It is different for different metal

**Question 2**

The peak value of e.m.f in a.c. is  $E_0$ . Write its (i) rms and (ii) average value over a complete cycle.

[1]

**Answer:**

$E_0$  = peak value of emf

1. rms value  $[E_{rms}] = \frac{E_0}{\sqrt{2}}$

2. average value  $[E_{av}] = \text{zero}$

**Question 3**

Two insulated charged copper spheres A and B of identical size have charges  $q_A$  and  $q_B$  respectively. A third sphere C of the same size but uncharged is brought in contact with the first and then in contact with the second and finally removed from both. What are the new charges on A and B?

[1]

**Answer:**

New charge on A is  $\frac{q_A}{2}$  and new charge on B is  $\frac{q_A + 2q_B}{2}$

**Question 4**

A narrow beam of protons and deuterons, each having the same momentum, enters a region of uniform magnetic field directed perpendicular to their direction of momentum. What would be the ratio of the radii of the circular paths described by them?

[1]

**Answer:**

Charge on deuteron ( $q_d$ ) = charge on proton ( $q_p$ )

$q_d = q_p$

Radius of circular path ( $r$ ) =  $\frac{p}{B_q}$  ( $\because qvB = \frac{mv^2}{r}$ )

$r \propto \frac{1}{q}$  [for constant momentum ( $P$ )]

so,  $\frac{r_p}{r_d} = \frac{q_d}{q_p} = \frac{q_p}{q_d} = 1$

Hence,  $r_p : r_d = 1:1$

**Question 5**

What is the function of a 'Repeater' in a communication system?

[1]

**Answer:**

A repeater which is a combination of a transmitter, an amplifier and a receiver which picks up signal from the transmitter, amplifies and retransmits it to the receiver.

**Question 6**

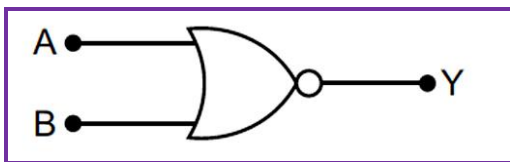
Draw the logic circuit of a NAND gate and write its truth table.

[1]



**Answer:**

Logic circuit of NAND gate:



Input		Output
A	B	Y
0	0	1
0	1	1
1	0	1
1	1	0

**Question 7**

How is the mean life of a radioactive sample related to its half-life?

[1]

**Answer:**

Mean life ( $\tau$ ) and half-life ( $T_{\frac{1}{2}}$ ) are related as:

$$\tau = \frac{T_{\frac{1}{2}}}{0.6931}$$

**Question 8**

Write two uses of microwaves.

[1]

**Answer:**

Uses of microwaves:

- In long distance communications.
- In radar

**Question 9**

Calculate the amount of work done in rotating a dipole, of dipole moment  $3 \times 10^{-8}$  cm. from its position of stable equilibrium to the position of unstable equilibrium, in a electric field of intensity  $10^4$  N/C

[2]

**Answer:**

$$P = 3 \times 10^{-8} \text{ cm} ; E = 10^4 \frac{\text{N}}{\text{C}}$$

At stable equilibrium ( $\theta_1$ ) =  $0^\circ$

At unstable equilibrium ( $\theta_2$ ) =  $180^\circ$

Work done in rotating dipole is given by:

$$W = PE (\cos \theta_1 - \cos \theta_2)$$

$$= (3 \times 10^{-8}) (10^4) [\cos 0^\circ - \cos 180^\circ]$$

$$= 3 \times 10^{-4} [1 - (-1)]$$

$$W = 6 \times 10^{-4} \text{ J}$$

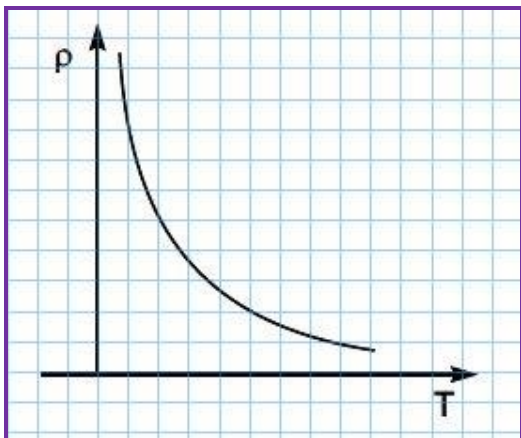


### Question 10

Plot a graph showing temperature dependence of resistivity for a typical semiconductor. How is this behavior explained? [2]

#### Answer:

Variation of resistivity ( $\rho$ ) with temperature (T) is shown below:



**Explanation:** In semiconductor the number density of free electrons ( $n$ ) increases with increase in temperature (T) and consequently the relaxation period decreases. But the effect of increase in  $n$  has higher impact than decrease of  $\tau$ . So, resistivity decreases with increase in temperature.

### Question 11

When four hydrogen nuclei combine to form a helium nucleus, estimate the amount of energy in MeV released in this process of fusion. (Neglect the masses of electrons and neutrinos) [2]

Given:

i. Mass of  ${}^1_1\text{H}$

ii. Mass of helium nucleus = 4.002603 u,  $1\text{u} = 931\text{ MeV} \frac{\text{V}}{\text{c}^2}$

#### Answer:

Energy released =  $\Delta m \times 931\text{ MeV}$

$\Delta m = 4m({}^1_1\text{H}) - m({}^4_2\text{He})$

Energy released (Q) =  $[4.m({}^1_1\text{H}) - m({}^4_2\text{He})] \times 931\text{ MeV}$

$= [4 \times 1.007825 - 4.002603] \times 931\text{ MeV} = 26.72\text{ MeV}.$

### Question 12

For an amplitude modulated wave, the maximum amplitude is found to be 10V while the minimum amplitude is 2V. Calculate the modulation index. Why modulation index is generally kept less than one? [2]

#### Answer:

$A_{\text{max}} = 10\text{V}$

$A_{\text{min}} = 2\text{ V}$

Modulation index =  $\frac{A_{\text{max}} - A_{\text{min}}}{A_{\text{max}} + A_{\text{min}}}$

$= \frac{10 - 2}{10 + 2}$



$$= \frac{8}{12}$$

$$= 0.67$$

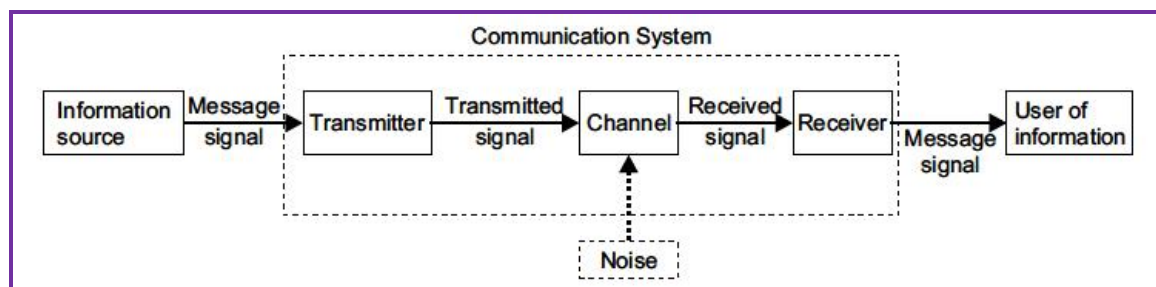
Generally, the modulation index is kept less than one to avoid distortion.

### Question 13

Draw a block diagram showing the important components in a communication system. What is the function of a transducer? [2]

**Answer:**

Block diagram of communication system:



Function of a transducer is to convert one form of energy into another form.

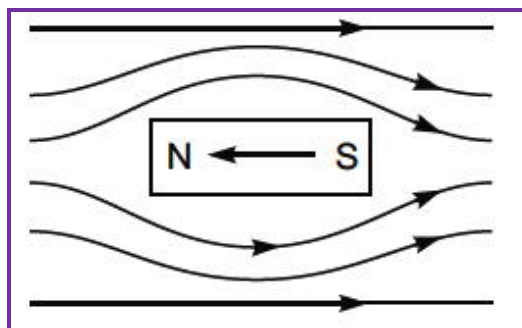
### Question 14

Explain the following: [2]

- Why do magnetic lines of force form continuous closed loops?
- Why are the field lines repelled (expelled) when a diamagnetic material is placed in an external uniform magnetic field?

**Answer:**

- Magnetic lines of force form continuous closed loops because a magnet is always a dipole and as a result, the net magnetic flux of a magnet is always zero.
- When a diamagnetic substance is placed in an external magnetic field, a feeble magnetism is induced in opposite direction. So, magnetic lines of force are repelled.



OR

- Name the three elements of the Earth's magnetic field.
- Where on the surface of the Earth is the vertical component of the Earth's magnetic field zero?



**Answer:**

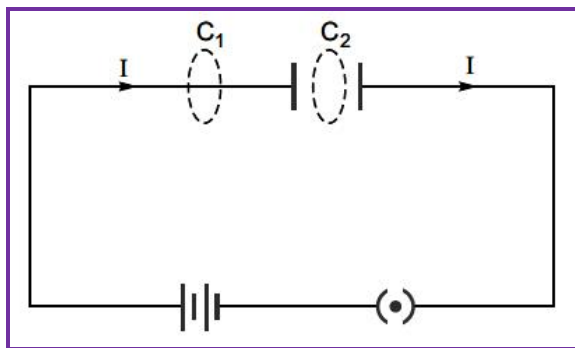
- i. Elements of earth's magnetic field:
  - a. Angle of declination ( $\theta$ )
  - b. Angle of dip ( $\delta$ )
  - c. Horizontal component of earth's magnetic field ( $B_H$ )
- ii. At equator.

**Question 15**

Show how the equation for Ampere's circuital law, viz.  $\oint \vec{B} \cdot d\vec{l} = \mu_0 I$  is modified in the presence of displacement current. [2]

**Answer:**

**Displacement current and generalised Ampere's Circuital Law:** Consider a parallel plate capacitor, being charged by a battery. A time varying current is flowing through the capacitor. If we consider only the conduction current  $I$ , then we apply Ampere's Circuital Law to two closed loops  $C_1$  and  $C_2$ , then we get



$$\oint_{C_1} \vec{B} \cdot d\vec{l} = \mu_0 I \dots\dots\dots(i)$$

$$\text{and } \oint_{C_2} \vec{B} \cdot d\vec{l} = 0 \dots\dots\dots(ii)$$

Since there cannot be any conduction current in region between the capacitor plates. As  $C_1$  and  $C_2$  are very close, we must expect

$$\oint_{C_1} \vec{B} \cdot d\vec{l} = \oint_{C_2} \vec{B} \cdot d\vec{l} \dots\dots\dots(iii)$$

But this condition is violated by equations (i) and (ii). Hence Ampere's Circuital Law seems to be inconsistent in this case. Therefore, Maxwell postulated the existence of displacement current which is produced by time varying electric field. If  $\sigma(t)$  is the surface charge density on capacitor plates and  $q(t)$  is the charge, then time varying electric field  $E(t) =$

$$\frac{\sigma(t)}{\epsilon_0} = \frac{q(t)}{A\epsilon_0}, \text{ where } A \text{ is area of each plate.}$$

$$\frac{dE}{dt} = \frac{1}{A\epsilon_0} \frac{dq(t)}{dt}$$

$$\text{or, } \frac{dq(t)}{dt} = \epsilon_0 A \frac{dE}{dt}$$

This is expression for displacement current ( $I_d$ ).  
Applying Kirchhoff's first law at power P, we get  $I = I_d$   
Hence, equation (i) and (ii) take the forms



$$\oint_{C_1} \vec{B} \cdot d\vec{l} = \mu_0 I \text{ and } \oint_{C_1} \vec{B} \cdot d\vec{l} = \mu_0 I_d = \mu_0 I$$

The total current is the sum of the conduction current and displacement current. Thus, modified form of Ampere's circuital law is

$$\oint \vec{B} \cdot d\vec{l} = \mu_0 (I + I_d) = \mu_0 (I + \epsilon_0 A \frac{dE}{dt})$$

But  $EA = \text{Electric flux } \phi_E$

$$\therefore \oint \vec{B} \cdot d\vec{l} = \mu_0 (I + \mu_0 \epsilon_0 \frac{d\phi_E}{dt})$$

### Question 16

Current in a circuit falls steadily from 5.0 A to 0.0 A in 100 ms. If an average e.m.f of 200V is induced, calculate the self-inductance of the circuit. [2]

#### Answer:

Change in current ( $\Delta I$ ) = (0.0 - 5.0) A = -5.0A

Time taken ( $\Delta t$ ) =  $100 \times 10^{-3}$  S

Induced emf ( $e$ ) = 200 V

Induced emf ( $e$ ) is given by

$$e = \frac{\Delta \phi}{\Delta t}$$

$$= - \frac{\Delta(LI)}{\Delta t} \quad (\phi = LI)$$

$$e = -L \frac{\Delta I}{\Delta t}$$

$$\text{or } L = -e \cdot \frac{\Delta t}{\Delta I}$$

$$= - \frac{(200) \cdot (100 \times 10^{-3})}{(-5.0)}$$

$$L = 4.0 \text{ H}$$

### Question 17

- a. You are required to select a carbon resistor of resistance  $47 \text{ k}\Omega \pm 10\%$  from a large collection. What should be the sequence of color bands used to code it? [2]

#### Answer:

Resistance =  $47 \text{ k}\Omega \pm 10\% = 47 \times 10^3 \Omega \pm 10\%$

Sequence of color should be:

Yellow, Violet, Orange and Silver

- b. Write two characteristics of manganin which make it suitable for making standard resistance.

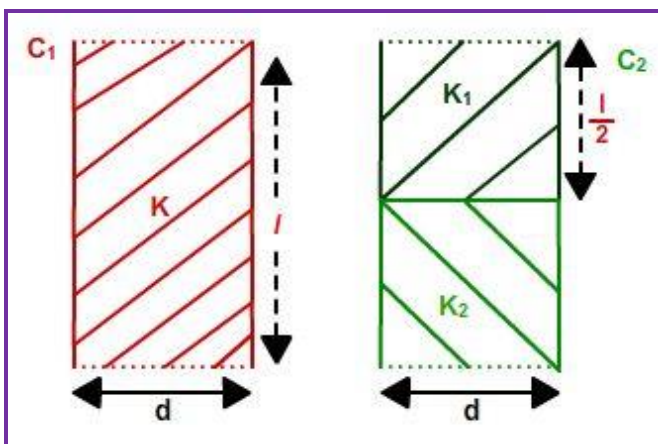
#### Answer:

- (i) Very low temperature coefficient of resistance.
- (ii) High resistivity

### Question 18

Two identical parallel plate (air) capacitors  $C_1$  and  $C_2$  have capacitances  $C$  each. The space between their plates is now filled with dielectrics as shown. If the two capacitors still have equal capacitance, obtain the relation between dielectric constants  $K_1$  and  $K_2$ . [2]





**Answer:**

Let  $A \rightarrow$  area of each plate.

Let initially  $C_1 = C = \frac{\epsilon_0 A}{d} = C_2$

After inserting respective dielectric slabs:

$C'_1 = KC$

And  $C'_2 = K_1 \frac{\epsilon_0 (\frac{A}{2})}{d} + \frac{K_2 \epsilon_0 (\frac{A}{2})}{d} \dots\dots\dots(i)$

$$= \frac{\epsilon_0 A}{2d} (K_1 + K_2)$$

$$C'_2 = \frac{C}{2} (K_1 + K_2) \dots\dots\dots(ii)$$

From (i) and (ii)

$$C'_1 = C'_2$$

$$KC = \frac{C}{2} (K_1 + K_2)$$

$$K = \frac{1}{2} (K_1 + K_2)$$

**Question 19**

State the principle of the device that can build up high voltages of the order of a few million volts. Draw its labelled diagram. A stage reaches in this device when the potential at the outer sphere cannot be increased further by piling up more charge on it. [3]

**Answer:**

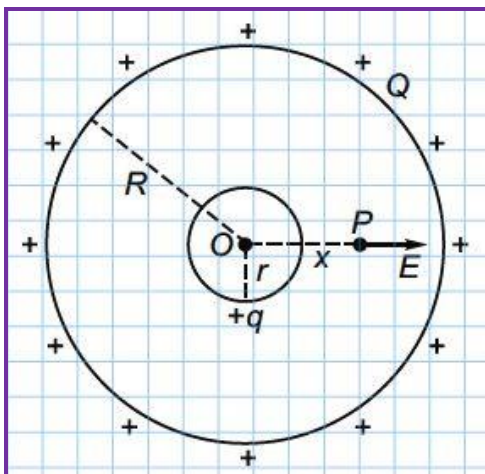
This device is Van de Graaff generator. **Principle:** Suppose we have a large spherical conducting shell of radius  $R$ , carrying charge  $Q$ .

The charge spreads uniformly over whole surface of the shell. Now suppose a small conducting sphere of radius ' $r$ ' is introduced inside the spherical shell and placed at its center, so that both the sphere and shell have same center  $O$ .

The electric field in the region inside the small sphere and large shell is due to charge  $+q$  only, so electric field strength at a distance  $x$  from the center  $O$  is







$$E = \frac{1}{4\pi\epsilon_0} \frac{q}{x^2}, \text{ directed radially outward}$$

The potential difference between the sphere and the shell

$$V(r) - U(R) = - \int_R^r \vec{E} \cdot d\vec{x}$$

$$= - \int_R^r \frac{1}{4\pi\epsilon_0} \frac{q}{x^2} dx$$

$$= - \frac{1}{4\pi\epsilon_0} \left[ \frac{x^{-1}}{-1} \right]_R^r = \frac{q}{4\pi\epsilon_0} \left( \frac{1}{r} - \frac{1}{R} \right)$$

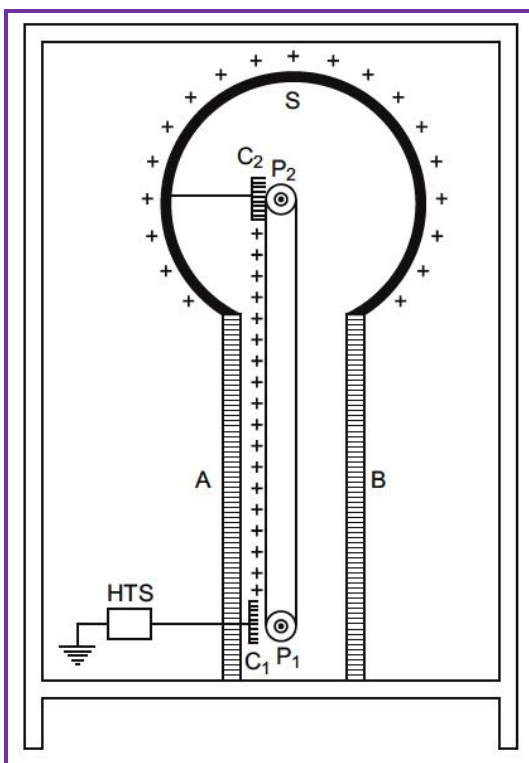
This is independent of charge Q on the large spherical shell. As  $r < R$ ;  $V(r) - U(R)$  is positive. As charge flows from higher to lower potentials therefore, if we connect the small sphere and large shell by a conducting wire, the charge flows from sphere to outer shell whatsoever the charge on outer shell may be.

This forms the principle of Van de Graaff generator. The maximum charge that may be given to outer shell which may cause discharge in air.

Working: When comb  $C_1$  is given very high potential, then it produces ions in its vicinity, due to action of sharp points. The positive ions, so produced, get sprayed on the belt due to the repulsion between positive ions and comb  $C_1$ . These positive ions are carried upward by the moving belt. The pointed end of  $C_2$  just touches the belt.

The comb  $C_2$  collects positive charge from the belt which immediately moves to the outer surface of sphere S. As the belt goes on revolving, it continues to take (+) charge upward, which is collected by comb  $C_2$  and transferred to outer surface of sphere S. Thus the outer surface of metallic sphere S gains positive charge continuously and its potential rises to a very high value.





When the potential of a metallic sphere gains very high value, the dielectric strength of surrounding air breaks down and its charge begins to leak, to the surrounding air. The maximum potential is reached when the rate of leakage of charge becomes equal to the rate of charge transferred to the sphere.

To prevent leakage of charge from the sphere, the generator is completely enclosed in an earthed connected steel tank which is filled with air under high pressure. Van de Graaff generator is used to accelerate stream of charged particles to very high velocities. Such a generator is installed at IIT Kanpur which accelerates charged particles upto 2 MeV energy.

### Question 20

Light wavelength  $2000 \text{ \AA}$  falls on a metal surface of work function  $4.2 \text{ eV}$ . What is the kinetic energy (in eV) of the fastest electrons emitted from the surface?

**Answer:**

$$\lambda = 2000 \text{ \AA} = 2000 \times 10^{-10} \text{ m}$$

$$W_0 = 4.2 \text{ eV}$$

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

$$\frac{hc}{\lambda} = W_0 + \text{KE}$$

$$\text{or, K.E.} = \frac{hc}{\lambda} - W_0$$

$$= \frac{(6.63 \times 10^{-34}) \times (3 \times 10^8)}{(2000 \times 10^{-10})} \times \frac{1}{1.6 \times 10^{-19}} \text{ eV} - 4.2 \text{ eV}$$

$$= (6.2 - 4.2) \text{ eV}$$

$$= 2.0 \text{ eV}$$



- a. What will be the change in the energy of the emitted electrons if the intensity of light with same wavelength is doubled?

**Answer:**

The energy of the emitted electrons does not depend upon intensity of incident light, hence the energy remains unchanged.

- b. If the same light falls on another surface of work function 6.5 eV, what will be the energy of emitted electrons? [3]

**Answer:**

For this surface, electrons will not be emitted as the energy of incident light (6.2 eV) is less than the work function (6.5 eV) of the surface.

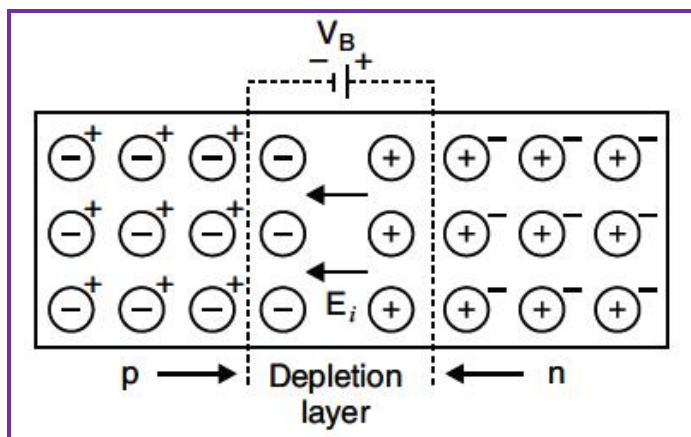
**Question 21**

Name the important processes that occur during the formation of a p-n junction. Explain briefly, with the help of a suitable diagram, how a p-n junction is formed. Define the term 'barrier potential' [3]

**Answer:**

At the junction there is diffusion of charge carriers due to thermal agitation; so that some of electrons of n-region diffuse to p-region while some of holes of p-region diffuse into n-region. Some charge carriers combine with opposite charges to neutralise each other.

Thus near the junction there is an excess of positively charged ions in n-region and an excess of negatively charged ions in p-region. This sets up a potential difference called potential barrier and hence an internal electric field  $E_i$  across the junctions.



**Barrier potential:** During the formation of a p-n junction the electrons diffuse from n region to p-region and holes diffuse from p-region to n-region. This forms recombination of charge carriers. In this process immobile positive ions are collected at a junction toward n region and negative ions at a junction toward p-region.

This causes a p.d. across the unbiased junction. This is called potential barrier or barrier potential.

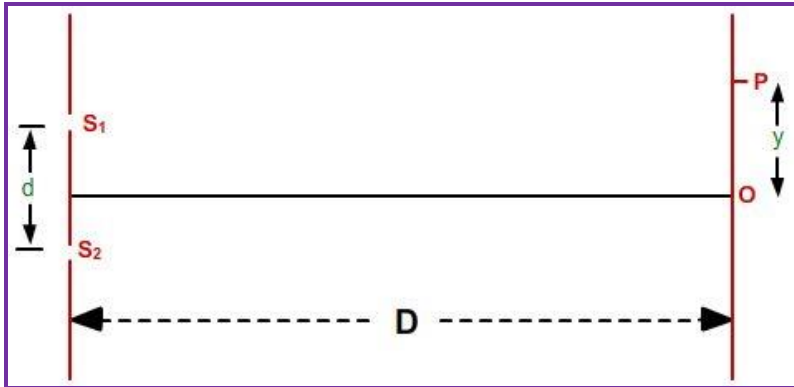


**Question 22**

The intensity at the central maxima (O) in a Young's double slit experiment is  $I_0$ . If the distance OP equals one-third of the fringe width of the pattern, show that the intensity at point P would be

$$\frac{I_0}{4}$$

[3]



**Answer:**

$$\text{Fringe width } (\beta) = \frac{\lambda D}{d}$$

$$y = \frac{\beta}{3} = \frac{\lambda D}{3d}$$

$$\text{Path diff } (\Delta p) = \frac{yd}{D} \Rightarrow \Delta p$$

$$= \frac{\lambda D}{3d} \cdot \frac{d}{D}$$

$$= \frac{\lambda}{3}$$

$$\Delta \phi = \frac{2\pi}{\lambda} \cdot \Delta p$$

$$= \frac{2\pi}{\lambda} \cdot \frac{\lambda}{3}$$

$$= \frac{2\pi}{3}$$

$$\text{Intensity at point P} = I_0$$

$$\cos^2 \Delta \phi = I_0 \left[ \cos \frac{2\pi}{3} \right]^2$$

$$= I_0 \left( \frac{1}{2} \right)^2$$

$$= \frac{I_0}{4}$$

OR

In the experiment on diffraction due to a single slit, show that

[3]

a. The intensity of diffraction fringes decreases as the order (n) increases.



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**Answer:**

In diffraction due to a single slit the path difference is given by:

$\Delta x = \alpha \sin \theta$  where,  $\alpha$  is the width of the slit

For maxima:  $\Delta x = (2x + 1) \frac{\lambda}{2}$

$$\Delta x = a \sin \theta = (2x + 1) \frac{\lambda}{2}$$

For  $n = 2$ ,  $\Delta x = \frac{3\lambda}{2}$

Let us divide the slit into three equal parts. If we take first two parts of slit, the path difference between rays diffracted from the extreme ends of first two parts

$$\begin{aligned} & \frac{2}{3} \alpha \sin \theta \\ &= \frac{2}{3} \alpha \times \frac{3\lambda}{2\alpha} \\ &= \lambda \end{aligned}$$

Then the first two parts will have a path difference of  $\frac{\lambda}{2}$  and cancel the effect of each other.

The remaining third part will contribute to the intensity at a point between two minima. This is called first secondary maxima. In similar manner we can show that the intensity of the other secondary maxima will go on decreasing.

b. Angular width of the central maximum is twice that of the first order secondary maximum.

**Answer:**

The general maxima has between first minima on either side of the central maxima. We know for first minima.

$$\alpha \sin \theta = \lambda \Rightarrow \alpha \theta = \lambda$$

$\therefore$  for small angle  $\sin \theta \approx \theta$

$$\tan \theta = \frac{y_1}{D}$$

$$\Rightarrow \theta = \frac{y_1}{D}$$

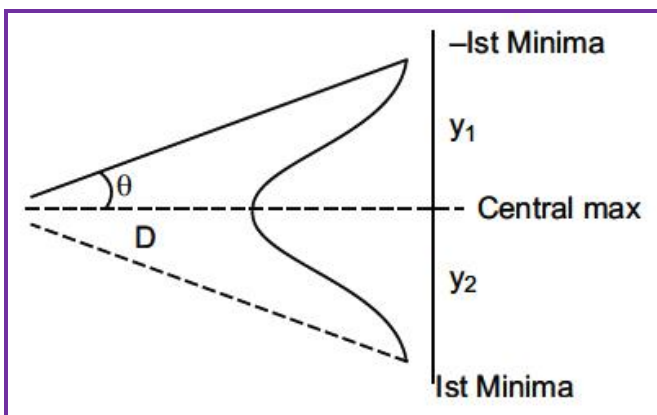
$$\Rightarrow \frac{\lambda}{\alpha} D = y_1 = y_2$$

Hence, whole width on secondary maxima on one side is  $\frac{\lambda D}{d}$ .

$$\text{The angular width of the central maxima} = \frac{2\lambda D}{\alpha}$$

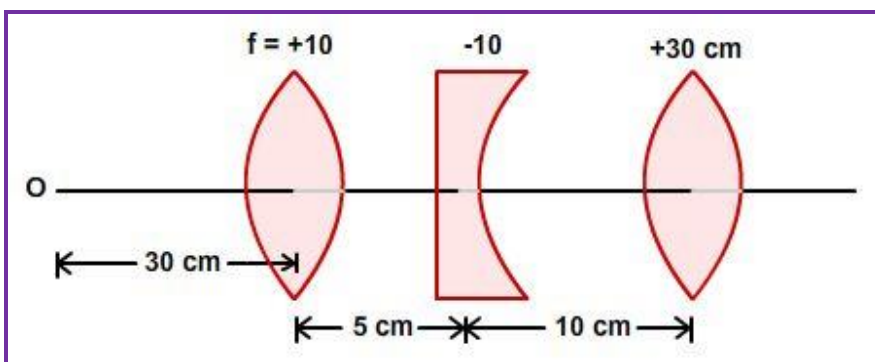
So, angular width of the central maxima is twice that of the first order secondary maximum.





### Question 23

Find the position of the image formed of the object 'O' by the lens combination given in the figure.



[3]

### Answer:

For first lens,  $u_1 = -30$  cm,  $f_1 = +10$  cm

$$\therefore \text{From lens formula } \frac{1}{f_1} = \frac{1}{v_1} - \frac{1}{u_1}$$

$$\Rightarrow \frac{1}{v_1} = \frac{1}{f_1} + \frac{1}{u_1}$$

$$= \frac{1}{10} - \frac{1}{30} = \frac{3-1}{30} \Rightarrow v_1$$

$$= 15 \text{ cm}$$

This means that the image formed by first lens is at a distance of 15 cm to the right of first lens.

This image serves as a virtual object for second lens.

For second lens,  $f_2 = -10$  cm,  $u_2 = 15 - 5 = +10$  cm

$$\therefore \frac{1}{v_2} = \frac{1}{f_2} + \frac{1}{u_2}$$

$$= \frac{1}{10} + \frac{1}{10} \Rightarrow v_2 = \infty$$

This means that the real image is formed by second lens at infinite distance. This acts as an object for third lens.

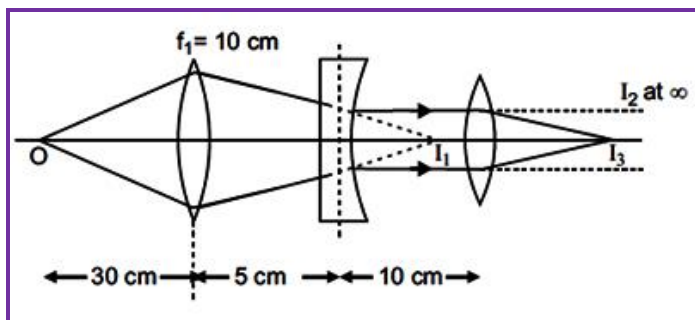
For third lens,  $f_3 = +30$  cm,  $u_3 = \infty$

$$\text{From lens formula } \frac{1}{v_2} = \frac{1}{f_3} + \frac{1}{u_3} = \frac{1}{30} + \frac{1}{\infty}$$



$$\Rightarrow v_3 = 30 \text{ cm}$$

i.e., final image is formed at a distance 30 cm to the right of third lens. The ray diagram of formation of image is shown in figure.

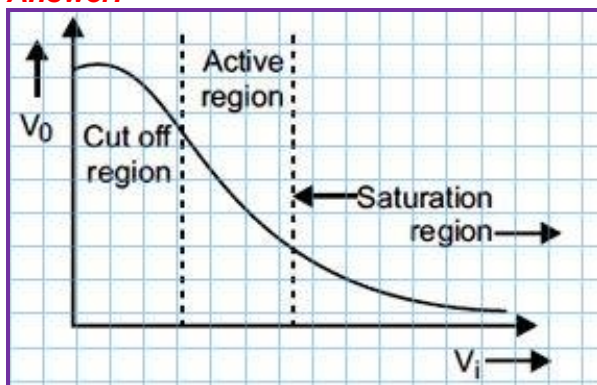


#### Question 24

Draw transfer characteristics of a common emitter n-p-n transistor. Point out the region in which the transistor operates as an amplifier. Define the following terms used in transistor amplifiers.[3]

- Input resistance
- Output resistance
- Current amplifier factor

**Answer:**



In active region the transistor is used as an amplifier.

- Input Resistance:** It is the ratio of change in emitter base voltage ( $\Delta V_{EB}$ ) to the corresponding change in emitter current ( $\Delta I_E$ ) at constant collector-base voltage ( $V_{CB}$ ) i.e.

$$\text{Input resistance } r_i = \left( \frac{\Delta V_{EB}}{\Delta I_E} \right)_{V_{CB} = \text{constant}}$$

Physically input resistance is the hindrance offered to the signal current. The input resistance is very small, of the order of a few ohms, because a small change in  $V_{EB}$  causes a large change in  $I_E$ .

- Output Resistance:** It is the ratio of change in collector-base voltage to the corresponding change in collector current at constant emitter current  $I_E$ .

$$\text{i.e., } r_o = \left( \frac{\Delta V_{CB}}{\Delta I_C} \right)_{V_{EB} = \text{constant}}$$

The output resistance is very high, of the order of several-tens kilo ohm because a large



change in collector-base voltage causes a very small change in collector current.

### 3. Current amplification factors of a transistor ( $\alpha$ and $\beta$ ):

The current gain  $\alpha$  is defined as the ratio of change in collector current to the change in emitter current for constant value of collector voltage in common base configuration, i.e.,

$$\alpha = \left( \frac{\Delta I_C}{\Delta I_E} \right)_{V_C = \text{constant}} \dots\dots\dots (i)$$

Practical value of  $\alpha$  ranges from 0.9 to 0.99 for junction transistor. The current gain  $\beta$  is defined as the ratio of change in collector current to the change in base current for constant value of collector voltage in common emitter configuration i. e.,

$$\beta = \left( \frac{\Delta I_C}{\Delta I_B} \right)_{V_C = \text{constant}} \dots\dots\dots (ii)$$

The value of  $\beta$  ranges from 20 to 200.

The current gains  $\alpha$  and  $\beta$  are related as  $\alpha = \frac{\beta}{1 + \beta}$

$$\text{or. } \beta = \frac{\alpha}{1 - \alpha} \dots\dots\dots (iii)$$

### Question 25

- a. Light passes through two polaroids  $P_1$  and  $P_2$  with its pass axis of  $P_2$  making an angle  $\theta$  with the pass axis of  $P_1$ . For what value of  $\theta$  is the intensity of emergent light zero?

**Answer:**

At  $\theta = 90^\circ$ , the intensity of emergent light is zero.

- b. A third polaroid is placed between  $P_1$  and  $P_2$  with its pass axis making an angle  $\beta$  with the pass axis of  $P_1$ . Find a value of  $\beta$  for which the intensity of light emerging from  $P_2$  is  $\frac{I_0}{8}$ , where  $I_0$  is the intensity of light on the polaroid  $P_1$ . [3]

**Answer:**

Intensity of light coming out polariser  $P_1 = \frac{I_0}{2}$

Intensity of light coming out from  $P_2 = \frac{I_0}{2} \cos^2 \beta \cos^2 (90 - \beta)$

$$= \frac{I_0}{2} \cos^2 \beta \sin^2 \beta$$

$$= \frac{I_0}{2} \left[ \frac{(2 \cos^2 \beta \sin^2 \beta)^2}{2} \right]$$

$$I = \frac{I_0}{8} (\sin 2\beta)^2$$

But it is given that intensity transmitted from  $P_2$  is

$$I = \frac{I_0}{8}$$

$$\text{So, } \frac{I_0}{8} = \frac{I_0}{8} (\sin 2\beta)^2$$





$$\text{or, } (\sin 2\beta)^2 = 1$$

$$\sin 2\beta = \sin \frac{\pi}{2} \Rightarrow \beta = \frac{\pi}{4}$$

### Question 26

Using the postulates of Bohr's model of hydrogen atom, obtain an expression from the higher energy state with quantum number  $n_i$  to the lower energy state with quantum number  $n_f$  ( $n_f < n_i$ )

[3]

### Answer:

Suppose  $m$  be the mass of an electron and  $v$  be its speed in  $n$ th orbit of radius  $r$ . The centripetal force for revolution is produced by electrostatic attraction between electron and nucleus.

$$\frac{mv^2}{r} = \frac{1}{4\pi\epsilon_0} \frac{(Ze)(e)}{r^2} \dots\dots\dots (i)$$

$$\text{or, } mv^2 = \frac{1}{4\pi\epsilon_0} \frac{Ze^2}{r}$$

$$\text{so, Kinetic energy [K]} = \frac{1}{2}mv^2$$

$$K = \frac{1}{4\pi\epsilon_0} \frac{Ze^2}{2r}$$

$$\text{Potential energy} = \frac{1}{4\pi\epsilon_0} \frac{(Ze)(-e)}{r}$$

$$= -\frac{1}{4\pi\epsilon_0} \frac{Ze^2}{r}$$

Total energy,  $E = KE + PE$

$$= -\frac{1}{4\pi\epsilon_0} \frac{Ze^2}{r} + \left( -\frac{1}{4\pi\epsilon_0} \frac{Ze^2}{r} \right)$$

$$E = -\frac{1}{4\pi\epsilon_0} \frac{Ze^2}{2r}$$

For  $n$ th orbit,  $E$  can be written as  $E_n$

$$\text{So, } E_n = -\frac{1}{4\pi\epsilon_0} \frac{Ze^2}{2r_n}$$

Again from Bohr's postulate for quantization of angular momentum

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

$$v = \frac{nh}{2\pi mr}$$

Substituting this value of  $v$  in equation (i), we get

$$\frac{m}{r} \left[ \frac{nh}{2\pi mr} \right]^2$$

$$= \frac{1}{4\pi\epsilon_0} \frac{Ze^2}{r^2}$$



$$\text{or, } r = \frac{\epsilon_0 h^2 n^2}{\pi m Z e^2}$$

$$\text{or, } r_n = \frac{\epsilon_0 h^2 n^2}{\pi m Z e^2}$$

Substituting value of  $r_n$  in equation (ii), we get

$$E_n = -\frac{1}{4\pi\epsilon_0} \frac{Z e^2}{2 \left( \frac{\epsilon_0 h^2 n^2}{\pi m Z e^2} \right)}$$

$$= -\frac{m Z^2 e^2}{8 \epsilon_0 h^2 n^2}$$

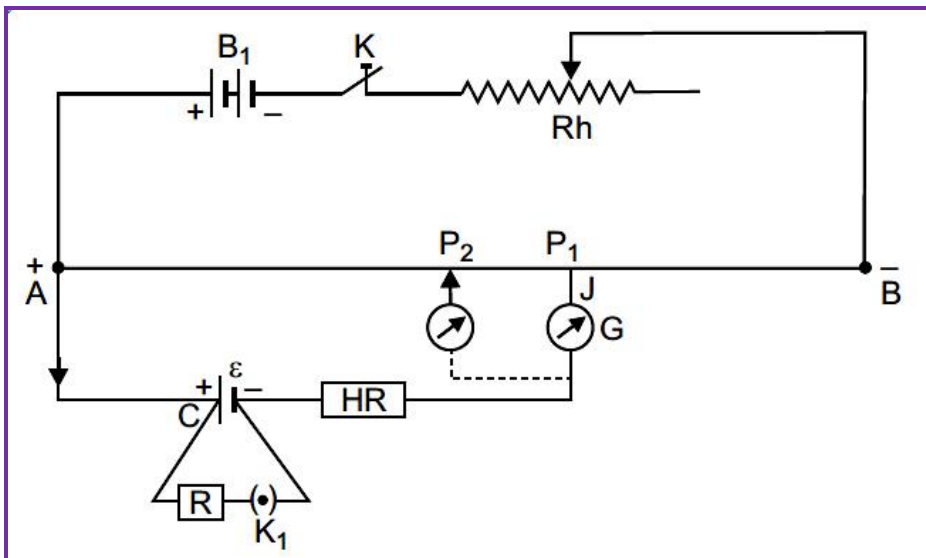
$$\text{or, } E_n = -\frac{Z^2 R h c}{n^2}$$

$$\text{where } R = \frac{m e^4}{8 \epsilon_0^2 h^3 c}$$

$R$  is called Rydberg constant.

For hydrogen atom  $Z=1$ ,

$$E_n = \frac{-R h c}{n^2}$$



If  $n_i$  and  $n_f$  are the quantum numbers of initial and final states and  $E_i$  &  $E_f$  are energies of electron in H-atom in initial and final state, we have

$$E_i = \frac{-R h c}{n_i^2} \text{ and } E_f = \frac{-R h c}{n_f^2}$$

If  $\nu$  is the frequency of emitted radiation. We get

$$\nu = \frac{E_i - E_f}{h}$$

$$\nu = \frac{-R c}{n_i^2} - \left( \frac{-R c}{n_f^2} \right)$$



$$v = Rc \left[ \frac{1}{n_f^2} - \frac{-Rc}{n_i^2} \right]$$

### Question 27

State the underlying principle of a potentiometer. Describe briefly, given the necessary circuit diagram, how a potentiometer is used to measure the internal resistance of a given cell. [3]

#### Answer:

**Principle of potentiometer:** If constant current is flowing through a wire of uniform area of cross-section at constant temperature, the potential drop across any portion of wire is directly proportional to the length of that portion

$$V \propto l$$

#### Determination of internal resistance of potentiometer.

- Initially key K is closed and a potential difference is applied across the wire AB. Now rheostat (Rh) is so adjusted that on touching the jockey J at ends A and B of potentiometer wire, the deflection in the galvanometer is on both sides. Suppose that in this position the potential gradient on the wire is k.
- Now key  $K_1$  is kept open and the position of null deflection is obtained by sliding and pressing the jockey on the wire. Let this position be  $P_1$  and  $AP_1 = l_1$ . In this situation the cell is in open circuit, therefore the terminal potential difference will be equal to the emf of cell, i.e.,  
emf  $\varepsilon = kl_1$  ... (i)
- Now a suitable resistance R is taken in the resistance box and key  $K_1$  is closed. Again, the position of null point is obtained on the wire by using jockey J. Let this position on wire be  $P_2$  and  $AP_2 = l_2$ .

In this situation the cell is in closed circuit, therefore the terminal potential difference (V) of cell will be equal to the potential difference across external resistance R, i.e.,

$$V = kl_2 \dots (ii)$$

$$\text{Dividing (i) by (ii), we get } \frac{\varepsilon}{V} = \frac{l_1}{l_2}$$

$$\therefore \text{Internal resistance of cell, } r = \left( \frac{\varepsilon}{V} - 1 \right) R = \left( \frac{l_1}{l_2} - 1 \right) R$$

From this formula r may be calculated.

### Question 28

[5]

- Show that a planar loop carrying a current I, having n closely wound turns and area of cross-section A, possesses a magnetic moment  $\vec{m} = NI\vec{A}$ .

#### Answer:

Torque ( $\tau$ ) on the loop is given by:

$$\vec{\tau} = NI\vec{A} \times \vec{B} \text{ which can be written as,}$$

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

where,  $\vec{M}$  is the magnetic dipole moment given by  $\vec{M} = NI\vec{A}$

- When this loop is placed in a magnetic field  $\vec{B}$ , find out the expression for the torque acting on it.

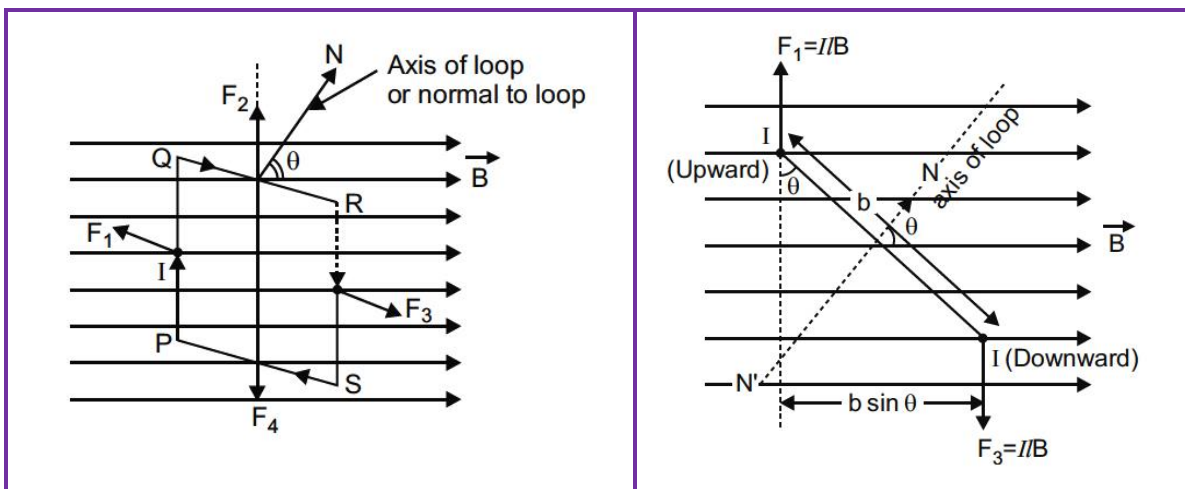


**Answer:**

Torque on a current carrying loop: Consider a rectangular loop PQRS of length  $l$ , breadth  $b$  suspended in a uniform magnetic field  $\vec{B}$ . The length of loop =  $PQ = RS = l$  and breadth =  $QR = SP = b$ .

Let at any instant the normal to the plane of loop make an angle  $\theta$  with the direction of magnetic field  $\vec{B}$  and  $I$  be the current in the loop. We know that a force acts on a current carrying wire placed in a magnetic field.

Therefore, each side of the loop will experience a force. The net force and torque acting on the loop will be determined by the forces acting on all sides of the loop. Suppose that the forces on sides PQ, QR, RS and SP are  $\vec{F}_1$ ,  $\vec{F}_2$ ,  $\vec{F}_3$  and  $\vec{F}_4$  respectively.



The sides QR and SP make angle  $(90^\circ - \theta)$  with the direction of magnetic field. Therefore each of the forces  $\vec{F}_2$  and  $\vec{F}_4$  acting on these sides has same magnitude  $F' = B l b \sin (90^\circ - \theta) = B l b \cos \theta$ . According to Fleming's left hand rule the forces  $\vec{F}_2$  and  $\vec{F}_4$  are equal and opposite but their line of action is same. Therefore these forces cancel each other i.e. the resultant of  $\vec{F}_2$  and  $\vec{F}_4$  is zero.

The sides PQ and RS of current loop are perpendicular to the magnetic field, therefore the magnitude of each of forces  $\vec{F}_1$  and  $\vec{F}_3$  is  $F = I l B \sin 90^\circ = I l B$ .

According to Fleming's left hand rule the forces  $\vec{F}_1$  and  $\vec{F}_3$  acting on sides PQ and RS are equal and opposite, but their lines of action are different; therefore the resultant force of  $\vec{F}_1$  and  $\vec{F}_3$  is zero, but they form a couple called the deflecting couple. When the normal to plane of loop makes an angle  $\theta$  with the direction of magnetic field  $B$ , the perpendicular distance between  $F_1$  and  $F_3$  is  $b \sin \theta$ .

$\therefore$  Moment of couple or Torque,

$$\tau = (\text{Magnitude of one force } F) \times \text{perpendicular distance} = (B l I) \cdot (b \sin \theta) = I (l b) B \sin \theta$$

But  $l b = \text{area of loop} = A$  (say)

$\therefore$  Torque,  $\tau = I A B \sin \theta$

If the loop contains  $N$ -turns, then  $\tau = N I A B \sin \theta$

In vector form  $\vec{\tau} = N I \vec{A} \times \vec{B}$



Direction of torque is perpendicular to direction of area of loop as well as the direction of magnetic field i.e., along  $\vec{A} \times \vec{B}$ .

- c. A galvanometer coil of  $50\Omega$  resistance shows full scale deflection for a current of  $5\text{mA}$ . How will you convert this galvanometer into a voltmeter of range 0 to  $15\text{V}$ ?

**Answer:**

$$G = 50\Omega$$

$$I_g = 5\text{ mA} = 5 \times 10^{-3}\text{ A}$$

$$V = 15\text{ V}$$

The galvanometer can be converted into a voltmeter when a high resistance  $R$  is connected in series with it. Value of  $R$  is given by:  $R = \frac{V}{I_g} - G = \frac{15}{5 \times 10^{-3}} - 50$

$$= 3000 - 50$$

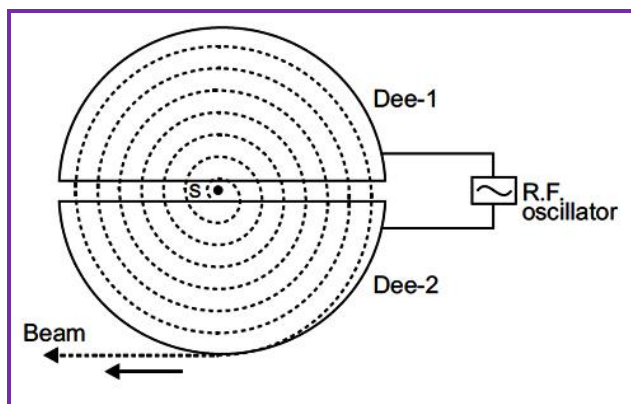
$$= 2950\Omega = 2.95\text{ k}\Omega$$

OR

- a. Draw a schematic sketch of a cyclotron, explain its working principle and deduce the expression for the kinetic energy of the ions accelerated.

**Answer:**

**Principle:** The positive ions produced from a source are accelerated. Due to the presence of perpendicular magnetic field the ion will move in a circular path. The phenomenon is continued till the ion reaches at the periphery where an auxiliary negative electrode (deflecting plate) deflects the accelerated ion on the target to be bombarded.



**Expression for K.E. attained:**

If  $R$  be the radius of the path and  $v_{\max}$  the velocity of the ion when it leaves the periphery, then

$$v_{\max} = \frac{qBR}{m}$$

The kinetic energy of the ion when it leaves the apparatus is,

$$\text{K.E.} = \frac{1}{2}mv_{\max}^2 = \frac{q^2B^2R^2}{2m}$$

When charged particle crosses the gap between dees it gains  $\text{KE} = qV$

In one revolution, it crosses the gap twice, therefore if it completes  $n$ -revolutions before emerging from the dees, the kinetic energy gained  $= 2nqV$ .



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$$\text{Thus K.E.} = \frac{q^2 B^2 R^2}{2m} = 2nqV$$

- b. Two long and parallel straight wires carrying currents of 2A and 5A in the opposite directions are separated by a distance of 1cm. find the nature and magnitude of the magnetic force between them.

[5]

**Answer:**

$$I_1 = 2A, I_2 = 5A, \alpha = 1 \text{ cm} = 1 \times 10^{-2} \text{ m}$$

$$\text{Force between two parallel wires per unit length is given by } F = \frac{\mu_0}{2\pi} \cdot \frac{I_1 I_2}{\alpha}$$

$$= 2 \times 10^{-7} \times \frac{2 \times 5}{1 \times 10^{-2}} = 20 \times 10^{-5} \text{ N (Repulsive)}$$

**Question 29**

[5]

- a. Derive the expression for the mutual inductance of two long coaxial solenoids of same length  $l$  having radii  $r_1$  and  $r_2$  ( $r_2 > r_1$  and  $l \gg r_2$ ).

**Answer:**

Suppose there are two coils  $C_1$  and  $C_2$ . The current  $I_1$  is flowing in primary coil  $C_1$ ; due to which an effective magnetic flux  $\Phi_2$  is linked with secondary coil  $C_2$ . By experiments

$$\Phi_2 \propto I_1 \text{ or } \Phi_2 = M I_1 \dots\dots\dots(i)$$

Where  $M$  is a constant, and is called the coefficient of mutual induction or mutual inductance.

$$\text{From (i) } M = \frac{\Phi_2}{I_1} \text{ If } I_1 = 1 \text{ ampere, } M = \Phi_2$$

i.e., the mutual inductance between two coils is numerically equal to the effective flux linkage with secondary coil, when current flowing in primary coil is 1 ampere. Mutual Inductance of Two Co-axial Solenoids: Consider two long co-axial solenoid each of length  $l$  with number of turns  $N_1$  and  $N_2$  wound one over the other. Number of turns per unit length in order (primary) solenoid,

$$n = \frac{N_1}{l} \text{ If } I_1 \text{ is the current flowing in primary solenoid, the magnetic field produced within this solenoid.}$$

$$B_1 = \frac{\mu_0 N_1 I_1}{l} \dots\dots\dots(ii)$$

The flux linked with each turn of inner solenoid coil is  $\Phi_2 = B_1 A_2$ , where  $A_2$  is the cross-sectional area of inner solenoid. The total flux linkage with inner coil of  $N_2$  -turns.

$$\Phi_2 = N_2 \phi_2 = N_2 B_1 A_2 = N_2 \left( \frac{\mu_0 N_1 I_1}{l} \right) A_2 = \frac{\mu_0 N_1 N_2}{l} A_2 I_1$$

$$\text{By definition Mutual Inductance, } M_{21} = \frac{\Phi_2}{I_1} = \frac{\mu_0 N_1 N_2 A_2}{l}$$

If  $n_1$  is number of turns per unit length of outer solenoid and  $r_2$  is radius of inner solenoid, then

$$M = \mu_0 N_1 N_2 \pi r_2^2$$

- b. Show that mutual induction of solenoid 1 due to solenoid 2,  $M_{12}$ , is the same as that of 2 due to 1 i.e.  $M_{21}$ .



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**Answer:**

Due to current  $I_1$  through solenoid of radius  $r_1$ , flux linked with second solenoid  $N_2\phi_2 = M_{21}I_1 \dots\dots\dots (i)$

But flux due to current  $I_1$  in first solenoid (using Ampere's circuital law) will be  $= \frac{\mu_0 N_1 I_1}{l}$ .

Hence  $N_2\phi_2 = N_2(\pi r_1^2) \left( \mu_0 \frac{N_1}{l} I_1 \right)$  as  $l \gg r_2$  and  $r_2 \gg r_1$

Using (1)  $M_{21} = \frac{\mu_0 N_1 I_1}{l} \pi r_1^2$  which is same as expression of mutual inductance derived in part (a) above  $\therefore M_{21} = M_{12}$

- c. A power transmission line feeds power at 2200 V with a current of 5A to a step down transformer with its primary winding having 4000 turns. Calculate the number of turns and the current in the secondary in order to get output power at 220V.

**Answer:**

$$V_p = 2200V. I_p = 5A. N_p = 4000$$

$$V_s = 220V. N_s = ? I_s = ?$$

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

$$\frac{220}{2200} = \frac{5}{I_s} = \frac{N_s}{4000}$$

$$\frac{220}{2200} = \frac{5}{I_s}$$

$$\frac{1}{10} = \frac{5}{I_s}$$

$$I_s = 50 A$$

$$\frac{5}{I_s} = \frac{N_s}{4000}$$

$$\frac{5}{50} = \frac{N_s}{4000}$$

$$N_s = 400$$

OR

- a. An alternating voltage  $v = v_m \sin \omega t$  applied to a series LCR circuit drives a current given by  $i = i_m \sin (\omega t + \phi)$ . Deduce an expression for the average power dissipated over a cycle.

**Answer:**

$$V = V_m \sin \omega t$$

$$i = i_m (\omega t + \phi)$$

and instantaneous power,  $P = Vi$

$$= V_m \sin \omega t \cdot i_m \sin (\omega t + \phi) = V_m i_m \sin \omega t \sin (\omega t + \phi)$$

$$= \frac{1}{2} V_m i_m 2 \sin \omega t \sin (\omega t + \phi)$$

From trigonometric formula  $2 \sin A \sin B = \cos (A - B) - \cos (A + B)$



$$\therefore \text{Instantaneous power, } P = \frac{1}{2} V_m i_m [\cos(\omega t + \phi - \omega t) - \cos(\omega t + \phi + \omega t)]$$

$$= \frac{1}{2} V_m i_m [\cos \phi - \cos(2\omega t + \phi)] \dots \dots \dots (i)$$

Average power for complete cycle

$$\bar{P} = \frac{1}{2} V_m i_m [\overline{\cos \phi} - \overline{\cos(2\omega t + \phi)}]$$

where  $\overline{\cos(2\omega t + \phi)}$  is the mean value of  $\cos(2\omega t + \phi)$  over complete cycle. But for a complete cycle,  $\overline{\cos(2\omega t + \phi)} = 0$

$$\therefore \text{Average power, } \bar{P} = \frac{1}{2} V_m i_m \cos \phi$$

$$= \frac{V_0}{\sqrt{2}} \frac{i_0}{\sqrt{2}} \cos \phi$$

$$\bar{P} = V_{rms} i_{rms} \cos \phi$$

- b. For circuits used for transporting electric power, a low power factor implies large power loss in transmission. Explain.

**Answer:**

The power is  $P = V_{rms} i_{rms} \cos \phi$ . If  $\cos \phi$  is small, then current considerably increases when voltage is constant. Power loss, we know is  $I^2 R$ . Hence, power loss increases.

- c. Determine the current and quality factor at resonance for a series LCR circuit with  $L = 1.00$  mH,  $C = 1.00$  nF and  $R = 100 \Omega$  connected to an a.c source having peak voltage of 100V.

**Answer:**

$$I_v = ?, Q = ?$$

$$L = 1.00 \text{ mH} = 1 \times 10^{-3} \text{ H, } C = 1.00 \text{ nF} = 1 \times 10^{-9} \text{ F}$$

$$R = 100 \Omega, E_0 = 100 \text{ V}$$

$$I_0 = \frac{E_0}{\sqrt{R^2 + \left(\omega L - \frac{1}{\omega C}\right)^2}} = \frac{E_0}{Z} \left\{ \begin{array}{l} \text{at resonance } \omega L = \frac{1}{\omega C} \\ \text{Hence } Z = R \end{array} \right\}$$

$$\therefore I = \frac{V}{R} = \frac{100}{100}$$

$$I_0 = 1 \text{ A}$$

$$I_v = \frac{I_0}{\sqrt{2}} = \frac{1}{\sqrt{2}} = \frac{\sqrt{2}}{2} = \frac{1.44}{2} = 0.707 \text{ A}$$

$$I_v = 0.707 \text{ A}$$

$$Q = \frac{1}{R} \sqrt{\frac{L}{C}} = \frac{1}{100} \sqrt{\frac{1.0 \times 10^{-3}}{1.0 \times 10^{-9}}} = \frac{1}{100} \times 10^3$$

$$= 10$$

$$Q = 10$$

### Question 30

- a. A plane wave front approaches a plane surface separating two media. If medium 'one' is optically denser and medium 'two' is optically rarer, using Huygen's principle, explain and show how a refracted wavefront is constructed.

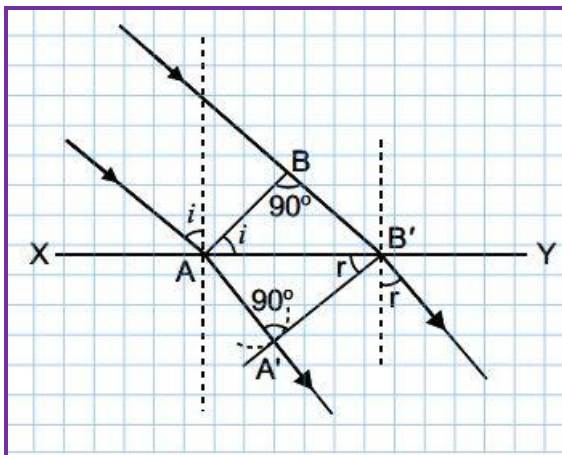




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**Answer:**

When a wave starting from one homogeneous medium enters the homogeneous medium, it is deviated from its path. This phenomenon is called refraction. In trans versing from first medium to another medium, the frequency of wave remains unchanged but its speed and the wavelength both are changed. Let XY be a surface separating the two media '1' and '2'. Let  $v_1$  and  $v_2$  be the speeds of waves in these media.



Suppose a plane wavefront AB in first medium is incident obliquely on the boundary surface XY and its end A touches the surface at A at time  $t = 0$  while the other end B reaches the surface at point B' after time-interval  $t$ . Clearly  $BB' = v_1 t$ . As the wavefront AB advances, it strikes the points between A and B' of boundary surface. According to Huygen's principle, secondary spherical wavelets originate from these points, which travel with speed  $v_1$  in the first medium and speed  $v_2$  in the second medium.

First of all secondary wavelet starts from A, which traverses a distance  $AA' (= v_2 t)$  in second medium in time  $t$ . In the same time-interval  $t$ , the point of wave front traverses a distance  $BB' (= v_1 t)$  in first medium and reaches B', from, where the secondary wavelet now starts. Clearly  $BB' = v_1 t$  and  $AA' = v_2 t$ .

Assuming A as centre, we draw a spherical arc of radius  $AA' (= v_2 t)$  and draw tangent B'A' on this arc from B'. As the incident wavefront AB advances, the secondary wavelets start from points between A and B', one after the other and will touch A'B' simultaneously. According to Huygen's principle A'B' is the new position of wavefront AB in the second medium. Hence A'B' will be the refracted wavefront.

b. Hence verify Snell's law.

**Answer:**

**Proof of Snell's law of Refraction using Huygen's wave theory:** When a wave starting from one homogeneous

**First law:** As AB, A'B' and surface XY are in the plane of paper, therefore the perpendicular drawn on them will be in the same plane. As the lines drawn normal to wave front denote the rays, therefore we may say that the incident ray, refracted ray and the normal at the point of incidence all lie in the same plane.

This is the first law of refraction.



**Second law:** Let the incident wavefront AB and refracted wavefront A' B' make angles i and r respectively with refracting surface XY.

In right-angled triangle AB' B,  $\angle ABB' = 90^\circ$

$$\therefore \sin i = \sin \angle BAB' = \frac{BB'}{AB'} = \frac{v_1 t}{AB'} \dots\dots\dots (i)$$

Similarly in right-angled triangle AA' B',  $\angle AA' B' = 90^\circ$

$$\therefore \sin r = \sin \angle A' A' B' = \frac{AA'}{AB'} = \frac{v_2 t}{AB'} \dots\dots\dots (ii)$$

Dividing equation (i) by (ii), we get

$$\frac{\sin i}{\sin r} = \frac{v_1}{v_2} = \text{constant} \dots\dots\dots (iii)$$

As the rays are always normal to the wavefront, therefore the incident and refracted rays make angles i and r with the normal drawn on the surface XY i.e. i and r are the angle of incidence and angle of refraction respectively. According to equation (3):

The ratio of sine of angle of incidence and the sine of angle of refraction is a constant and is equal to the ratio of velocities of waves in the two media. This is the second law of refraction, and is called the Snell's law.

- c. When a light wave travels from a rarer to a denser medium, the speed decreases. Does it imply reduction in its energy? Explain.

**Answer:**

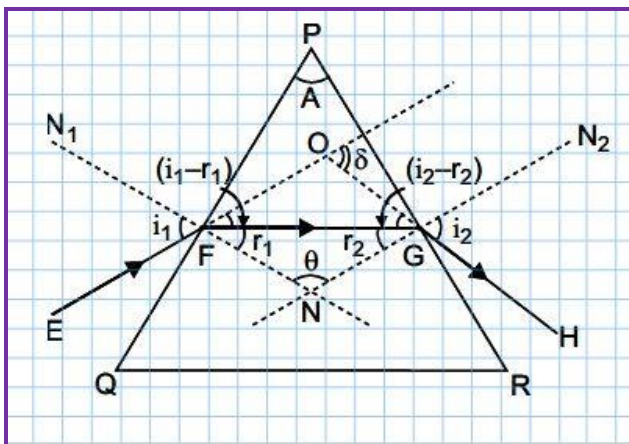
No. Because energy of wave depends on its frequency and not on its speed.

OR

- a. A ray of monochromatic light is incident on one of the faces of an equilateral triangular prism of refracting angle A. trace the path of ray passing through the prism. Hence derive an expression for the refractive index of the material of the prism in terms of the angle of minimum deviation and its refracting angle.

**Answer:**

Let PQR be the principal section of the prism. The refracting angle of the prism is A. A ray of monochromatic light EF is incident on face PQ at angle of incidence  $i_1$ . The refractive index of material of prism for this ray is n.



This ray enters from rarer to denser medium and so is deviated towards the normal FN and gets refracted along the direction FG. The angle of refraction for this face is  $r_1$ . The refracted ray FG becomes incident on face PR and is refracted away from the normal  $GN_2$  and emerges in the direction GH.

The angle of incidence on this face is  $r_2$  (into prism) and angle of refraction (into air) is  $i_2$ . The incident ray EF and emergent ray GH when produced meet at O. The angle between these two rays is called angle of deviation ' $\delta$ '.

$$\angle OFG = i_1 - r_1 \text{ and } \angle OGF = i_2 - r_2$$

In  $\triangle FOG$ ,  $\delta$  is exterior angle

$$\therefore \delta = \angle OFG + \angle OGF = (i_1 - r_1) + (i_2 - r_2)$$

$$= (i_1 + r_1) - (i_2 + r_2) \dots\dots\dots (i)$$

The normals  $FN_1$  and  $GN_2$  on faces PQ and PR respectively, when produced meet at N. Let  $\angle FNG = \theta$ .

$$\text{In } \triangle FGN, r_1 + r_2 + \theta = 180^\circ \dots\dots\dots (ii)$$

In quadrilateral PFNG,  $\angle PFN = 90^\circ$ ,  $\angle PGN = 90^\circ$

$$\therefore A + 90^\circ + \theta + 90^\circ = 360^\circ \text{ or, } A + \theta = 180^\circ \dots\dots\dots (iii)$$

$$\text{Comparing (ii) and (iii), } r_1 + r_2 = A \dots\dots\dots (iv)$$

Substituting this value in (i), we get

$$\delta = i_1 + i_2 - A \dots\dots\dots (v)$$

$$\text{or, } i_1 + i_2 = A + \delta \dots\dots\dots (vi)$$

$$\text{From Snell's law } n = \frac{\sin i_1}{\sin r_1} = \frac{\sin i_2}{\sin r_2} \dots\dots\dots (vii)$$

For minimum deviation  $i_1$  and  $i_2$  become coincident, i.e.,  $i_1 = i_2 = i$  (say) So from (vii)  $r_1 = r_2 = r$  (say)

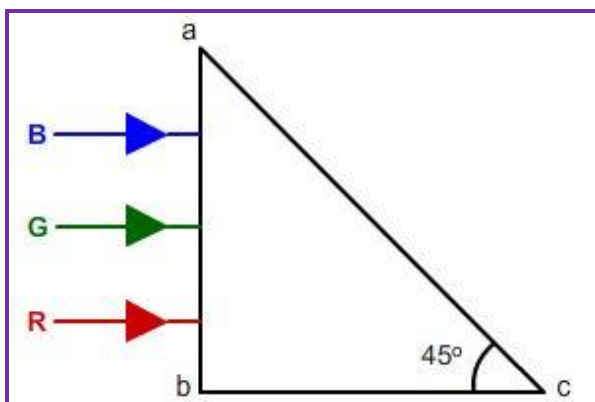
$$\text{Hence from (iv) and (vi), we get } r + r = A \text{ or } r = \frac{A}{2}$$

$$\text{and } i + i = A + \delta_m \text{ or } i = \frac{A + \delta_m}{2}$$

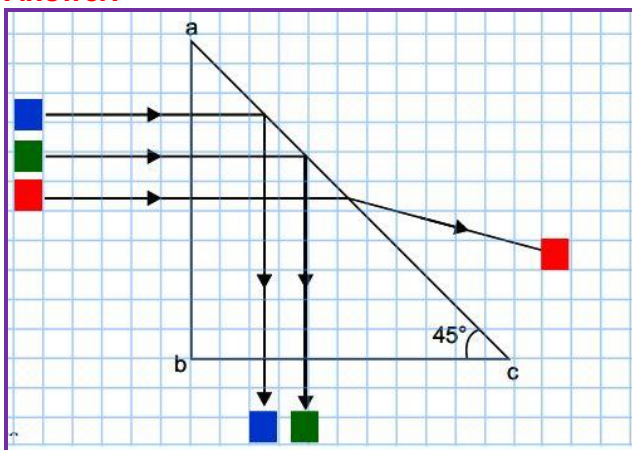
$$\text{Hence from Snell's law, } n = \frac{\sin i}{\sin r} = \frac{\sin\left(\frac{A + \delta_m}{2}\right)}{\sin\left(\frac{A}{2}\right)}$$

- b. Three light rays (R), green (G) and blue (B) are incident on the right angled prism abc at face ab. The refractive indices of the material of the prism for red, green and blue wavelengths are respectively 1.39, 1.44 and 1.47. Trace the paths of these rays reasoning out the difference in their behavior.





**Answer:**



Angle of incidence at face ac for all three colors,  
 $i = 45^\circ$

Refractive index corresponding to critical angle  $45^\circ$  is  $\mu = \frac{1}{\sin 45^\circ} = \sqrt{2} = 1.414$

The ray will be transmitted through face 'ac' if  $i < i_c$ . This condition is satisfied for red color ( $\mu = 1.39$ ). So only red ray will be transmitted, blue and Green rays will be totally reflected.

