Solution

MOVING CHARGES AND MAGNETISM

Class 12 - Physics

1. A magnetic needle brought close to a straight current-carrying wire aligns itself perpendicular to the wire, reversing the direction of current reverses the direction of deflection.
2. The electron will continue to follow its straight path because a parallel magnetic field does not exert any force on the electron.
3. This means that no force is acting on the current-carrying wire due to the magnetic field. This is possible when the conductor is parallel to the direction of the magnetic field.
4. When $\theta = 0^\circ$ or 180° ,
   $F_m = qvB\sin\theta = qvB(0) = 0$
   So when a charge moves parallel or antiparallel to the direction of the magnetic field, it experiences minimum (zero) force.
5. The magnetic field consists of concentric circular lines of force with the conductor at its centre and in a plane perpendicular to the conductor.
6. B = $\mu_0 nI = \mu_0 \frac{N}{l} I$
   N = $\frac{Bl}{\mu_0 I} = \frac{4.0\times10^{-2}\times0.50}{4\times3.14\times10^{-7}\times8}$ = 1990
7. The sides AB and DC are along the field lines hence the force on each side is zero.
   The torque on each vertical wire is given as
   $\tau = nBIA\sin\theta$
   $\tau = 50\times0.25\times2\times0.12\times0.1\sin\theta$
   = 0.3 N-m clockwise
8. Magnetic field due to a straight current-carrying conductor,
   B = $\frac{\mu_0 I}{2\pi r}$ i.e., $B \propto \frac{1}{r}$
   $\therefore \frac{B_Q}{B_P} = \frac{r_P}{r_Q}$
   or B_Q = $\frac{r_P}{r_Q}\cdot B_P = \frac{4}{12}\times10^{-3}$
   = 3.33×10^{-4} T
9.
   i. The magnetic field is zero inside the pipe,
   ii. A finite magnetic field exists outside the pipe.
10. The number of turns per unit length is,
    $n = \frac{500}{0.5} = 1000$ turns/m
    The length l = 0.5 m and radius r = 0.01 m. Thus, l/r = 50 i.e., l >> r
    Hence, we can use the long solenoid formula, namely,
    $B = \mu_0 nI$
    = $4\pi\times10^{-7}\times10^{3}\times5$
    = 6.28×10^{-3} T
11. Principle of moving coil galvanometer: It states that when a current-carrying coil is placed in a magnetic field, it experiences torque due to the magnetic force.
    When resistance R_1 is connected, then the galvanometer equation can be written as:
    $R_1 = \frac{V}{I} - G$ ..... (i)
    When resistance R_2 is connected, then the galvanometer equation can be written as:
    $R_2 = \frac{V}{2I} - G$ ...... (ii)
    From both these equations, we get,
    $R_1 - R_2 = \frac{V}{2I}$ ..... (iii)
    and
    $G = R_1 - 2R_2$ ..... (iv)
    When resistance R_3 is connected to make it read 2V, then the galvanometer equation can be written as:
    $R_3 = \frac{2V}{I} - G$
    Using equations (iii) and (iv) we get
    $R_3 = 4(R_1 - R_2) - (R_1 - 2R_2) = 3R_1 - 2R_2$

12. Here N = 100, A = 7.0 A, r = 1.0 cm = 1.0×10^{-2} m, B = 0.2 Wb m^{-2}

Magnetic moment associated with the coil is

m = NIA = $NI \times \pi r^2$

= $100 \times 7.0 \times \frac{22}{7} \times \left(1.0 \times 10^{-2}\right)^2$ = 0.22 Am^2

i. The stable equilibrium corresponds to $\vec{m}$ parallel to B. The potential energy is then minimum.

Umin = -mB $\cos 0^o$ = $-0.22 \times 0.2 \times 1$ = -0.044 J.

ii. The unstable equilibrium corresponds to $\vec{m}$ antiparallel to $\vec{B}$. The potential energy is then maximum.

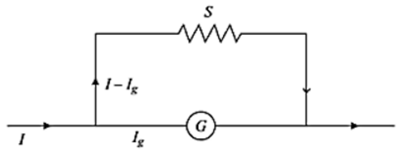
Umax = -mB cos 180^o = $-0.22 \times 0.2 \times (-1)$ = +0.044 J

13. i. **Current sensitivity:** It is defined as the deflection produced in the galvanometer when a unit current flows through it.

I = k n A B θ, Where N = no. of turns in the coil, B = magnetic field, A = area of the coil of galvanometer

Or The sensitivity (i.e. current sensitivity) of a galvanometer is defined as the angle of deflection per unit current flowing through it.

ii. a.



Galvanometer can be converted into an ammeter by connecting a shunt (small resistance) S with parallel to the galvanometer.

As galvanometer and shunt are connected in parallel, so,

Potential across G = Potential across S

$I_g G = (I - I_g)S$

$\therefore S = \frac{I_g}{I-I_g}G$

b. Effective resistance of this ammeter will be

$\frac{1}{R_s} = \frac{1}{G} + \frac{1}{S}$

$R_A = \frac{GS}{G+S}$

14. Torque on a current loop, $\tau = NIBA\sin\theta$

If the circular coil has N turns, each of radius r, then $L = 2\pi rN$

$\therefore \quad r = \frac{L}{2\pi N}$

Area of the coil,

$A = \pi r^2 = \frac{\pi L^2}{4\pi^2 N^2} = \frac{L^2}{4\pi N^2}$

Hence $\tau = NIB \cdot \frac{L^2}{4\pi N^2} \cdot \sin\theta = \frac{L^2 IB \sin\theta}{4\pi N}$

Clearly, torque will be maximum when sin 0 is maximum and N is minimum i.e., $\sin\theta = 1$ and N = 1.

Then $\tau_{\max} = \frac{L^2 IB}{4\pi}$

15. Resistance per volt is another way of specifying the current at full scale deflection. The grading of 5000 ΩV^{-1} at full scale deflection means that the current required for full-scale deflection is

$I_g = \frac{1}{5000}\ \mathrm{A} = 0.2\ \mathrm{mA}$

In order to convert it into a voltmeter of range 0 to 20 V, a resistance R has to be connected in series with it. Then on applying an extra P.D. of 15 V (20 V - 5 V), the current through it is again 0.2 mA at full scale deflection.

$\therefore R \times 0.2 \times 10^{-3} = 15$

or $R = \frac{15}{0.2 \times 10^{-3}}\Omega = 75,000\Omega$

Thus

i. to convert the given voltmeter (0 - 5 V range) into a voltmeter of range 0 to 20 V, a resistance of 75,000 Ω should be connected in series with the given meter.

ii. Original resistance of voltmeter

=5000 $\Omega V^{-1} \times 5$ V = 25,000 Ω

$\therefore$ Total resistance after conversion

= 25/100 + 75/100 = 100/300 μ

Resistance per volt of new meter

$= \frac{100,000}{20} = 5,000\Omega V^{-1}$

i.e., it has the same grading as before.

iii. The higher the 'resistance per volt' of the meter, the lesser is the current it draws from the circuit and the better it is. So this meter is more accurate than the one graded as 2000 ΩV^{-1}.

16. a. i. According to Fleming's left-hand rule, the proton moving in the direction from left to right will be deflected in the plane of the paper and in the downward direction, if the magnetic field acts perpendicular to the plane of the paper and in the outward direction.

ii. The force on a charged particle moving inside the magnetic field provides a centripetal force to make proton move along a circular path.

$\therefore Bqv = \frac{mv^2}{r}$ or $r = \frac{mv}{Bq}$

Here, B = 0.12T, v = 4.5 $\times$ 10^6 ms^{-1},

m = 1.66 $\times$ 10^{-27}kg, q = 1.6 $\times$ 10^{-19}C

$\therefore r = \frac{1.66\times10^{-27}\times4.5\times10^6}{0.12\times1.6\times10^{-19}}$ = 0.39m

b. i. The proton will pass undeviated if it is deflected by the electric field in the plane of the paper and in the upward direction. For this, the electric field should be applied in the plane of the paper and in an upward direction.

ii. For no deflection of the charged particle,

$F_{mag} = F_{ele}$

or Bqv = qE

or E = Bv = 0.12 $\times$ 4.5 $\times$ 10^6 = 5.4 $\times$ 10^5 Vm^{-1}

c. It is because the gravitational force (i.e. weight of the proton) is negligibly small in comparison to both the magnetic and electric forces on the proton.

17. Given:

Length of solenoid, L_1 = 60 cm = 0.6 m

Radius of solenoid, r = 4 cm = 0.04 m

Number of layers, n_1 = 3

Number of turns, N = 300

Total number of turns,n = N $\times$ n_1 = 900

Length of wire, L_2 = 2 cm =0.02 m

Mass of wire, m = 2.5 gm = 2.5 $\times 10^{-3}$ kg

Current flowing through the wire, I_2 = 6 A

Acceleration due to gravity, g = 9.8 ms^{-2}

Intuitively, this problem can be broken down into three parts. In the first part, we will establish the magnetic field inside the solenoid and in the second part, we introduce a current-carrying conductor in the magnetic field. Then we can evaluate the force on the wire. In the final part, we try to find the balancing force and finally the current.

Part (1)

We know that the magnetic field inside a solenoid is given by,

$B = \frac{\mu_0 \times n \times I}{L}$ ...(1)

Where,

B = Magnetic field strength

n = total number of turns

I_1 = current through the coil

L_1 = length of the coil

μ_0 is the permeability of free space.

μ_0= 4 $\times$ π $\times$ 10^{-7} TmA^{-1}

Part (2)

We know that, when a current-carrying conductor is placed in a magnetic field, it experiences a force given by,

F = B $\times$ I_2 $\times$ L_2 ...(2)

Now putting the value of B from equation 1 into equation 2.

$F = \frac{\mu \times n \times I_1 \times I_2 \times L_2}{L_1}$ ...(3)

Where I_2 = current through the conductor

L_2 = length of wire

Part (3)

Since the wire is suspended inside the solenoid, the upward force on it must be equal to its weight.

By equating the weight (m $\times$ g) of the body with force in equation (3), we get

$m \times g = \frac{\mu \times n \times I_1 \times I_2 \times L_2}{L_1}$ ...(4)

$\Rightarrow I_1 = \frac{m \times g \times L_1}{\mu_0 \times n \times I_2 \times L_2}$

$\Rightarrow I_1 = \frac{.0025 kg \times 9.8 ms^{-2} \times 0.6 m}{4\pi \times 10^{-7} TmA^{-1} \times 900 \times 0.02 m \times 6 A}$

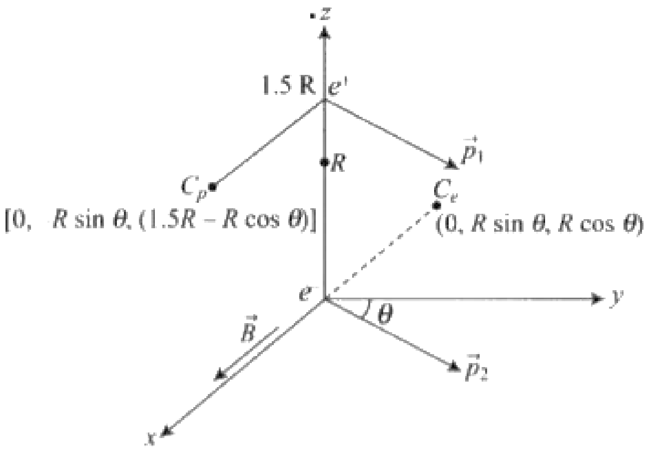
$\Rightarrow I_1 = 108A$

18. The magnetic field B is along the x-axis, hence for a circular orbit the momenta of the two particles are in the y-z plane. Let p_1 and p_2 be the momentum of the electron (e^-) and positron (e^+), respectively. Both traverse a circle of radius R of opposite sense. Let p, make an angle θ with they-axis p_2 must make the same angle withy axis.

The centres of the respective circles must be perpendicular to the momenta and at a distance R. Let the centre of the electron be at C_e and of the positron at C_p.

The coordinates of C_e is given by $C_e = (0, -R \sin\theta, R \cos\theta)$

The coordinates of C_p is given by $C_p = [0, -R \sin\theta, (1.5 R - R \cos\theta)]$



The circular orbits of electron and positron shall not overlap if the distance between the two centers are greater than 2R.

Let d be the distance between C_e and C_p. Then,

$d^2 = [R \sin\theta - (-R \sin\theta)]^2 + [R \cos\theta - (\frac{3}{2} R - R \cos\theta)]^2$

$= (2 R \sin\theta)^2 + (2 R \cos\theta - \frac{3}{2} R)^2$

$= 4 R^2 \sin 2\theta + 4R^2 \cos^2\theta - 6 R^2 \cos^2\theta + \frac{9}{4} R^2$

$= 4R^2 + \frac{9}{4} R^2 - 6R^2 \cos\theta$

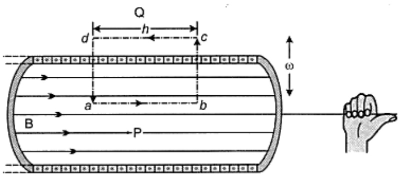
As d has to be greater than 2R, $d^2 > 4R^2$

$\Rightarrow 4R^2 + \frac{9}{4} R^2 - 6R^2 \cos\theta > 4R^2$

or, $\frac{9}{4} > 6 \cos\theta$ thus the conditions on the direction of momentum will the orbits be non-intersecting circles is $\cos\theta < \frac{3}{8}$

19. i. A current-carrying surface can be divided into small line elements of length dl. Considering tangential components of magnetic field and finding sum of all elements of B.dl tends to an integral ,which can be expressed as: $\oint \vec{B} \cdot \vec{dl} = \mu_0 i$

This form is known as Ampere's circuital law.



Let n be the number of turns per unit length. Then total number of turns in the length 'h' is nh. Hence, total enclosed current =

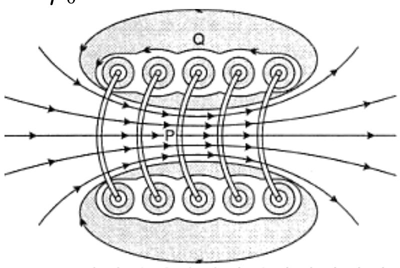
nhl

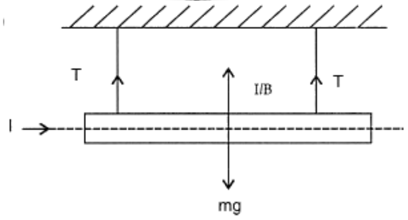
Using Ampere's circuital law

$\oint \vec{B} \cdot \overrightarrow{dl} = \mu_0 nhI$

Bh = $\mu_0$nhl

B = μ_0nI



ii. 

mass m= 60g. and I= 5 A L= 0.45 meter As per the given figure, magnetic field must be vertically inwards, to make tension zero, (If a student shows currently in the opposite direction the magnetic field should be set up vertically upwards).

ILB = mg

For tension to be zero, B = $\frac{mg}{\mathrm{IL}} = \frac{60 \times 10^{-3} \times 9.8}{5.0 \times 0.45}\mathrm{T}$ = 0.26 T