Physics (Theory)

[*Time allowed: 3 hours*] [*Maximum marks:70*]

General Instructions:

(i) **All** questions are compulsory.

(ii) There are **30** questions in total.

Questions **1** to **8** carry **one** mark each.

Questions **9** to **18** carry **two** marks each.

Question **19** to **27** carry **three** marks each.

Question **28** to **30** carry **five** marks each.

(iii) 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. You have to attempt only one of the choices in such questions.

(iv) Use of calculators is **not** permitted.

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

$C = 3 \times 108 \text{ ms}^{-1}$

$H = 6.626 \times 10^{-34} \text{ Js}$

$e = 1.602 \times 10^{-19} \text{ C}$

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

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

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

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

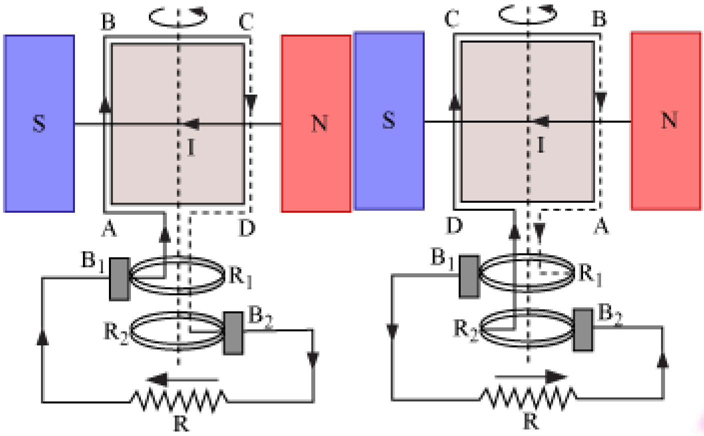
Boltzmann's constant $k = 1.381 \times 10^{-23} \text{ JK}^{-1}$

Avogadro's number $N_A = 6.022 \times 10^{23} \text{ mol}^{-1}$

Radius of earth = 6400 km

28. State the working of a.c. generator with the help of a labeled diagram.
The coil of an a.c. generator having N turns, each of area A, is rotated with a constant angular velocityω. Deduce the expression for the alternating e.m.f. generated in the coil.
What is the source of energy generation in this device?

Solution:
AC Generator:
Principle − Based on the phenomenon of electromagnetic induction
Construction:

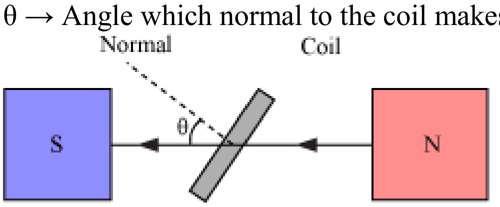


(a) (b)

Main parts of an ac generator:

- Armature − Rectangular coil ABCD
- Filed Magnets − Two pole pieces of a strong electromagnet
- Slip Rings − The ends of coil ABCD are connected to two hollow metallic rings R_1 and R_2.
- Brushes − B_1 and B_2 are two flexible metal plates or carbon rods. They are fixed and are kept in tight contact with R_1 and R_2 respectively.

Theory and Working − As the armature coil is rotated in the magnetic field, angle θ between the field and normal to the coil changes continuously. Therefore, magnetic flux linked with the coil changes. An *emf* is induced in the coil. According to Fleming's right hand rule, current induced in AB is from A to B and it is from C to D in CD. In the external circuit, current flows from B_2 to B_1.
To calculate the magnitude of *emf* induced:
Suppose
$A \rightarrow$ Area of each turn of the coil
$N \rightarrow$ Number of turns in the coil
$\vec{B} \rightarrow$ Strength of magnetic field
$\theta \rightarrow$ Angle which normal to the coil makes with $\vec{B}$ at any instant t



$\therefore$ Magnetic flux linked with the coil in this position:
$\phi = N(\vec{B} \cdot \vec{A}) = NBA \cos\theta = NBA \cos\omega t$ …(i)
Where, 'ω' is angular velocity of the coil

As the coil rotates, angle θ changes. Therefore, magnetic flux Φ linked with the coil changes and hence, an *emf* is induced in the coil. At this instant t, if e is the *emf* induced in the coil, then

$$e=-\frac{d\theta}{dt}=-\frac{d}{dt}(NAB\cos\omega t)$$

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

$$=-NAB(-\sin\omega t)\omega$$

$\therefore e$ = NAB ω sin ωt

The generator converts the mechanical energy into electrical energy. The mechanical energy may be obtained from the rotation of the turbine associated with the generator. The turbine in turn, may be working by the kinetic energy of running water, wind or steam.

OR

(a) Show that in an a.c. circuit containing a pure inductor, the voltage is ahead of current by $\pi/2$ in phase.

(b) A horizontal straight wire of length L extending from east to west is falling with speed v at right angles to the horizontal component of Earth's magnetic field B.

(i) Write the expression for the instantaneous value of the e.m.f. induced in the wire.

(ii) What is the direction of the e.m.f.?

(iii) Which end of the wire is at the higher potential?

Solution:

(a) AC voltage applied to an inductor

Source, $v = v_m \sin \omega t$

Using Kirchhoff's loop rule,

$$\sum \varepsilon(t)=0$$

$$v-\frac{Ldi}{dt}=0$$

$$\frac{di}{dt}=\frac{v}{L}=\frac{v_m}{L}\sin\omega t$$

Integrating *di/dt* with respect to time,

$$\int \frac{di}{dt}dt = \frac{v_m}{L}\int \sin(\omega t)dt$$

$$i = -\frac{v_m}{\omega L}\cos(\omega t) + \text{constant}$$

$$-\cos\omega t = \sin\left(\omega t - \frac{\pi}{2}\right)$$

$$\therefore i = i_m \sin\left(\omega t - \frac{\pi}{2}\right)$$

$\because$ Where, $i_m = \frac{v_m}{\omega L}$ is the amplitude of current

(b) Given
Length of wire = L
Velocity with which it is falling = v
Magnetic field = $B_H = B \cos\theta$
Angle between v & B, $\phi = 90°$

(i) As the wire fall downwards due to this motion e^- within the wire also moves downwards and feels a force due to Earth's magnetic field towards west

$\vec{F} = -e\vec{v}\times\vec{B} \Rightarrow F = -evB$

As electrons moves towards west end of wire they apply opposite or repelling force to new incoming charge. As more and more electron's come, eventually we achieve an equilibrium situation where no more electrons can come towards west side end. At this particular situation.

$eE = -evB$
$E = -vB$
$V = -EL$
$\Rightarrow V = +vBL$ e.m.f. setup within in the wire.

ii) The direction of the e.m.f. will be the polarity of the rod, which is positive at the east end and negative at the west end.

iii) As the electrons get accumulated at the west end it would mean that the west end is at negative potential. Which implies east end is at high potential (non zero potential).

29. State the importance of coherent sources in the phenomenon of interference.
In Young's double slit experiment to produce interference pattern, obtain the conditions for constructive and destructive interference. Hence deduce the expression for the fringe width. How does the fringe width get affected, if the entire experimental apparatus of Young is immersed in water?

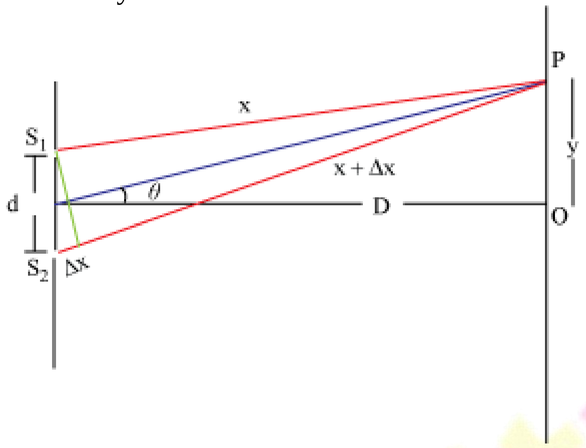
OR

(a) State Huygen's principle. Using this principle explain how a diffraction pattern is obtained on a screen due to a narrow slit on which a narrow beam coming from a

$\Rightarrow n = \frac{v\lambda}{v\lambda_w}$ monochromatic source of light is incident normally.

(b) Show that the angular width of the first diffraction fringe is half of that of the central fringe.
(c) If a monochromatic source of light is replaced by white light, what change would you observe in the diffraction pattern?

Solution:
Two sources are called coherent sources, if the phase difference between them is either zero or constant. And this is essential for interference of light.
For any other incoherent source of light a steady interference pattern can never be obtained, even if the sources emit waves of equal wavelengths and equal amplitudes. This is because the waves emitted by a source undergo rapid and irregular changes of phase, so that the intensity at any point is never constant. Naturally the phase difference between the waves emitted by the two sources cannot remain constant.



The two waves interfering at P have different distances $S_1P = x$ and $S_2P = x + \Delta x$.
So, for the two sources S_1 and S_2 we can respectively write,

$$I_1 = I_{01}\sin(kx - wt)$$

$$I_1 = I_{02}\sin(k(x+\Delta x) - wt) = I_{02}\sin(kx - wt + \delta)$$

$$\delta = k\Delta x = (2\pi/\lambda)\times\Delta x$$

The resultant can be written as,

$$I = I_0\sin(kx - wt + \varepsilon)$$

Where $I_0^2 = I_{01}^2 + I_{02}^2 + 2 I_{01} I_{02}\cos\delta$

And $\tan\varepsilon = I_{02}\sin\delta/(I_{01} + I_{02}\cos\delta)$

The condition for constructive (bright fringe) and destructive (dark fringe) interference are as follows;

$\delta = 2n\pi$ for bright fringes

$\delta = (2n+1)\pi$ for dark fringes

Where n is an integer.

Now to find the fringe width,
The path difference is $\Delta x = S_2P - S_1P$,

nearly equal to $d\sin\theta = d\tan\theta = \frac{dy}{D}$

Hence we can write, $y = \frac{n\lambda D}{d}$, n is an integer.

Fringe width is the distance between two consecutive dark or bright fringes, so we have fringe width $= \dfrac{\lambda D}{d}$.

If the whole apparatus is immersed in water and refractive index of water is n then,

$\dfrac{v}{c} = \dfrac{1}{n}$ Where v is velocity of light in water

$\Rightarrow n = \dfrac{\nu\lambda}{\nu\lambda_\omega}$ λ = wavelength of light in air

$\Rightarrow n = \dfrac{\nu\lambda}{\lambda_\omega}$ λ_ω = wavelength of light in water

$\lambda_\omega = \dfrac{\lambda}{n}$ ν = frequency of light in air and water

Hence

$$\beta_\omega = \frac{\lambda_\omega d}{D} = \frac{\lambda d}{nD}$$

$$\boxed{\beta_\omega = \frac{1}{n}\beta}$$

This shows fringe width will be reduced by the factor of the refractive index of water.

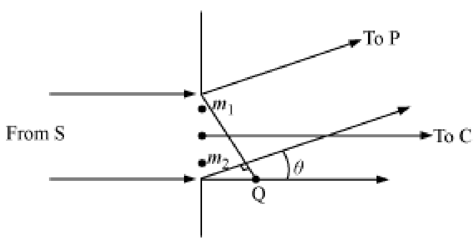
OR

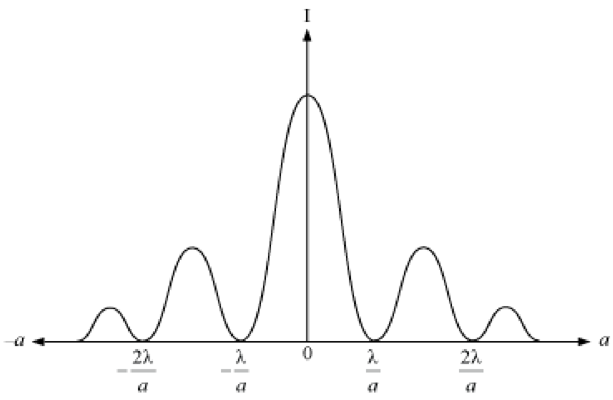
a) Huygen's Principle

It states that
i) Rays (light rays) are perpendicular to wave fronts.
Where wave fronts are defined as a surface of constant phase.

ii) The time taken for light to travel from one wave front to another is same along any ray.

Diffraction Pattern:
Explanation of diffraction phenomena along with the following diagrams.





(b) Derivation to show

β or $\Delta\theta = \dfrac{\lambda}{d}$ for interference central fringe

and

β or $\Delta\theta = \dfrac{\lambda}{2d}$ For diffraction first fringe.

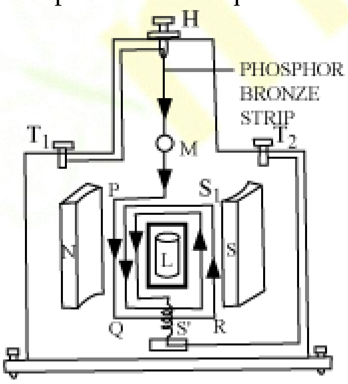
(c) Following changes will be observed
(i) Central fringe will be bright but subsequent bright fringes will be coloured instead of just being bright.
(ii) Fringe width, angular fringe width will not be constant.

30. (a) State the principle of the working of a moving coil galvanometer, giving its labeled diagram.
(b) "Increasing the current sensitivity of a galvanometer may not necessarily increase its voltage sensitivity." Justify this statement.
(c) Outline the necessary steps to convert a galvanometer of resistance R_G into an ammeter of a given range.

OR

(a) Using Ampere's circuital law, obtain the expression for the magnetic field due to a long solenoid at a point inside the solenoid on its axis.
(b) In what respect is a toroid different from a solenoid? Draw and compare the pattern of the magnetic field lines in the two cases.
(c) How is the magnetic field inside a given solenoid made strong?

Solution:
(a) Moving coil Galvanometer
Principle:
Its working is based on the fact that when a current carrying coil is placed in a magnetic field, it experiences a torque.



Working:
Suppose the coil *PQRS* is suspended freely in the magnetic field.
Let
l = Length *PQ* or *RS* of the coil
b = Breadth *QR* or *SP* of the coil
n = Number of turns in the coil
Area of each turn of the coil, $A = l \times b$

Let B = Strength of the magnetic field in which coil is suspended
I = Current passing through the coil in the direction $PQRS$
Let, at any instant, α be the angle which the normal drawn on the plane of the coil makes with the direction of magnetic field.
The rectangular coil carrying current when placed in the magnetic field experiences a torque whose magnitude is given by,
$\tau = nIBA \sin \alpha$

(b) "Increasing the current sensitivity of a galvanometer may not necessarily increase its voltage sensitivity."
Due to deflecting torque, the coil rotates and suspension wire gets twisted. A restoring torque is set up in the suspension wire.
Let θ be the twist produced in the phosphor bronze strip due to rotation of the coil and K be the restoring torque per unit twist of the phosphor bronze strip. Then,
Total restoring torque produced = $k\theta$
In equilibrium position of the coil,
Deflecting torque = Restoring torque
$\therefore NIBA = k\theta$

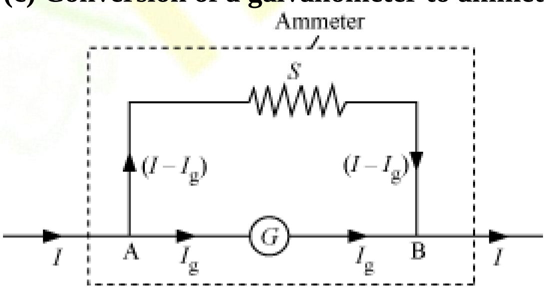
Or,
$$I = \frac{k}{NBA}\theta \text{ or } G\theta$$

Where,
$$\frac{k}{NBA} = G = a$$
[constant for a galvanometer]

It is known as galvanometer constant.

- Current sensitivity of the galvanometer is the deflection per unit current.
$$\therefore \frac{\phi}{I} = \frac{NAB}{k}$$
- Voltage sensitivity is the deflection per unit voltage.
$$\therefore \frac{\phi}{V} = \left(\frac{NAB}{k}\right)\frac{I}{V}$$
$$= \frac{NAB}{k}\frac{1}{R} \qquad (\because V = IR)$$

(c) Conversion of a galvanometer to ammeter



- A shunt (low resistance) is connected in parallel with the galvanometer.
$$S = \left(\frac{I_g}{I - I_g}\right)G$$

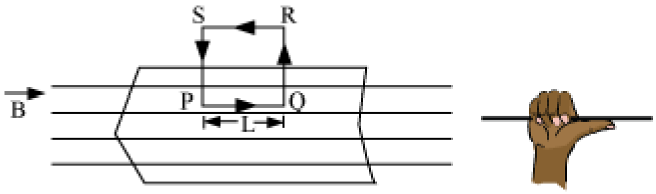
Where,
$I \rightarrow$ Total current in circuit

$G \rightarrow$ Resistance of the galvanometer
$S \rightarrow$ Resistance of the shunt
$I_g \rightarrow$ Current through galvanometer

OR

(a)
Solenoid

- It consists of an insulating long wire closely wound in the form of helix.
- Its length is large as compared to its diameter.



- Magnetic field due to RQ and SP path is zero because they are perpendicular to the axis of solenoid. Since SR is outside the solenoid, the magnetic field is zero.
- The line integral of magnetic field induction $\vec{B}$ over the closed path PQRS is

$$\oint_{PQRS} \vec{B}\cdot\vec{dl} = \oint_{PQ} \vec{B}\cdot\vec{dl} = BL$$

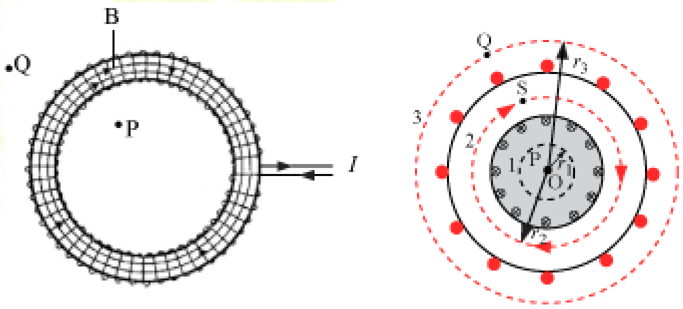
From Ampere's circuital law,

$$\oint_{PQRS} \vec{B}\cdot\vec{dl} = \mu_0 \times \text{Total current through rectangle PQRS}$$

$BL = \mu_0 \times$ Number of turns in rectangle $\times$ Current
$BL = \mu_0 nLI$
$\therefore\ B = \mu_0 nI$

(b) Toroid

- It is a hollow circular ring on which a large number of turns of a wire are closely wound.



(a) (b)

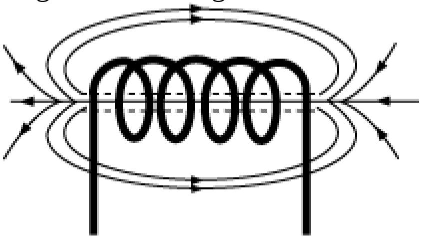
- Three Amperian loops (1, 2, and 3) are shown by dotted lines.
- Magnetic field along loop 1 is zero because the loop encloses no current.
- Magnetic field along loop 3 is zero because the current coming out of the paper is cancelled exactly by the current going out of it.
- Magnetic field at S (along loop 2):

From Ampere's law,
$\therefore B\,(2\pi r) = \mu_0\, NI$
Where,
$B \rightarrow$ Magnetic field

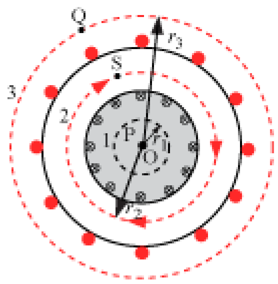
$r \rightarrow$ Radius
$I \rightarrow$ Current
$N \rightarrow$ Number of turns of toroidal coil

$$\therefore B = \frac{\mu_0 NI}{2\pi r}$$

(b) Magnetic field diagrams are as followed



Magnetic Field around a Solenoid



(b)

(c) The magnetic field lines inside a solenoid can be made strong by
(i) Inserting a ferromagnetic core
(ii) Increasing the number of turns of the solenoid
(iii) Increasing the current passing through the solenoid.

----------End of the Exam---------