4. MOVING CHARGES AND MAGNETISM

One marks questions & answers

1. Who concluded that moving charges or current produces magnetic field in the surrounding surface?
   - **Christian Oersted.**
2. Mention the expression for the magnetic force experienced by moving charge.
   - **F = q ($\vec{v}\times\vec{B}$) or f= qvB sin θ $\hat{n}$**
3. In a certain arrangement a proton does not get deflected while passing through a magnetic field region. Under what condition is it possible?
   - **It is possible if the proton enters the magnetic field along the field direction.**
4. What is the trajectory of charged particle moving perpendicular to the direction of uniform magnetic field?
   - **Circle**
5. What is significance of velocity selector?
   - **Velocity selector is used in accelerator to select charged particle of particular velocity out of a beam containing charges moving with different speeds.**
6. which one of the fallowing will describe the smallest circle when projected with the same velocity v perpendicular to the magnetic field B :(i) α -particle (ii) β - particle
   - **α -particle**
7. What is cyclotron?
   - **It is a device used to accelerate charged particles or ions.**
8. Who invented Cyclotron?
   - **E .O Lawrence and M. S. Livingston**
9. What is resonance condition in cyclotron?
   - **The condition in which the trajectory of the applied voltage is adjusted so that the polarity of the Dee's is reversed in the same time that it takes the ions to complete one half of the revolution.**
10. What is solenoid?
    - **Solenoids consist of a long insulated wire wound in the form of a helix where neighboring turns are closely spaced.**
11. What is toroid?

- **This is a hallow circular ring on which a large number of turns of a wire are closely wound.**

12. What is an ideal toroid?

- **The ideal toroid is one in which coils are circular.**

13. Define magnetic dipole moment of a current loop.

- **The magnetic moment of a current loop is defined as the product of current *I* and the area vector $\vec{A}$ of the loop**

14. What is the value of Bohr magneton?

- μ_l**=9.27×10^{-27}Am^2**

15. Define current sensitivity of the galvanometer?

- **It is defined as deflection per unit current of Moving coil galvanometer.**

17. An ammeter and a milliammeter are converted from the galvanometer. Out of the two, Which current measuring instrument has higher resistance?

- **Higher is the range lower will be the value of shunt, so milliammeter will be having higher resistance.**

Two marks questions & answers

1. **Mention the expression for Lorentz's force.**

In the presence of both electric field, E(r) and magnetic field, B(r) a point charge 'q' is moving with a velocity v. Then the total force on that charge is Lorentz force,

i.e $F= F_{electric} + F_{magnetic} = qE(r) + qvB(r)$

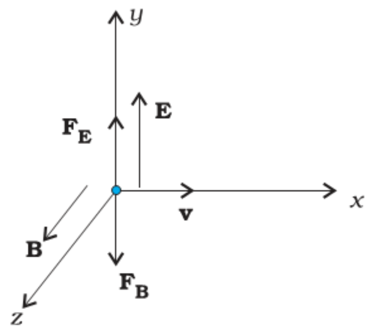
Note: 1. Magnetic force on the charge depends on 'q', 'v' and 'B'

2. $\vec{F}_{magnetic} = q\left(\vec{v} \times \vec{B}\right)$; and is always perpendicular to the plane containing $\vec{v}$ and $\vec{B}$.

Also, $F=qvB\sin\theta\ \hat{n}$

3. If θ=0 or 180o, then F=0 and if θ= 90, then F=Fmaximum= qvB.

2. **Show that crossed electric and magnetic fields serves as velocity selector.**



Suppose we consider a charged particle 'q' moving with velocity 'v' in presence of both electric and magnetic fields, experiences a force given by $F = F_E + F_B = (qE+qvB)\hat{j}$ ($\therefore$ assuming $\theta = 90^o$).

If E is perpendicular to B as shown in the diagram, then $F=(qE-qvB)\hat{j}$

Suppose we adjust the values of E and B, such that qE=qvB, then E=vB

Or $v = \frac{E}{B}$.

This velocity is that chosen velocity under which the charged particle move undeflected through the fields. The ratio $\frac{E}{B}$ is called velocity selector.

Note: $\frac{E}{B}$ is independent of 'q' and 'm' of the particle under motion.

3. **Mention the uses of cyclotron.**
   It is used to implant ions into solids and modify their properties
   It is used in hospitals to produce radioactive substance. This can be used in diagnosis and treatment.

4. **State and explain Ampere's circuital law.**
   " The line integral of resultant magnetic field along a closed plane curve is equal to μ0 time the total current crossing the area bounded by the closed curve provided the electric field inside the loop remains constant"
   i.e $\oint B.dl = \mu_o I$; where I is the total current through the surface.

5. Mention the expression for angular for deflection produced in Moving Coil Galvanometer?

$$\phi = \left(\frac{NAB}{k}\right)I$$

Where, **N** is number of turns
B Magnetic field

A Area of the coil, **K** is torsional constant of the spring.

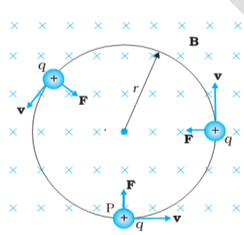
Three marks questions & answers

1. **Derive the expression for magnetic force in a current carrying conductor. F=*i*(l × B)**
   Consider a rod of a uniform cross-sectional area A and length l. Let n be the number density of charge carriers(free electrons) in it.
   Then the total number of mobile charge carriers in it is= nAl. Assume that these charge carriers are under motion with a drift velocity, vd.
   In the F= (n A l) q vd × B; here q is the charge of each charge carrier.
   presence of an external magnetic field B, the force on these charge carriers is
   But current density j = n q vd
   ∴ F= j A l × B
   But, j A = I, the electric current in the conductor, then

   $\boxed{\therefore F = I\, l \times B}$
   i.e F=(I*l*B sinθ)

2. **Obtain the expression for radius of circular path traversed by a charge in a magnetic field.**

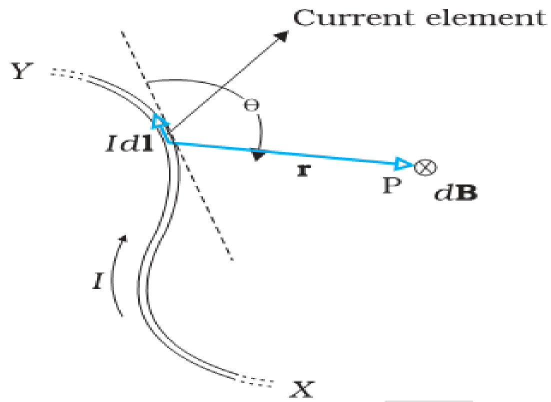
   Assume that a charged particle 'q' is moving perpendicular to the uniform magnetic field B, i.e θ=90. The perpendicular force F = qv x B acts as centripetal force, thus producing a uniform circular motion for the particle in a plane pependicular to the field



i.e $\frac{mv^2}{r} = qvB$ or $\frac{mv}{r} = qB$; here m is the mass the particle, r is the radius of the circular path traced

$$\boxed{\therefore r = \frac{mv}{qB}}$$

3. **State and explain Biot-Savart's law.**



Consider a conductor XY carrying current I. There we choose an infinitesimal element dl of the conductor. The magnetic field dB due to this element is to be determined at a point P which is at a distance 'r' from it. Let θ be the angle between dl and the position vector 'r'.

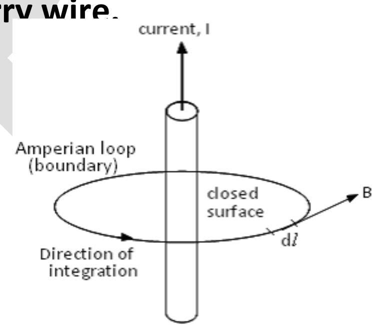
According to Biot-Savart's law, the magnitude of the magnetic field dB at a point p is proportional to the current I, the element length |dl|, and inversely proportional to the square of the distance r and dB is directed perpendicular to the plane containing dl and r .

i.e $\vec{dB} = \frac{\mu_o}{4\pi}\frac{I\vec{dl}x\vec{r}}{r^3}$ or

$$\left|\vec{dB}\right| = \frac{\mu_o}{4\pi}\frac{I\left|\vec{dl}\right|\left|\vec{r}\right|\sin\theta}{r^3} = \frac{\mu_o}{4\pi}\frac{Idl\sin\theta}{r^2}$$

here $\mu_o = 4\pi x10^{-7}$ Hm^{-1} is a constant called permeability of vacuum.

4. **Using ampere circuital law, obtain an expression for magnetic field due to infinitely long straight current carry wire.**



Consider a infinitely long conductor carrying current. Let I_e be the current enclosed by the loop and L be the length of the loop for which B is tangential, then the amperes circuital law

$\oint B.dl = \mu_o I_i$ becomes $BL=\mu_o Ie$

If we assume a straight conductor and the boundary of the surface surrounding the conductor as a circle, t hen length of the boundary is the circumference, $2\pi r$; where 'r' is the radius of the circle. Then $B.2\pi r = \mu_o I$

$$\boxed{\therefore B = \frac{\mu_o I}{2\pi r}}$$

5. **Show that current loop as a magnetic dipole?**

When x>>R, (i.e at a long distance from O along the x-axis),

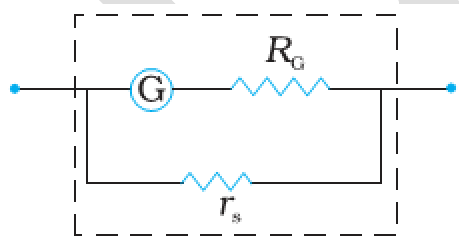
$B = \frac{\mu_o N I R^2}{2x^3} = \frac{\mu_o N I \pi R^2}{2\pi x^3} = \frac{\mu_o N I A}{2\pi x^3} = \frac{\mu_o}{2\pi}\frac{m}{x^3} = \frac{\mu_o}{4\pi}\frac{2m}{x^3}$; here m=NIA called Magnetic dipole moment of the loop and $A=\pi R^2$, the circular area of the loop.

Similarly in electrostatics, for an electric dipole, electric field due to the dipole along its axis, $E = \frac{1}{4\pi\varepsilon_o}\frac{2p_e}{x^3}$; here p_e is the electric dipole moment.

This shows the current carrying circular loop is equivalent to a magnetic dipole.

6. **Explain how do you convert moving coile galvanometer into an ammeter.**

A small resistance rs , called shunt resistance is connected in parallel with the galvanometer coil; so that most of the current passes through the shunt.



Ammeter

The resistance of this arrangement is $\frac{1}{R_G} + \frac{1}{r_s}$

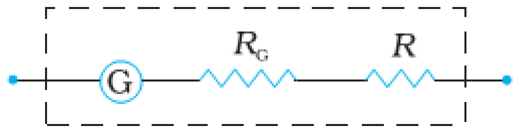
$$\Rightarrow \frac{R_G r_s}{R_G + r_s}$$

If RG >> rs, then the resistance of the arrangement $\approx \frac{R_G r_s}{R_G} = r_s$

This arrangement is calibrated to standard values of currents and hence we define, the current sensitivity of the galvanometer as the deflection per unit current, i.e $\frac{\phi}{I} = \frac{NAB}{k}$

7. **Explain how do you convert moving coile galvanometer into voltmeter.**

For this the galvanometer must be connected in parallel with a high resistance R. in series



Voltmeter

The resistance of the voltmeter is now, RG+ R

Since R >> RG, RG+R ≈ R

The scale of the voltmeter is calibrated to read off the p.d across a circuit.

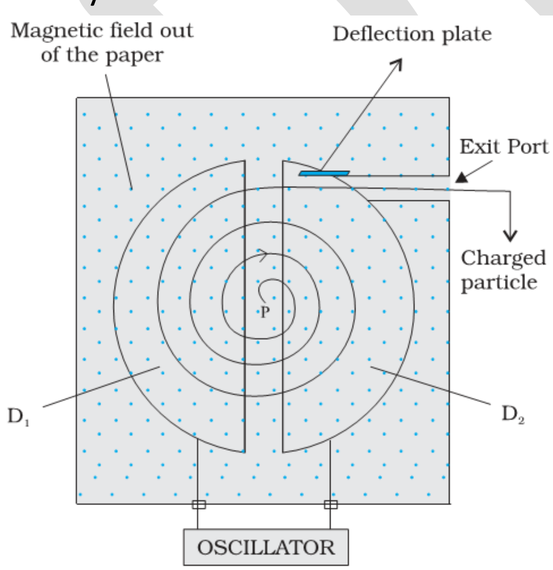
We define the voltage sensitivity as the deflection per unit voltage,

i.e $\frac{\phi}{V} = \left(\frac{NAB}{k}\right)\frac{1}{R}$ [because, $\phi = \left(\frac{NAB}{k}\right)I \Rightarrow \frac{\phi}{V} = \left(\frac{NAB}{k}\right)\frac{I}{V} \Rightarrow \frac{\phi}{V} = \left(\frac{NAB}{k}\right)\frac{1}{R}$

Five marks questions & answers

1. **Describe the construction and working theory of cyclotron.**

The cyclotron is a machine to accelerate charged particles or ions to high energies.



In the digarm there is a completely evacuated chamber and there are two metal semicircular containers, D1 and D2 called ‘dees’, which are connected to a high frequency oscillator as shown, which produces an alternating electric field ‘E’ at the gap between the dees. In the diagram ‘dot’ represents the applied magnetic field ‘B’.

As soon as the positively charged ion or particle 'P' is injected into the dees, B brings the particle into circular motion. As the particle enters the gap between the dees, the tuned 'E' accelerates the particle and the radius of the circular path increases, because of increased kinetic energy.

It should be noted that P enters the gap between the dees at regular interval of $\frac{T}{2}$; where T is the period of revolution.

i.e. $T = \frac{1}{\nu_c} = \frac{2\pi m}{qB}$ or $\nu_c = \frac{qB}{2\pi m}$ -----(1) This frequency is called cyclotron frequency.

Let ν_a is the frequency of the applied p.d across the dees through oscillator. If we adjust $\nu_a = \nu_c$ is called resonance condition. In this case, as the positive charge arrives at the edge of D1, D2 is at lower potential and vice versa. As a result the particle gets acceleration inside the gap.

Each time the kinetic energy increases by qV; V is the p.d across the gap. As it is found to have the radius approximately equal to that of dees, the deflecting plate throws the particle out through the exit port.

From (1), $2\pi\nu c = qB/m$ But, $2\pi\nu c = \omega$

$\Rightarrow \omega = qB/m$

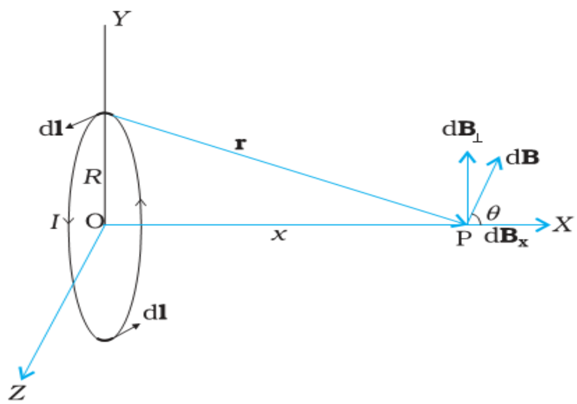
But, velocity at the exit, $v = R\omega$ or $\omega = \frac{v}{R}$; R is the radius at the exit.

$$\Rightarrow \frac{v}{R} = \frac{qB}{m} \quad ; \quad \text{i.e} \quad v = \frac{qBR}{m}$$

Squaring on both sides, we get $v^2 = \frac{q^2B^2R^2}{m^2}$

$\frac{1}{2}mv^2 = \frac{q^2B^2R^2}{m}$; This is the kinetic energy acquired by the positive charged particle or ion at the exit of the cyclotron.

2. **Derive an expression for magnetic field on the axis of a circular current loop.**



Consider a circular loop carrying a steady current I. The loop is placed in the y-z plane with its centre at the origin O and has a radius R. The x-axis is the axis of the loop. We want to find the magnetic field at P and is at a distance x from O.

Let us consider an element Idl on the loop and which produces a tiny magnetic field dB at P.

i.e $dB = \frac{\mu_o}{4\pi}\frac{I|dl x r|}{r^3} = \frac{\mu_o}{4\pi}\frac{Idl r \sin\theta}{r^3} = \frac{\mu_o}{4\pi}\frac{Idl \sin\theta}{r^2}$

Since d$l \perp$ r, $dB = \frac{\mu_o}{4\pi}\frac{Idl}{r^2}$

But $r^2 = x^2 + R^2$,

$\Rightarrow dB = \frac{\mu_o}{4\pi}\frac{Idl}{\left(x^2 + R^2\right)}$

The direction of dB is θ as shown, and it has x-component dB_x and y-component $dB\perp$.

But $\Sigma dB\perp = \Sigma dB\sin\theta = 0$ [since, each $dB\perp$ due to diagonally opposite Idl vanish).

Thus, the net magnetic field at P is $\Sigma dB_x = \Sigma dB\cos\theta$

But $\cos\theta = \frac{R}{r} = \frac{R}{\left(x^2 + R^2\right)^{\frac{1}{2}}}$

$\therefore \sum dB_x = \sum \frac{\mu_o Idl}{4\pi}\frac{R}{\left(x^2 + R^2\right)^{\frac{3}{2}}} \Rightarrow B = \frac{\mu_o}{4\pi}\frac{IR}{\left(x^2 + R^2\right)^{\frac{3}{2}}}\sum dl$; B is the total field

The summation of elements dl over the loop yields 2πR, the circumference of the loop.

Thus, $B=\frac{\mu_o}{4\pi}\frac{IR}{\left(x^2+R^2\right)^{\frac{3}{2}}}x2\pi R \Rightarrow B=\frac{\mu_o IR^2}{2\left(x^2+R^2\right)^{\frac{3}{2}}}$

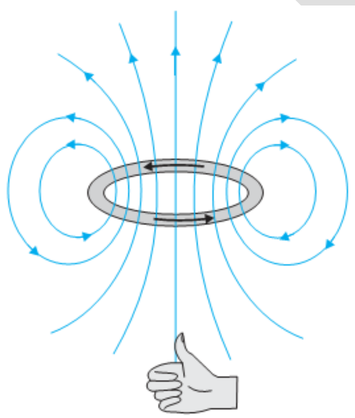
Note: (i) In vector form, $\vec{B}=\frac{\mu_o IR^2}{2\left(x^2+R^2\right)^{\frac{3}{2}}}\hat{i}$; $\hat{i}$ is the unit vector along x-axis

(ii) For multiple loops(i.e of N turns) $B=\frac{\mu_o NIR^2}{2\left(x^2+R^2\right)^{\frac{3}{2}}}$

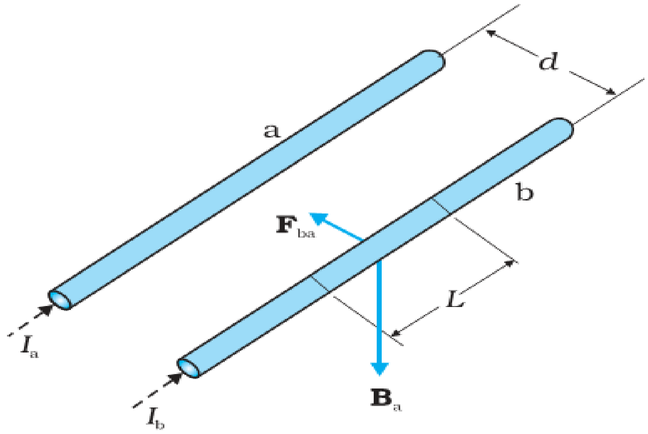
The direction of the magnetic field due to closed wire loop carrying current is given by right thumb rule.

RIGHT HAND THUMB RULE

Curl the palm of your right hand around the circular wire with the fingers pointing in the direction of the current. The right-hand thumb gives the direction of the magnetic field.



3. **Obtain the expression for the force per unit length of two parallel conductors carrying current and hence define one ampere.**



Shows two long parallel conductors a and b separated by a distance 'd' and carrying (parallel) currents I_a and I_b, respectively. The conductor 'a' produces, the same magnetic field B_a at all points along the conductor 'b'.

According to Ampere's circuital law, $B_a = \frac{\mu_o I_a}{2\pi d}$

The conductor 'b' carrying a current I_b will experience a sideways force due to the field B_a . The direction of this force is towards the conductor 'a', F_{ba} the force on a segment Lof 'b' due to 'a'.

i.e $F_{ba} = I_b L\, B_a$

i.e $F_{ba} = I_b L\left(\frac{\mu_o I_a}{2\pi d}\right)$

$\Rightarrow F_{ba} = \frac{\mu_o I_a I_b L}{2\pi d}$

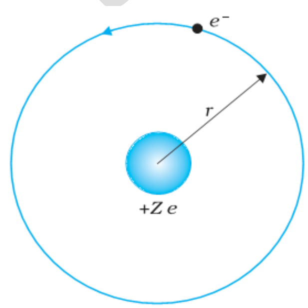
Similarly, if F_{ab} is the force on 'a' due to 'b', then $F_{ba} = -F_{ab}$.

Let f_{ba} represent the magnitude of the force F_{ba} per unit length. Then $f_{ba} = \frac{\mu_o I_a I_b}{2\pi d}$

DEFINITION OF AMPERE

The ampere is the value of that 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 to 2×10^{-7} newtons per metre of length.

4. **Derive an expression to magnetic dipole moment of a revolving electron in a hydrogen atom and hence deduce Bohr magneton.**



An electron revolving around the nucleus possesses a dipole moment and the system acts like a tiny magnet. According to Bohr's model, the magnetic moment of an electron is $\mu l = I\pi r^2 = \frac{evr}{2}$; here 'e' is an electron charge, 'v' is its speed in the orbit and 'r' is the corresponding radius of the orbit.

The direction of this magnetic moment is into the plane of the paper.

We know angular momentum, $\mu_l = \frac{evr}{2}$

Dividing the above expression on RHS by electron mass m_e, we get

$$\mu_l = \frac{e}{2m_e}(m_e vr)$$

But, $m_e vr = l$, the angular momentum,

$$\mu_l = \frac{e}{2m_e} l$$

Vectorially,

$$\overrightarrow{\mu_l} = -\frac{e}{2m_e}\vec{l}$$

; here the negative sign indicates that $\overrightarrow{\mu_l}$ and $\vec{l}$ are in opposite directions.

Further, $\frac{\mu_l}{l} = \frac{e}{2m_e}$ and $l = n\frac{h}{2\pi}$; here n=1,2,3… called principal quantum number and h is Planck's constant.

Since l is minimum when n=1, we write, $\frac{(\mu_l)_{min}}{h/2\pi} = \frac{e}{2m_e}$ or $(\mu_l)_{min} = \frac{eh}{4\pi m_e}$

And on substituting all the values, we get $(\mu_l)_{min} = 9.27 \times 10^{-24}\,Am^2$ and is called Bohr magneton.

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