

SET-1

**PHYSICS**

Series OSR

Paper &amp; Solution

Code: 55/1

Time: 3 Hrs.

Max. Marks: 70

**General Instructions:**

- (i) All questions are compulsory.
- (ii) There are **30** questions in total. Questions No. **1** to **8** are very short answer type questions and carry **one** mark each.
- (iii) Questions No. **9** to **18** carry **two** marks each, questions **19** to **27** carry **three** marks each and questions **28** to **30** carry **five** marks each.
- (iv) One of the questions carrying three marks weightage is value based question
- (v) 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 each weightage. You have to attempt only one of the choices in such questions.
- (vi) Use of calculators is **not** permitted. However, you may use log tables if necessary.
- (vii) You may use the following values of physical constants wherever necessary:

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

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

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

$$\mu_0 = 4\pi \times 10^{-7} \text{ TmA}^{-1}$$

$$\frac{1}{4\pi\epsilon_0} = 9 \times 10^9 \text{ Nm}^2\text{C}^{-2}$$

$$m_e = 9.1 \times 10^{-31} \text{ kg}$$

1. Using the concept of force between two infinitely long parallel current carrying conductors, define one ampere of current.

**Solution:**

**Definition :** One ampere is the value of steady current which when maintained in each of the two very long, straight, parallel conductors of negligible cross section and placed one metre apart in vacuum, would produce on each of these conductors a force equal of  $2 \times 10^{-7} \text{ N/m}$  of its length.

**Alternatively**

If the student writes  $F = \frac{\mu_0}{2\pi} \frac{I_1 I_2}{R} L$

and says that when  $I_1 = I_2 = 1 \text{ ampere}$

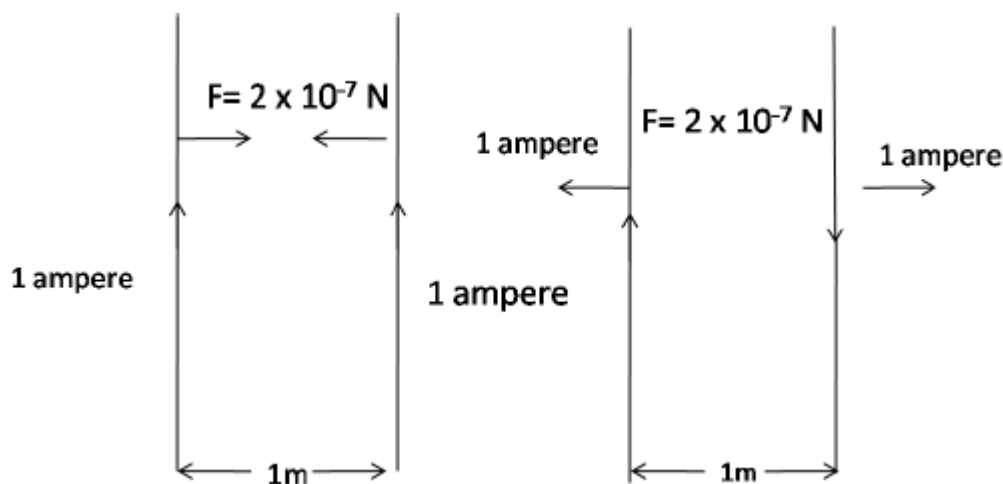
$R = 1 \text{ meter}$  and  $L = 1 \text{ meter}$ , then

$$F = 2 \times 10^{-7} \text{ N}$$

**Marks: 1 mark**

**Alternatively**

If the student draws any one of the two diagram, as shown ,



2. To which part of the electromagnetic spectrum does a wave of frequency  $5 \times 10^{19} \text{ Hz}$  belong ?

**Solution:**

X – rays /  $\gamma$  – rays

3. Two equal balls having equal positive charge ‘q’ coulombs are suspended by two insulating strings of equal length. What would be the effect on the force when a plastic sheet is inserted between the two ?

**Solution:**

Force decreases

4. Define intensity of radiation on the basis of photon picture of light. Write its S.I. unit.

**Solution:**

Intensity of radiation depends on the number of photons incident per unit area per unit time.

[Note: Also accept the definition: ‘number of quanta of radiation per unit area per unit time’. Also accept if the student writes:

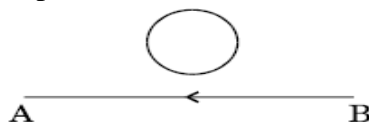
All photons, of a particular frequency, have the same kinetic energy and momentum, irrespective of the intensity of incident radiation.

**Alternatively**

The amount of light energy / Photon energy, incident per metre square per second is called intensity of radiation

**SI Unit :**  $\text{W/m}^2$  or  $\text{J}/(\text{s} \cdot \text{m}^2)$

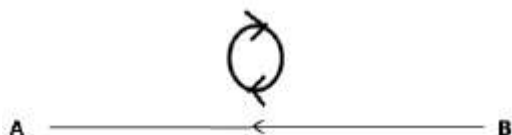
5. The electric current flowing in a wire in the direction from B to A is decreasing. Find out the direction of the induced current in the metallic loop kept above the wire as shown.



**Solution:**

Clockwise

**Alternatively**



6. Why is it found experimentally difficult to detect neutrinos in nuclear  $\beta$ -decay ?

**Solution:**

Neutrinos are neutral (chargeless), (almost) massless particles that hardly interact with matter.

**Alternatively**

The neutrinos can penetrate large quantity of matter without any interaction

**OR**

Neutrinos are chargeless and (almost) massless particles.

7. Why is the use of a.c. voltage preferred over d.c. voltage ? Give two reasons.

**Solution:**

**Any two** of the following (or any other correct) reasons :

- AC can be transmitted with much lower energy losses as compared to DC
- AC voltage can be adjusted (stepped up or stepped down) as per requirement.
- AC current in a circuit can be controlled using (almost) wattless devices like the choke coil.
- AC is easier to generate.

8. A biconvex lens made of a transparent material of refractive index 1.25 is immersed in water of refractive index 1.33. Will the lens behave as a converging or a diverging lens ? Give reason.

**Solution:**

As a diverging lens

Light rays diverge on going from a rarer to a denser medium.

**[Alternatively**

Also accept the reason given on the basis of lens maker's formula.]

9. Using Rutherford model of the atom, derive the expression for the total energy of the electron in hydrogen atom. What is the significance of total negative energy possessed by the electron ?

**OR**

Using Bohr's postulates of the atomic model, derive the expression for radius of  $n^{\text{th}}$  electron orbit. Hence obtain the expression for Bohr's radius.

**Solution:**

Derivation of energy expression

Significance of negative sign

As per Rutherford's model

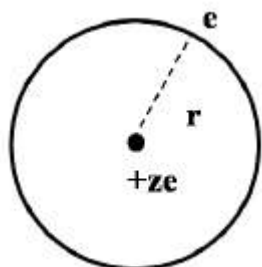
$$\frac{mv^2}{r} = \frac{1}{4\pi\epsilon_0} \frac{ze^2}{r}$$

$$\Rightarrow mv^2 = \frac{1}{4\pi\epsilon_0} \frac{ze^2}{r}$$

Total energy = P.E + K.E.

$$= -\frac{1}{4\pi \epsilon_0} \frac{ze^2}{r} + \frac{1}{2}mv^2$$

$$= -\frac{1}{2} \cdot \frac{1}{4\pi \epsilon_0} \frac{ze^2}{r} = -\frac{1}{8\pi \epsilon_0} \frac{ze^2}{r}$$



Negative Sign implies that

Electron – nucleus form a bound system.

**Alternatively**

Electron – nucleus form an attractive system)

**OR**

Bohr's Postulate

Derivation of radius of nth orbit

Bohr's radius

For the electron, we have

Bohr's Postulate  $\left( mvr = \frac{nh}{2\pi} \right)$

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

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

$$\therefore m^2 v^2 r^2 = \frac{n^2 h^2}{4\pi^2}$$

and  $mv^2 r = \frac{1}{4\pi \epsilon_0} ze^2$

$$\therefore r = \frac{\epsilon_0 n^2 h^2}{\pi z e^2 m}$$

Bohr's radius (for  $n = 1$ )  $= \epsilon_0 h^2 / \pi z e^2 m$

10. A parallel plate capacitor of capacitance  $C$  is charged to a potential  $V$ . It is then connected to another uncharged capacitor having the same capacitance. Find out the ratio of the energy stored in the combined system to that stored initially in the single capacitor.

**Solution:**

Formula for energy stored

New value of capacitance

Calculation of ratio

$$\text{Energy stored in a capacitor} = \frac{1}{2} QV = \frac{1}{2} CV^2 = \frac{1}{2} \frac{Q^2}{C} \text{ (any one)}$$

Capacitance of the (parallel) combination =  $C+C=2C$

Here, total charge,  $Q$ , remains the same

$$\therefore \text{initial energy} = \frac{1}{2} \frac{Q^2}{C}$$

$$\text{And final energy} = \frac{1}{2} \frac{Q^2}{2C}$$

$$\therefore \frac{\text{final energy}}{\text{initial energy}} = \frac{1}{2}$$

[**Note** : If the student does the correct calculations by assuming the voltage across the

(i) Parallel or (ii) Series combination to remain constant ( $=V$ ) and obtain the answers as (i) 2:1 or (ii) 1:2 , award full marks ]

11. Considering the case of a parallel plate capacitor being charged, show how one is required to generalize Ampere's circuital law to include the term due to displacement current.

**Solution:**

Statement of Ampere's circuital law

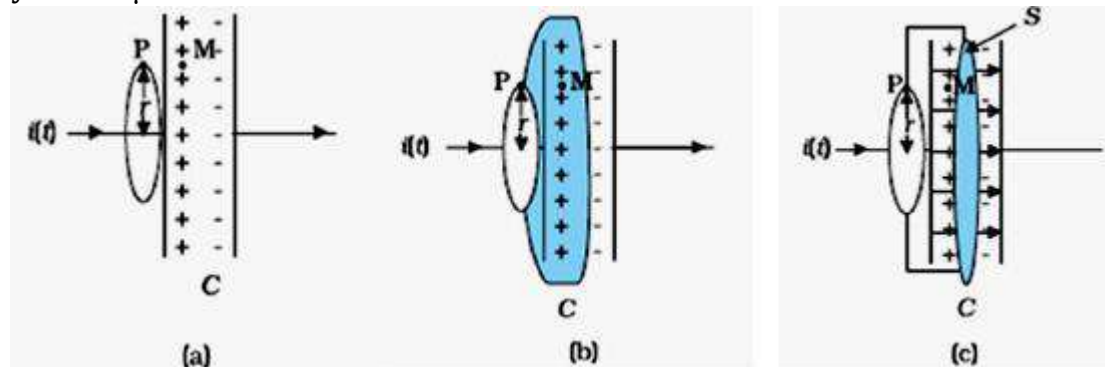
Showing inconsistency during the process of charging

Displacement Current

According to

Ampere's circuital Law

$$\oint \vec{B} \cdot d\vec{l} = \mu_0 I$$



Applying ampere's circuital law to fig (a) we see that, during charging, the right hand side in Ampere's circuital law equals  $\mu_0 I$

However on applying it to the surfaces of the fig (b) or fig (c), the right hand side is zero.

Hence, there is a contradiction.

We can remove the contradiction by assuming that there exists a current (associated with the changing electric field during charging), known as the displacement current.

When this current ( $= \frac{d\phi_E}{dt}$ ) is added on the right hand side, Ampere's circuital

law, the inconsistency disappears.

It was, therefore necessary, to generalize the Ampere's circuital law, as

$$\oint \vec{B} \cdot d\vec{l} = \mu_0 I_c + \mu_0 \epsilon_0 \frac{d\phi_E}{dt}$$

[**Note** : If the student does the reasoning by using the (detailed) mathematics, relevant to displacement current, award full 2 marks ]

12. A cell of emf 'E' and internal resistance 'r' is connected across a variable resistor 'R'. Plot a graph showing variation of terminal voltage 'V' of the cell versus the current 'I'. Using the plot, show how the emf of the cell and its internal resistance can be determined.

**Solution:**

Relation between V and I

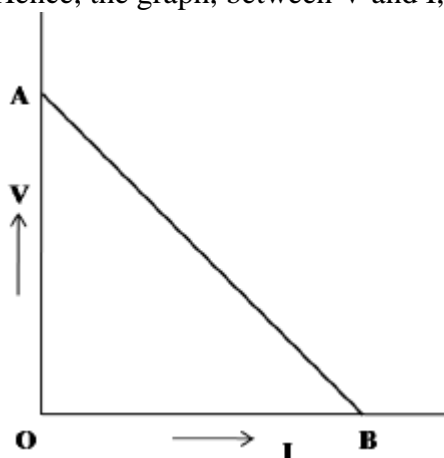
Graph

Determination of emf and internal resistance

The relation between V and I is

$$V = E - Ir$$

Hence, the graph, between V and I, has the form shown below.



For point A,  $I=0$ , Hence,  $V_A = E$

For point B,  $V=0$ , Hence,  $E = IB_r$

Therefore,  $r = \frac{E}{I_B}$

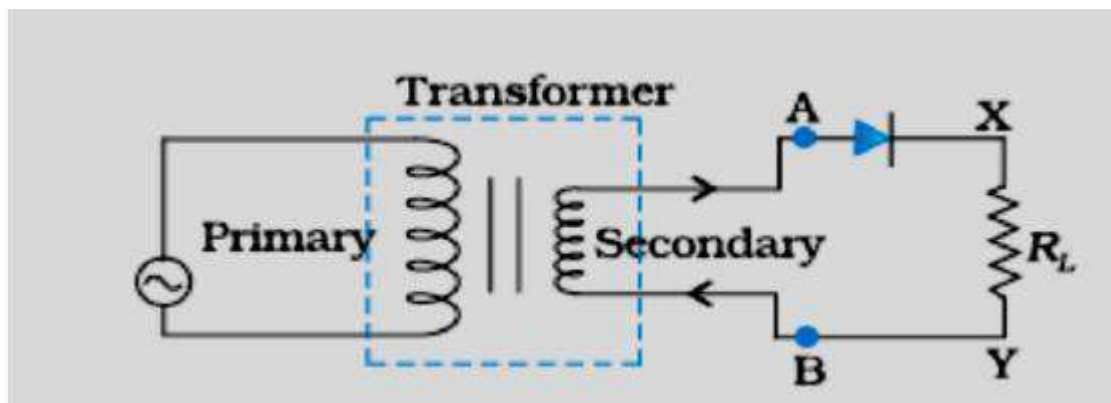
**Alternatively:** emf (E) equals the intercept on the vertical axis. Internal resistance (r) equals the negative of the slope of the graph.

13. Explain, with the help of a circuit diagram, the working of a p-n junction diode as a half-wave rectifier.

**Solution:**

Circuit diagram

Working

**Working:**

During one half of the input AC, the diode is forward biased and a current flows through  $R_L$ .

During the other half of the input AC, the diode is reverse biased and no current flows through the load  $R_L$ .

Hence, the given AC input is rectified

[Note : If the student just draws the waveforms, for the input AC voltage and output voltage (without giving any explanation) (award  $\frac{1}{2}$  mark only for “working”)]

14. Estimate the average drift speed of conduction electrons in a copper wire of cross-sectional area  $1.0 \times 10^{-7} \text{ m}^2$  carrying a current of 1.5 A. Assume the density of conduction electrons to be  $9 \times 10^{28} \text{ m}^{-3}$ .

**Solution:**

Formula

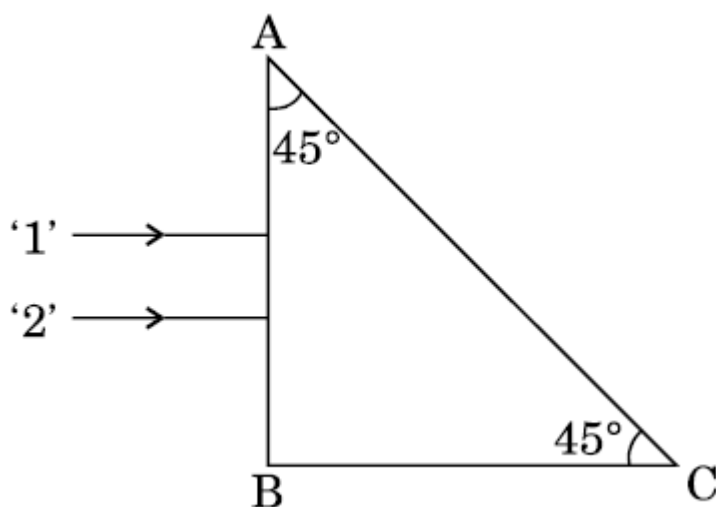
Substitution and calculation

$$I = neA V_d$$

$$V_d = \frac{I}{neA} = \frac{1.5}{9 \times 10^{28} \times 1.6 \times 10^{-19} \times 1.0 \times 10^{-7}} \text{ m/s}$$

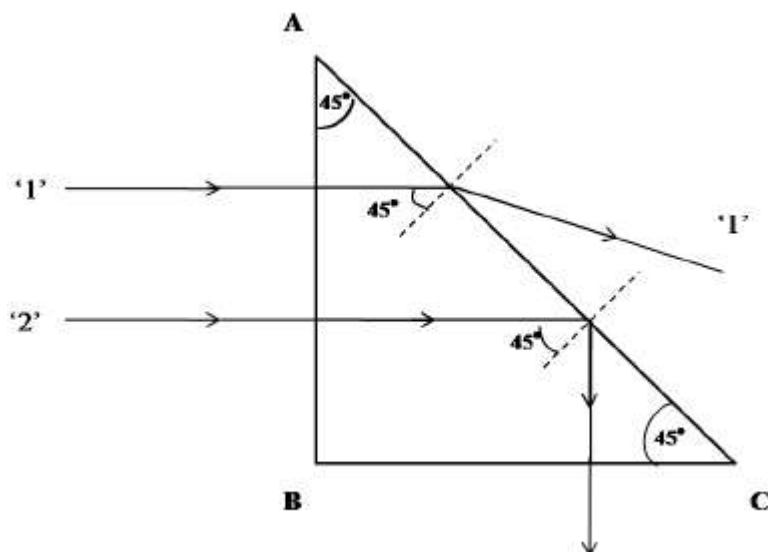
$$= 1.048 \times 10^{-3} \text{ m/s} (\approx 1 \text{ mm/s})$$

15. Two monochromatic rays of light are incident normally on the face AB of an isosceles right-angled prism ABC. The refractive indices of the glass prism for the two rays ‘1’ and ‘2’ are respectively 1.35 and 1.45. Trace the path of these rays after entering through the prism.

**Solution:**

Tracing of Path of Ray 1

## Tracing of Path of Ray 2



[Note : If the student just writes (without drawing any diagram) that angle of incidence for both rays '1' and '2' on face AC equals  $45^\circ$ , and says that it is less than critical angle for ray '1' (which therefore gets refracted) and more than critical angle for ray '2' (which undergoes total internal reflection), award only  $\frac{1}{2} + \frac{1}{2}$  marks.]

16. Write the functions of the following in communication systems :

(i) Transducer

(ii) Repeater

**Solution:**

Function of Transducer

Function of Repeater

**Transducer** : Any device that converts one form of energy to another.

**Repeater** : A repeater accepts the signal from the transmitter, amplifies and retransmits it to the receiver.

17. Show diagrammatically the behaviour of magnetic field lines in the presence of (i) paramagnetic and (ii) diamagnetic substances. How does one explain this distinguishing feature ?

**Solution:**

Diagrams

Explanations





A paramagnetic material tends to move from weaker to stronger regions of the magnetic field and hence increases the number of lines of magnetic field passing through it.

[**Alternatively:** A paramagnetic material, dipole moments are induced in the direction of the field.]

A diamagnetic material tends to move from stronger to weaker regions of the magnetic field and hence, decreases the number of lines of magnetic field passing through it.

[**Alternatively:** A diamagnetic material, dipole moments are induced in the opposite direction of the field.]

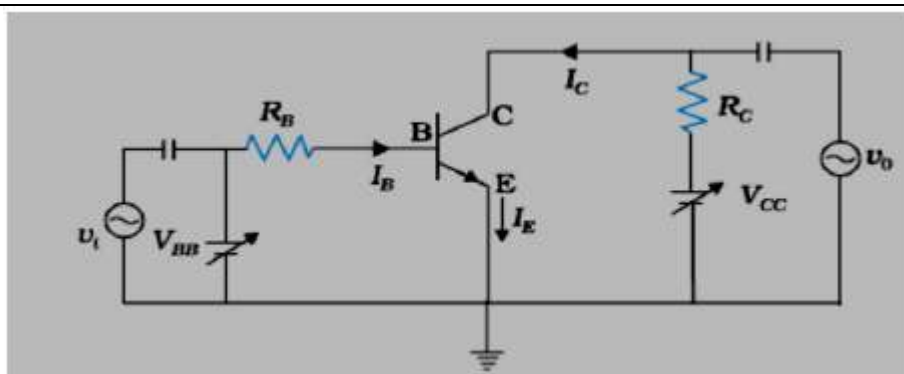
[**Note:** If the student just writes that a paramagnetic material has a small positive susceptibility ( $0 < X < 1$ ) and a diamagnetic material has a negative susceptibility ( $-1 < X < 0$ ), award the  $\frac{1}{2}$  mark for the second part of the question.]

18. Draw a circuit diagram of n-p-n transistor amplifier in CE configuration. Under what condition does the transistor act as an amplifier ?

**Solution:**

Circuit diagram

Condition



**Condition :** The transistor must be operated close to the centre of its active region.

**Alternatively**

The base-emitter junction of the transistor must be (suitably) forward biased and the collector-emitter junction must be (suitably) reverse biased.

19. (a) Using the phenomenon of polarisation, show how transverse nature of light can be demonstrated.

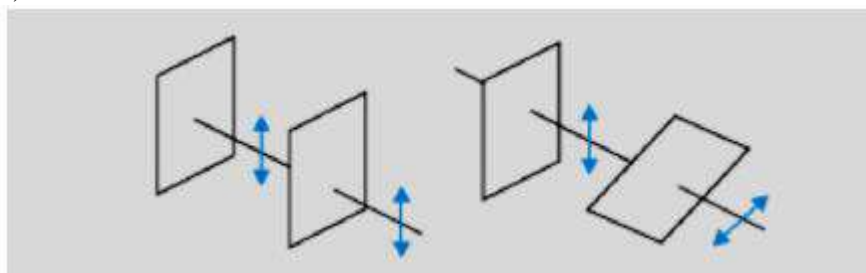
(b) Two polaroids  $P_1$  and  $P_2$  are placed with their pass axes perpendicular to each other. Unpolarised light of intensity  $I_0$  is incident on  $P_1$ . A third polaroid  $P_3$  is kept in between  $P_1$  and  $P_2$  such that its pass axis makes an angle of  $30^\circ$  with that of  $P_1$ . Determine the intensity of light transmitted through  $P_1$ ,  $P_2$  and  $P_3$ .

**Solution:**

a) Demonstration of transverse nature of light

b) Calculation of intensity through  $P_1$ ,  $P_2$  &  $P_3$

a)



Light from the sodium lamp passing through the single Polaroid sheet ( $P_1$ ) does not show any variation in intensity when this sheet is rotated.

However, if the light, transmitted by  $P_1$ , is made to pass through another Polaroid sheet ( $P_2$ ) the light intensity, coming out of  $P_2$ , varies from a maximum to zero, and again to maximum, when  $P_2$  is rotated. These observations are consistent only with the transverse nature of light waves.

b) Intensity of light transmitted through  $P_1 = I_0 / 2$

$$\begin{aligned} \text{Intensity of light transmitted through } P_3 &= (I_0 / 2) \times \cos^2 30^\circ \\ &= 3 I_0 / 8 \end{aligned}$$

$$\begin{aligned} \text{Intensity of light transmitted through } P_2 &= \frac{3}{8} I_0 \cos^2 60^\circ \\ &= \frac{3}{32} I_0 \end{aligned}$$

[**Note :** If the student takes the intensity of light transmitted through  $P_1$  as  $I_0$  and calculates the intensity through  $P_3$  and  $P_2$  as  $\frac{3}{4} I_0$  and  $\frac{3}{16} I_0$  award 1 mark for part (b) ]

20. Define the term ‘mutual inductance’ between the two coils. Obtain the expression for mutual inductance of a pair of long coaxial solenoids each of length  $l$  and radii  $r_1$  and  $r_2$  ( $r_2 \gg r_1$ ). Total number of turns in the two solenoids are  $N_1$  and  $N_2$  respectively.

**Solution:**

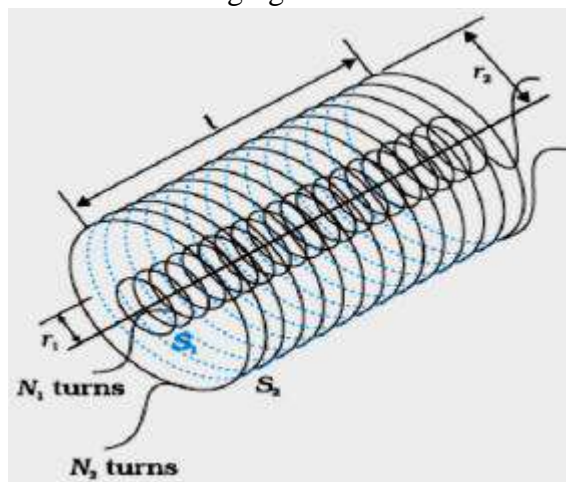
Definition of mutual induction

Obtaining the expression

Mutual inductance, between a pair of coils, equals the magnetic flux, linked with one of them, due to a unit current flowing in the other.

**Alternatively**

The mutual inductance, for a pair of coils, equals the emf induced, in one of them, when the current in the other coil is changing at a unit rate.



Let a current  $I_2$  flow through the outer coil.

The magnetic field due to this current

$$= \mu_0 \frac{N_2}{l} \times I_2$$

The resulting magnetic flux linked with the inner coil

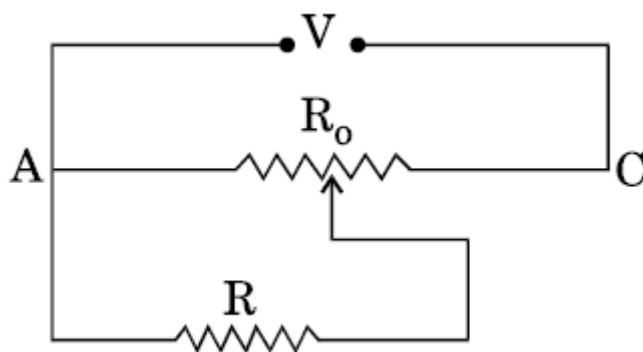
$$\begin{aligned}
 \Phi_{12} &= N_1 \cdot \left( \mu_o \frac{N_2}{l} \times I_2 \right) \times \pi r_1^2 \\
 &= \left( \mu_o \frac{N_1 N_2}{l} \cdot \pi r_1^2 \right) I_2 \\
 \therefore M_{12} &= \mu_o \frac{N_1 N_2}{l} \cdot \pi r_1^2
 \end{aligned}$$

21. Answer the following :

- Why are the connections between the resistors in a meter bridge made of thick copper strips ?
- Why is it generally preferred to obtain the balance point in the middle of the meter bridge wire ?
- Which material is used for the meter bridge wire and why ?

**OR**

A resistance of  $R \, \Omega$  draws current from a potentiometer as shown in the figure. The potentiometer has a total resistance  $R_o \, \Omega$ . A voltage  $V$  is supplied to the potentiometer. Derive an expression for the voltage across  $R$  when the sliding contact is in the middle of the potentiometer.



**Solution:**

Answers to each of the three parts

- This is to ensure that the connections do not contribute any extra, unknown, resistances in the circuit.
- This is done to minimize the percentage error in the value of the unknown resistance.

**[Alternatively:** This is done to have a better “balancing out” of the effects of any irregularity or non-uniformity in the metre bridge wire.

**Or**

This can help in increasing the sensitivity of the metre bridge circuit.]

- Manganian / constantan / Nichrome

This material has a low temperature (**any one**) of coefficient of resistance/high resistivity.

**OR**

Calculation of total resistance of the circuit

Calculation of total current drawn from the voltage Source

Calculation of current through  $R$

Calculation of potential drop across  $R$

$$R_{total} = \frac{R_o}{2} + \frac{\frac{R_o}{2} \cdot R}{\frac{R_o}{2} + R}$$

$$= \frac{R(R_o + 4R)}{2(R_o + 2R)}$$

$$I_{(total)} = \frac{V}{R_{total}}$$

$$\text{Current through R} = I_2 = I_{total} \times \frac{\frac{R_o}{2}}{\frac{R_o}{2} + R}$$

$$= I_{total} \times \frac{R_o}{R_o + 2R}$$

$$= \frac{V \cdot 2(R_o + 2R)}{R(R_o + 4R)} \times \frac{R_o}{R_o + 2R}$$

$$= \frac{2VR_o}{R(R_o + 4R)}$$

$$\text{Voltage across R} = I_2 R = \left( \frac{2VR_o}{R_o + 4R} \right)$$

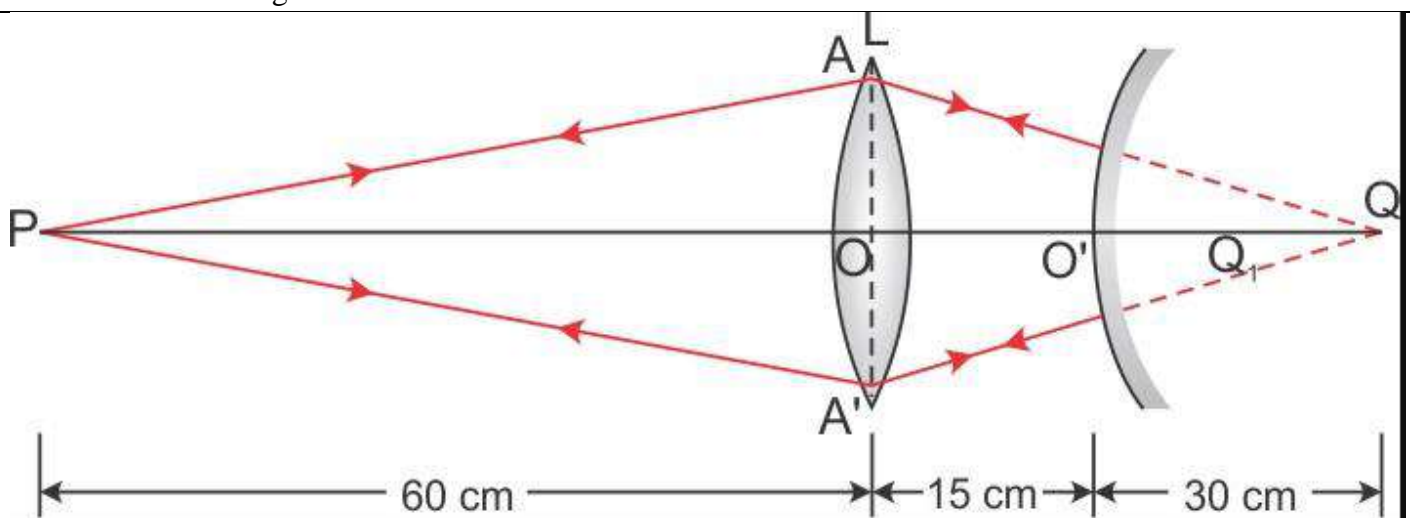
22. A convex lens of focal length 20 cm is placed coaxially with a convex mirror of radius of curvature 20 cm. The two are kept at 15 cm from each other. A point object lies 60 cm in front of the convex lens. Draw a ray diagram to show the formation of the image by the combination. Determine the nature and position of the image formed.

**Solution:**

Ray diagram

Nature of final image

Position of final image



For the convex lens

$$u = -60 \text{ cm}, f = +20 \text{ cm}$$

$$\frac{1}{v} - \frac{1}{u} = \frac{1}{f} \text{ gives } v = +30 \text{ cm}$$

For the convex mirror

$$u = + (30 - 15) \text{ cm} = 15 \text{ cm}, f = \frac{20}{2} \text{ cm} = 10 \text{ cm}$$

$$\frac{1}{v} + \frac{1}{u} = \frac{1}{f} \text{ gives } v = +30 \text{ cm}$$

Final image is formed at the distance of 30 cm from the convex mirror (or 45 cm from the convex lens) to the right of the convex mirror. The final image formed is a virtual image.

23. A voltage  $V = V_0 \sin \omega t$  is applied to a series LCR circuit. Derive the expression for the average power dissipated over a cycle. Under what condition is (i) no power dissipated even though the current flows through the circuit, (ii) maximum power dissipated in the circuit ?

**Solution:**

Deriving the expression for average power

Condition for no power dissipation

Condition for maximum power dissipation

Applied voltage =  $V_0 \sin \omega t$

Current in the circuit =  $I_0 \sin (\omega t - \phi)$

where  $\phi$  is the phase lag of the current with respect to the voltage applied ,

Hence instantaneous power dissipation

$$= V_0 \sin \omega t \times I_0 \sin (\omega t - \phi)$$

$$= \frac{V_0 I_0}{2} [2 \sin \omega t \cdot \sin (\omega t - \phi)]$$

$$= \frac{V_0 I_0}{2} [\cos \phi - \cos (2\omega t - \phi)]$$

Therefore, average power for one complete cycle

$$= \text{average of } \left[ \frac{V_0 I_0}{2} [\cos \phi - \cos (2\omega t - \phi)] \right]$$

The average of the second term over a complete cycle is zero .

$$\text{Hence , average power dissipated over one complete cycle} = \frac{V_0 I_0}{2} \cos \phi$$

[Note : Please also accept alternative correct approach.]

Conditions

(i) No power is dissipated when  $R = 0$  (or  $\phi = 90^\circ$ )

[Note: Also accepts if the student writes ‘This condition cannot be satisfied for a series LCR circuit’.]

(ii) Maximum power is dissipated when  $X_L = X_C$

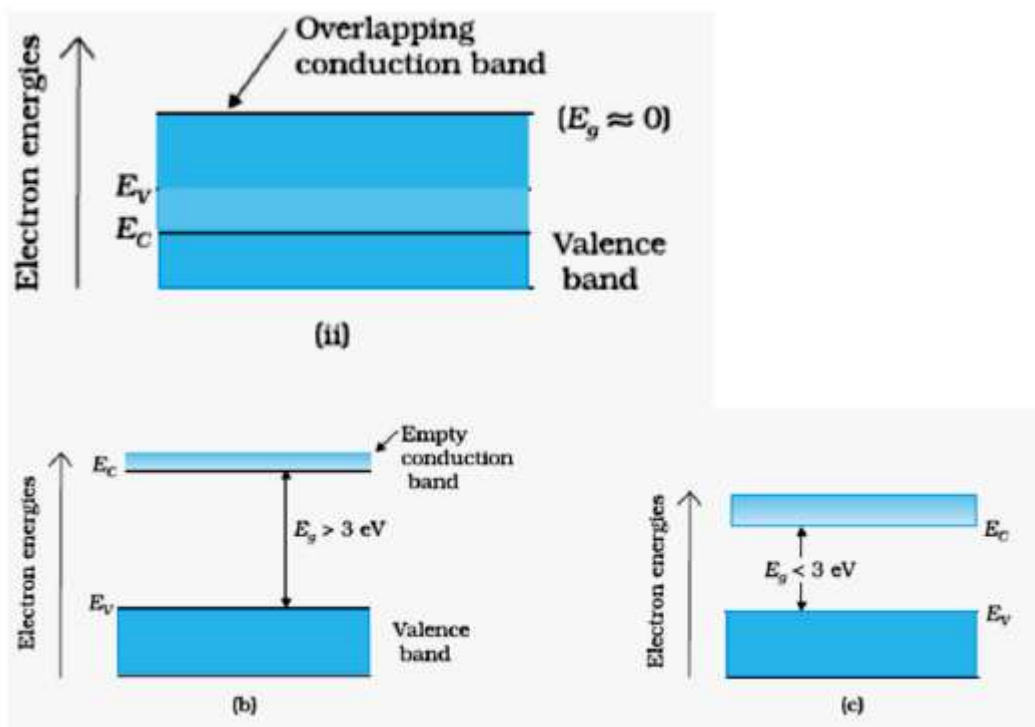
$$\text{or } \omega L = \frac{1}{\omega C} \text{ (or } \phi = 0)$$

24. Write any two distinguishing features between conductors, semiconductors and insulators on the basis of energy band diagrams.

**Solution:**

Energy band diagrams

Two distinguishing features



**Two distinguishing features:**

- In conductors, the valency band and conduction band tend to overlap ( or nearly overlap ) while in insulators they are separated by a large energy gap and in semiconductors are separated by a small energy gap.
- The conduction band, of a conductor, has a large number of electrons available for electrical conduction. However the conduction band of insulators is almost empty while that of the semi- conductor has only a ( very ) small number of such electrons available for electrical conduction.

25. For the past some time, Aarti had been observing some erratic body movement, unsteadiness and lack of coordination in the activities of her sister Radha, who also used to complain of severe headache occasionally. Aarti suggested to her parents to get a medical check-up of Radha. The doctor thoroughly examined Radha and diagnosed that she has a brain tumour.

- What, according to you, are the values displayed by Aarti ?
- How can radioisotopes help a doctor to diagnose brain tumour ?

**Solution:**

Values displayed

Diagnosis

- keen observer/ helpful/ concerned / responsible/ respectful towards elders. **(Any two)**
- The doctor can trace and observe, the difference between the movement of an appropriate radio- isotope through a normal brain and a brain having tumor in it.

[Note : Also accept any other appropriate explanation.]

26. Write two basic modes of communication. Explain the process of amplitude modulation. Draw a schematic sketch showing how amplitude modulated signal is obtained by superposing a modulating signal over a sinusoidal carrier wave.

**Solution:**

Two basic modes of communication

Process of Amplitude Modulation

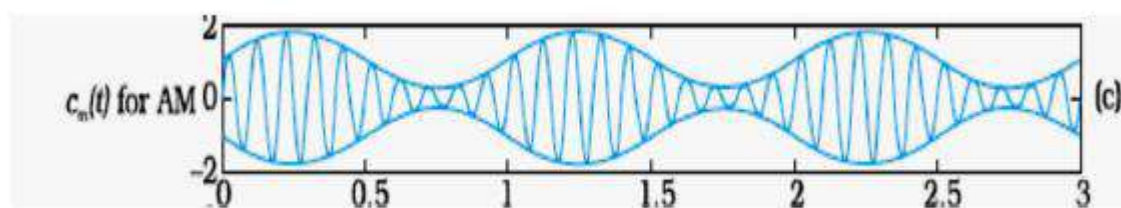
Schematic Sketch

Two basic modes of communication are

i. Point – to –point

ii. Broadcast

In Amplitude modulation the amplitude of a carrier wave is made to vary, with time, in the same way as the modulating signal varies with time



27. An electron microscope uses electrons accelerated by a voltage of 50 kV. Determine the de-Broglie wavelength associated with the electrons. Taking other factors, such as numerical aperture etc. to be same, how does the resolving power of an electron microscope compare with that of an optical microscope which uses yellow light ?

**Solution:**

Formula

Calculation of deBroglie wavelength

Comparison

$$\lambda = \frac{h}{p} = \frac{h}{\sqrt{2meV}} \text{ or } \lambda = \frac{12.27}{\sqrt{V}} \text{ \AA}$$

$$\therefore \lambda = \frac{6.63 \times 10^{-34}}{\sqrt{(2 \times 9.1 \times 10^{-31} \times 1.6 \times 10^{-19} \times 50 \times 10^3)}}$$

$$\lambda = 5.33 \times 10^{-12} \text{ m}$$

The resolving power of an electron microscope is much better than that of optical microscope.

[Note : If the student writes R.P  $\propto \frac{h}{\lambda}$ , award this ½ mark]

28. Draw a labelled diagram of Van de Graaff generator. State its working principle to show how by introducing a small charged sphere into a larger sphere, a large amount of charge can be transferred to the outer sphere. State the use of this machine and also point out its limitations.

**OR**

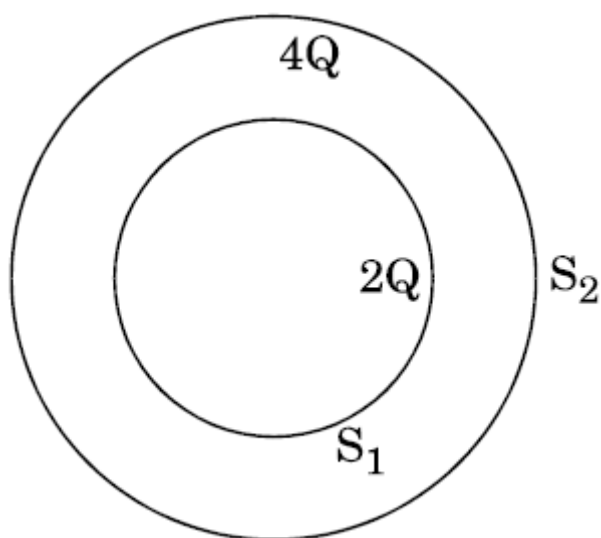
(a) Deduce the expression for the torque acting on a dipole of dipole moment

$\vec{p}$  in the presence of a uniform electric field  $\vec{E}$ .

(b) Consider two hollow concentric spheres,  $S_1$  and  $S_2$ , enclosing charges  $2Q$  and  $4Q$  respectively as shown in the figure. (i) Find out the ratio of the electric flux through them. (ii) How will the electric flux through

the sphere  $S_1$  change if a medium of dielectric constant ' $\epsilon_r$ ' is introduced in the space inside  $S_1$  in place of air ?

Deduce the necessary expression.

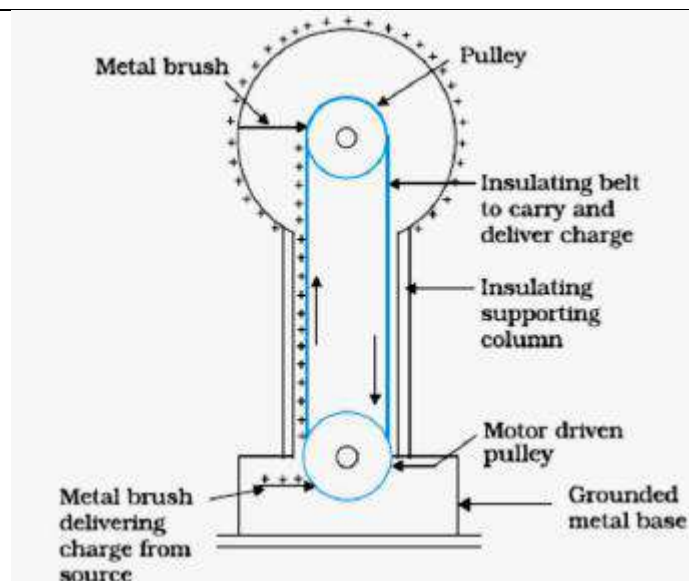


**Solution:**

Diagram

Principle and working

Use and limitation

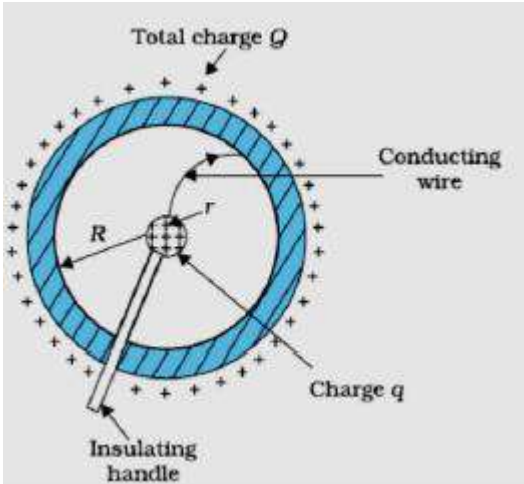


[Note : Award 1 mark only if the diagram is not labelled]

**Principle & working**

Consider a set up of the type shown here





i. Potential inside and on the surface, of the conducting sphere of radius 'R':

$$V'_R = \frac{1}{4\pi\epsilon_0} \cdot \frac{Q}{R}$$

ii. Potential due to small sphere of radius 'r' carrying a charge 'q':

$$\text{At the surface of the smaller sphere : } V'_R = \frac{1}{4\pi\epsilon_0} \cdot \frac{q}{r}$$

$$\text{At the surface of the larger sphere : } V''_R = \frac{1}{4\pi\epsilon_0} \cdot \frac{Q}{R}$$

∴ The difference of potential between the smaller and the larger sphere:

$$\begin{aligned} \Delta V &= \frac{1}{4\pi\epsilon_0} \cdot \left[ \left( \frac{Q}{R} + \frac{q}{r} \right) - \left( \frac{Q}{R} + \frac{q}{r} \right) \right] \\ &= \frac{q}{4\pi\epsilon_0} \left( \frac{1}{r} - \frac{1}{R} \right) \end{aligned}$$

When 'q' is positive, the inner sphere would always be at a higher potential with respect to outer sphere, irrespective of the amount of charges on the two.

∴ When both the spheres are connected, charge will flow from the smaller sphere to the larger sphere. Thus for a set up of the type shown, charge would keep on piling up on the larger sphere.

**Use :** This machine is used to accelerate charged particles (electron, protons, ions) to high energies.

**Limitation:** It can build up potentials upto a few million volts only.

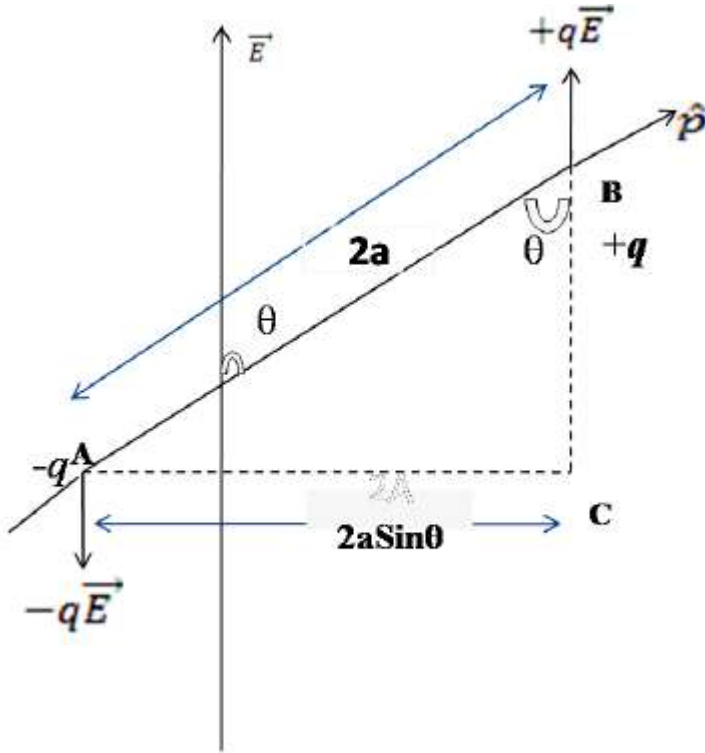
**OR**

- (a) Deducing the expression for torque
- (b) Finding the ratio of the flux through the two spheres
- (c) Finding the change in flux

(a)

The forces, acting on the two charges of the dipole, are

$$+q\vec{E} \text{ and } -q\vec{E}$$



The net force on the dipole is zero.

The two forces are, however, equivalent to a torque having a magnitude

$$\begin{aligned}\tau &= (qE)AC \\ &= qE \cdot 2a \sin\theta \\ &= pE \sin\theta\end{aligned}$$

The direction of this torque is that of the cross product  $(\vec{p} \times \vec{E})$ . Hence, the torque acting on the dipole, is given by

$$\vec{\tau} = \vec{p} \times \vec{E}$$

(b)

As per Gauss's Theorem

$$\text{Electric Flux } \oint_s \vec{E} \cdot d\vec{S} = \frac{q_{\text{enclosed}}}{\epsilon_0}$$

$$\therefore \text{For sphere } S_1, \text{ flux enclosed} = \phi_1 = \frac{2Q}{\epsilon_0}$$

$$\text{For sphere } S_2, \text{ flux enclosed} = \phi_2 = \frac{2Q + 4Q}{\epsilon_0} = \frac{6Q}{\epsilon_0}$$

$$\therefore \frac{\phi_1}{\phi_2} = \frac{1}{3}$$

When a medium of dielectric consistent  $\epsilon_r$  is introduced in sphere  $S_1$  the flux through  $S_1$  would be  $\phi'_1 = \frac{2Q}{\epsilon_r}$

[Also award this mark if the student writes  $\phi_1 = \frac{2Q}{\epsilon_0 \epsilon_r}$ ]

[Note : If the student just writes that the flux through  $S_1$  decreases, award  $\frac{1}{2}$  mark only.]

29. (a) In Young's double slit experiment, describe briefly how bright and dark fringes are obtained on the screen kept in front of a double slit. Hence obtain the expression for the fringe width. (b) The ratio of the intensities at minima to the maxima in the

Young's double slit experiment is 9 : 25. Find the ratio of the widths of the two slits.

OR

(a) Describe briefly how a diffraction pattern is obtained on a screen due to a single narrow slit illuminated by a monochromatic source of light. Hence obtain the conditions for the angular width of secondary maxima and secondary minima.

(b) Two wavelengths of sodium light of 590 nm and 596 nm are used in turn to study the diffraction taking place at a single slit of aperture  $2 \times 10^{-6}$  m. The distance between the slit and the screen is 1.5 m. Calculate the separation between the positions of first maxima of the diffraction pattern obtained in the two cases.

**Solution:**

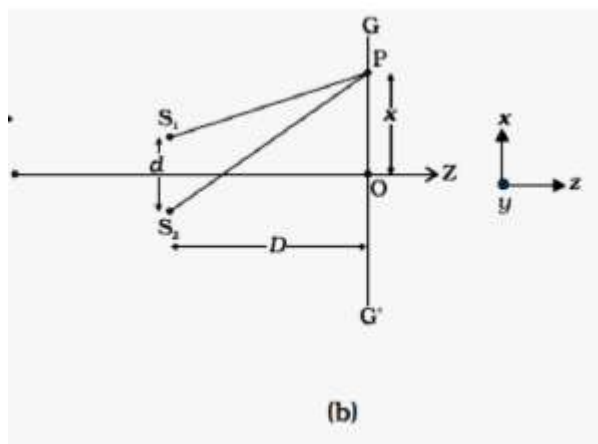
a) Formation of bright and dark fringes

Obtaining the expression for fringe width

(b) Finding the ratio

(a) The light rays from the two (coherent) slits, reaching a point 'P' on the screen, have a path difference ( $S_2P - S_1P$ ). The point 'P' would, therefore be a i. Point of maxima (bright fringe), if  $S_2P - S_1P = n\lambda$ .

ii. Point of minima (dark fringe), if  $S_2P - S_1P = (2n + 1)\frac{\lambda}{2}$



We have

$$(S_2P)^2 - (S_1P)^2 = \left\{ D^2 - \left( x + \frac{d}{2} \right)^2 \right\} - \left\{ D^2 + \left( x - \frac{d}{2} \right)^2 \right\}$$

$$= 2xd$$

$$S_2P - S_1P = \frac{1xd}{S_2P + S_1P} \approx \frac{2xd}{2D} = \frac{xd}{D}$$

$\therefore$  We have maxima at points, where

$$\frac{xd}{D} = n\lambda$$

and minima at points where

$$\frac{xd}{D} = \left( \frac{2n+1}{2} \right) \lambda$$

Now, fringe width  $\beta$  = separation between two successive maxima ( or two successive minima) =  $x_n - x_{n-1}$

$$\therefore \beta = \frac{\lambda D}{d}$$

(b) We have

$$\frac{l_{\max}}{l_{\min}} = \frac{(a_1 + a_2)^2}{(a_1 - a_2)^2} = \frac{25}{9}$$

$$\therefore \frac{a_1}{a_2} = \frac{4}{1}$$

$$\therefore \frac{W_1}{W_2} = \frac{l_1}{l_2} = \frac{(a_1)^2}{(a_2)^2} = \frac{16}{1}$$

[Note: Give ½ mark if the student just writes Intensity  $\propto$  width

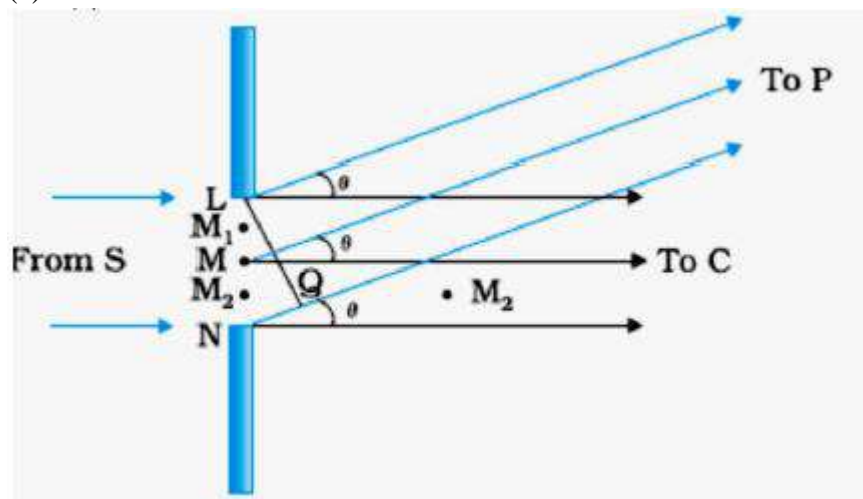
**OR**

a) Obtaining the diffraction pattern

Conditions for angular width

b) Calculation of separation

(a)



The path difference ( NP-LP) , between the two edges of the slit, is given by

$$NP-LP = a \sin \theta \approx a \theta$$

We, therefore, get maxima and minima, at different points of the screen, depending on the path difference between the contributions from the wavelets, emanating from different points of the slit. This results in a diffraction pattern on the screen.

The path difference between two points  $M_1, M_2$ , in the slit plane, separated by a distance 'y', is  $y\theta$ .

At the central point, 'C', on the screen, ' $\theta$ ' is zero.

All parts of the slit contribute in phase

Hence 'C' is a maximum.

At all points where ' $\theta \cong (n + \frac{1}{2}) \frac{\lambda}{a}$ ', we get (secondary) maxima of varying intensity. This is because of the non-zero contribution of a (decreasing) part of the slit at these points.

At all points where  $\theta \approx \frac{n\lambda}{a}$ , we get minima.

This is because of a net (almost) zero contribution of the whole slit at the sepoints.

[Note : Please also accept alternative correct diagram with appropriate explanation.]

(b) Angular width of the secondary maxima  $\approx 2(2n+1) \frac{\lambda}{a}$

$$\therefore \text{Linear width} = [(2n+1) \frac{\lambda}{a}] D$$

$\therefore$  Linear separation, between the first maxima ( $n=1$ ) of the two wavelengths, on the screen, is

$$\frac{3(\lambda_2 - \lambda_1)}{a} \times D$$

$$\therefore \text{Separation} = \frac{3(596 - 590) \times 10^{-9}}{2 \times 10^{-6}} \times 1.5 \text{ m}$$

$$= 13.5 \times 10^{-3} \text{ m} (= 13.5 \text{ mm})$$

30. (a) Deduce an expression for the frequency of revolution of a charged particle in a magnetic field and show that it is independent of velocity or energy of the particle.

(b) Draw a schematic sketch of a cyclotron. Explain, giving the essential details of its construction, how it is used to accelerate the charged particles.

**OR**

(a) Draw a labelled diagram of a moving coil galvanometer. Describe briefly its principle and working.

(b) Answer the following :

(i) Why is it necessary to introduce a cylindrical soft iron core inside the coil of a galvanometer ?

(ii) Increasing the current sensitivity of a galvanometer may not necessarily increase its voltage sensitivity.

Explain, giving reason.

**Solution:**

(a) Expression for frequency

Frequency Independent of 'v' or energy

(b) Sketch of cyclotron

Construction

Working

(a) When a particle of mass 'm' and charge 'q', moves with a velocity **v**, in a uniform magnetic field **B**, it experiences a force **F** where

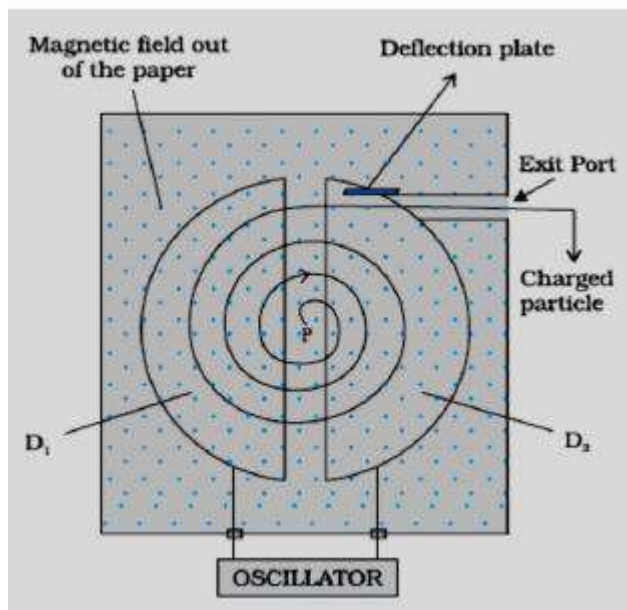
$$\vec{F} = q (\vec{v} \times \vec{B})$$

$$\therefore \text{Centripetal force} \frac{mv^2}{r} = qvB_{\perp}$$

$$\therefore r = \frac{mv}{qB_{\perp}}$$

$$\therefore \text{frequency} = \frac{v}{2\pi r} = \frac{qB_{\perp}}{2\pi m}$$

$\therefore$  It is independent of the velocity or the energy of the particle.



**Construction:** The cyclotron is made up of two hollow semi-circular disc like metal containers,  $D_1$  and  $D_2$ , called dees. It uses crossed electric and magnetic fields. The electric field is provided by an oscillator of adjustable frequency.

[**Note:** Award this mark even if the student labels the diagram properly without writing the details of the construction.]

**Working:** In a cyclotron, the frequency of the applied alternating field is adjusted to be equal to the frequency of revolution of the charged particles in the magnetic field. This ensures that the particles get accelerated every time they cross the space between the two dees. The radius of their path increases with increase in energy and they are finally made to leave the system via an exit slit.

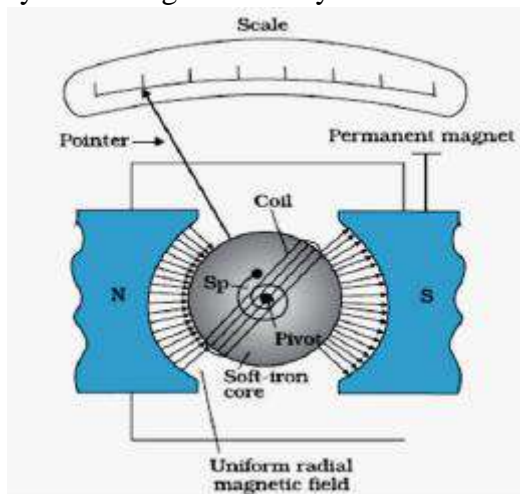
OR

(a) Labelled diagram

Principle and working

(b) i) Reason for cylindrical soft iron core

ii) Comparison of current sensitivity and voltage sensitivity



**Principle and working:** A current carrying coil, placed in a uniform magnetic field, (can) experience a torque

Consider a rectangular coil for which no. of turns = N, Area of cross- section =  $l \times b = A$ ,

Intensity of the uniform magnetic field = B, Current through the coil = I

$$\therefore \text{Deflecting torque} = BIL \times b = BIA$$

$$\text{For } N \text{ turns } \tau = NBIA$$

$$\text{Restoring torque in the spring} = k\theta$$

(k = restoring torque per unit twist)

$$\therefore NBIA = k\theta$$

$$\therefore I = \left( \frac{k}{NBA} \right)$$

$$\therefore I \propto \theta$$

The deflection of the coil, is, therefore, proportional to the current flowing through it.

(b) (i) The soft iron core not only makes the field radial but also increases the strength of the magnetic field.

[ **Note:-** Award this one mark even if the student writes just one of the two reasons given above ]

(ii) We have

$$\text{Current sensitivity} = \frac{\theta}{I} = NBA/k$$

$$\text{Voltage sensitivity} = \frac{\theta}{V} = \frac{\theta}{IR} = \left( \frac{NBA}{k} \right) \cdot \frac{1}{R}$$

It follows that an increase in current sensitivity may not necessarily increase the voltage sensitivity.