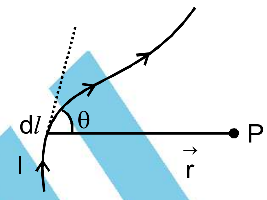
1. Source and Units of Magnetic field

Oersted's Experiment : Oersted, in 1820, demonstrated that a magnetic needle is deflected by a current carrying wire. This concluded that the magnetic field is caused by current elements (or moving charges). The unit of magnetic field strength in S.I. system is tesla (T) or webr/metre^2 (Wb m^{-2}) or newton/amp-metre (N A^{-1} m^{-1}). In C.G.S system has unit of magnetic field is gauss (G).

$$1\ T = 10^4\ G$$

2. Biot Savart Law

It states that the magnetic field strength (dB) produced due to a current element (of current I and length dl) at a point having position vector $\vec{r}$ relative to current element is

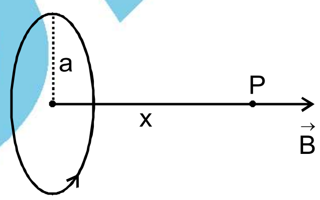


$$d\vec{B} = \frac{\mu_0}{4\pi}\frac{I d\vec{l} \times \vec{r}}{r^3}$$

where μ_0 is the angle between current element $I\vec{dl}$ and position vector $\vec{r}$. The direction of magnetic field $d\vec{B}$ is perpendicular to plane containing $I\vec{dl}$ and $\vec{r}$.

3. Magnetic Field due to a Circuit Coil

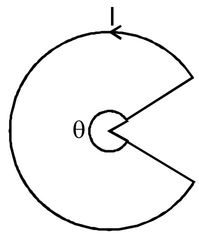
The magnetic field due to current carrying circular coil of N-turns, radius a, carrying current I at a distance x from the centre of coil is $B = \frac{\mu_0 N I a^2}{2\pi(a^2 + x^2)^{3/2}}$ along the axis.



At centre x = 0

$$\therefore \qquad B_C = \frac{\mu_0 NI}{2a}$$

In general the field produced by a circular arc subtending an angle θ at centre



$$B_C = \frac{\mu_0 I}{2a}.\frac{\theta}{2\pi} \qquad (\theta \text{ in radian})$$

4. Ampere's Circuital Law

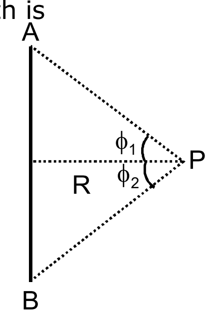
It states that the line integral of magnetic field induction along a closed path is equal to μ_0 - times the current enclosed by the path i.e.,

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

5. Magnetic field due to a Straight Conductor Carrying a Current

The magnetic field due to a straight current carrying wire of finite length is

$$B = \frac{\mu_0 I}{4\pi R}(\sin\phi_1 + \sin\phi_2)$$



The direction of magnetic field is given by right hand grip rule.

Special cases : If the wire is infinitely long. then $\phi_1 = \pi/2$, $\phi_2 = \pi/2$

$$B = \frac{\mu_0 I}{4\pi R}$$

If point is near one end of a long wire, ($\phi_1 = \frac{\pi}{2}$, $\phi_2 = 0$), then

$$B = \frac{\mu_0 I}{4\pi R}$$

6. Magnetic field due to a Solenoid

(i) At the axis of a long solenoid

$$B = \mu_0 n I$$

where n = number of turns per metre length.

Magnetic field at one end of solenoid $B_{end} = \frac{\mu_0 n I}{2}$

7. Magnetic Field due to a Toroid (Endless Solenoid)

Magntic field within the turns of toroid

$$B = \frac{\mu_0 N I}{2\pi r}$$

where r is average radius.

Magnetic field outside the toroid is zero.

8. Force on a Charged Particle in Magnetic field

The force on a charged particle moving with velocity $\vec{v}$ in a uniform magnetic field $\vec{B}$ is given by

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

The direction of this force is perpendicualr to both $\vec{v}$ and $\vec{B}$

When $\vec{v}$ is parallel to $\vec{B}$, then $\vec{F}_m = 0$

When $\vec{v}$ is perpendicualar to $\vec{B}$, then $\vec{F}_m$ is maximum, $(F_m) = qvB$.

9. Force on a Charged Particle in Simultaneous Electric and Magnetic fields

The total force on a charged particle moving in simultaneous electric field $\vec{E}$ and magnetic field $\vec{B}$ is given by

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

This is called Lorents force.

10. Path of Charged Particle in Magnetic Filed.

(i) If $\vec{v}$ is parallel to the direction of $\vec{B}$, then magnetic force = zero. So the path of particle is an undelfected straight line.

(ii) If $\vec{v}$ is perpendicular to $\vec{B}$, then magnetic field provides necessary centripetal force for **Circular path,** the radius r of path is given by

$$\frac{mv^2}{r} = qvB \Rightarrow r = \frac{mv}{qB}$$

If E is kinetic energy of particle

$$r = \frac{\sqrt{2mE}}{qB}$$

If V is accelerating potential in volt, E = qV

$$\therefore \quad r = \frac{\sqrt{2mE}}{qB} = \frac{l}{B}\sqrt{\frac{2mV}{q}}$$

Time period of path $T = \frac{2\pi m}{qB}$

(iii) If a particle's velocity $\vec{v}$ is oblique to magnetic field $\vec{B}$, then the particle follows a helical path of radius

$$r = \frac{mv\sin\theta}{qB} = \frac{mv_{\perp}}{qB}$$

Time period $T = \frac{2\pi m}{qB}$

and pitch $p = v'T = v\cos\theta \frac{2\pi m}{qB}$

where v′ is a component of velocity parallel to the direction of magnetic field.

11. Simultaneous Electric and Magnetic Fields

If a particle of charge q enters in a region of simultaneous electric and magnetic field of strength $\vec{E}$ and $\vec{B}$ respectively. then the net force on charged particle is $\vec{F} = \vec{F}_e + \vec{F}_m = q\vec{E} + q\vec{v} \times \vec{B}$

i.e., $\vec{F} = q(\vec{E} + \vec{v} \times \vec{B})$

12. Velocity Filter

If electric and magnetic fields are mutually perpendicular and a charged particle enters this region with velocity $\vec{v}$ which is perpendicular to both electric and magnetic fields, then it may happen that the electric and magnetic forces are equal and opposite and charged particle with given velocity v remain undeflected in both fields. In such a codition.

$$qE = qvB \Rightarrow v = \frac{E}{B}$$

This arrangemnt is called velocity filter or velocity selector.

13. Cyclotron

It is a device to accelerate charged particles with the help of magnetic field. It consists of two holow dees placed in a perpendicualr magnetic field with a little gap between them. A radio frequency potential difference is applied across the dees. For acceleration of charged particle the resonance condition is

"The frequency of revolution of charged particle must be equal to the frequency of radio frequency voltage source."

The frequency is given by $f = \frac{qB}{2\pi m}$

This frequency is called cyclotron frequency. Clearly it is independent of the speed of the particle.

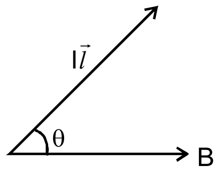
Energy gained per revolution = 2qV

Energy gained in n-revolutions, $E = 2nqV = \frac{B^2q^2R^2}{2m}$

where R is radius of dee.

14. Magnetic Force on a Current Carrying Conductor or Length $\vec{l}$ is given by

$$\vec{F}_m = I\vec{l} \times \vec{B}$$



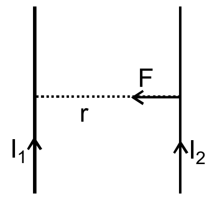
where the direction of $\vec{l}$ is along the direction of current.

Magnitude of force

$$F_m = IlB\sin\theta$$

Direction of force $\vec{F}$ is normal to $\vec{l}$ and $\vec{B}$ given by rule of vector product. If $\theta = 0$ (i.e., $\vec{l}$ is paralel to $\vec{B}$), then magnetic force is zero.

15. Force between Parallel Current Carrying Conductors

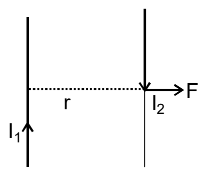


Parallel currents attract while antiparallel curents repel.

The magnetic force per unit length on either current carrying conductor at separation 'r' given by

$$f = \frac{F}{l} = \frac{\mu_0 I_1 I_2}{2\pi r} \text{ newton/metre} = 2 \times 10^{-7} \frac{I_1 I_2}{r} \text{N/m}$$

16. Definition of Ampere is S.I. system



I ampere is the current which when flowing in each of the two parallel wires in vaccum at separation 1 m exert a force of

$\frac{\mu_0}{2\pi} = 2 \times 10^{-7}$ N/m on either wire.

17. Torque experienced by a current loop (of area $\vec{A}$) carrying current I in a uniform magnetic field $\vec{B}$ is given by

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

where $\vec{M} = NI\vec{A}$ is magnetic moment of loop. The unit of magnetic moment in S.I. system is ampre × metre^2 (Am^2)

18. Potential energy of a current loop in a magnetic field

When a current loop of magnetic moment M is placed in a magnetic field, then potenial energy of dipole is :

$$U = -\vec{M}.\vec{B} = -MB\cos\theta$$

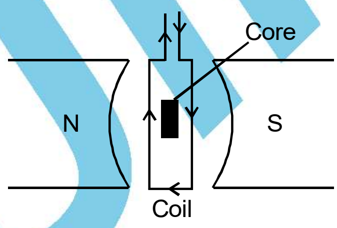
(i) When θ = 0, U = – MB (minimum or stable equilibrium position)

(ii) When $\theta = \pi$, U = + MB (maximum or unstable equilibrium position)

(iii) When $\theta = \frac{\pi}{2}$, potential energy is zero.

19. Moving Coil Galvanometer

A moving coil galvanometer consists of a rectangular coil plaed in a uniform magnetic field produced by cylindrical pole pieces to make the magnetic field radial. Torque on coil τ = N I AB where N is number of turns. A is area of coil. If k is torsional rigidity of material of suspension wire, then for deflection θ, torque $\tau = k\theta$



$\therefore$ For equilibrium NIAB = k θ

$\Rightarrow$ $$\theta = \frac{NAB}{k} I$$

Clearly deflection in galvanometer is directly proportional to current, so the scale of galanometer is linear.

Sensitivity of galvanometer : Current sensitivity : It is defined as the deflection of coil per unit current flowing in it.

Sensitivity $$S_I = \left(\frac{\theta}{I}\right) = \frac{NAB}{k}$$

Voltage sensitivity : If is defined on the deflection of coil per unit potenial difference across its ends

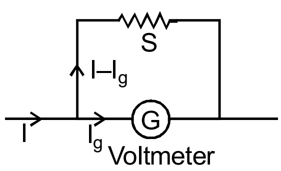
i.e., $$S_v = \frac{\theta}{V} = \frac{NAB}{kR}$$

where G is resistance of galvanometer.

Clearly for greater sensitivity number of turns N, area A and magnetic field strength B should be large and torsional rigidity α of suspension should be small.

20. Conversion of Galvanometer into Ammeter

A galvanometer may be converted into ammeter by using very small resistance in parallel with the galvanometer coil. The small resistance connected in parallel is called a shunt. If G is resistance of galvanometer, I_g is current in galvanometer for full scale deflection, then for conversion of galvanometer into ammter of range I ampere, the shunt is given by



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

21. Conversion of Galvanometer into Voltmeter

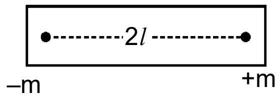
A galvanometer may be converted into voltmeter by connecting high resistance (R) in series with the coil of gavanometer. If V volt is the range of voltmeter formed, then series resistance

$$R = \frac{V}{I_g} - G$$

22. **Magnetic dipole moment of a current loop and revolving electron**

Magnetic dipole moment of a magnet, M = m $2l$ amp-m^2 where m is pole strength, $2l$ is separation between poles. Magnetic dipole moment of a current loop.

$$M = N\,I\,A \text{ amp-m}^2$$



Magnetic dipole moment of revolving electron

$$= I\,A = fe\,\pi r^2$$

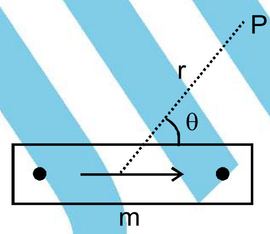
where f is frequency, r = radius of orbit

$$M = \frac{e}{2m_e} L \text{ amp} - m^2$$

23. **Magnetic field intensity due to a magnetic dipole**

Magnetic field intensity at a general point having polar coordinates (r, θ) due to a short magnet is given by

$$B = \frac{\mu_0}{4\pi}\frac{M}{r^3}\sqrt{1+3\cos^2\theta}$$



Special Cases

(i) At axial point θ = 0,

$$B_{axis} = \frac{\mu_0}{4\pi}\frac{2M}{r^3}$$

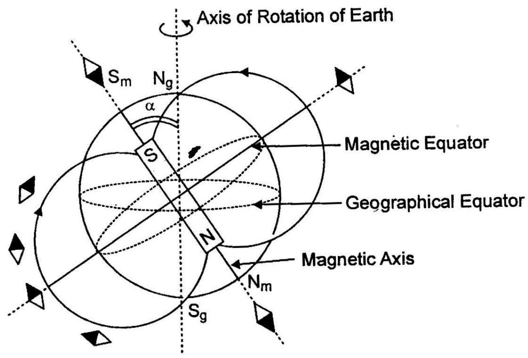
(ii) At equation point θ = 90°

$$B_{eqn.} = \frac{\mu_0}{4\pi}\frac{M}{r^3}$$

24. **Earth's Magnetism**

Earth behaves as a magnet. Its magnetism is assumed due to interaction of charged particles of earth's atmosphere and rotation of earth about its axis.

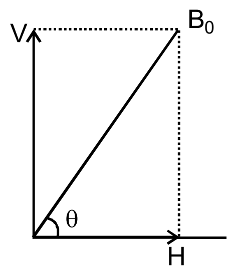
The earth's magnetic field may be approximated by a magntic dipole lying at the centre of earth such that the magnetic north pole N_m is near geographical south pole S_g and its magnetic south pole S_m is near geographical north pole $N_{g.}$ This magnetic dipole is aligned slightly with earth's rotations axis. The magnitude of earth's magnetic field at earth's surface is about 4 × 10^{-5} T



25. **Elements of Earths' Magnetic Field**

Earth's magnetic field may be specified completely by three quantities called the elements of earth's magnetic field. These quantities are :

(i) Angle of declination (α) : It is the angle made by resultant magnetic field B_e with the horizontal. angle of dip is 0 at magnetic equator and 90° at magnetic poles



(ii) Angle of dip (θ) : It is the angle made by resultant magnetic field B_e with the horizontal. The angle of dip is 0

at magnetic equator and 90° at magnetic poles.

(iii) Horizontal component of earth's magnetic field (B_e)

$H = B_e \cos\theta$

Vertical component of B_e is $V = B_e \sin\theta$

$\therefore \quad B_e = \sqrt{H^2 + V^2}$ and $\tan\theta = \dfrac{V}{H}$

26. Important Terms in Magnetism

(i) Magnetic permeability (μ) : it is the ability of a material to allow magnetic lines of force to pass through it.

Thre relative magnetic permeability $\mu_r = \dfrac{B}{B_0} = \dfrac{\mu}{\mu_0}$

where B_0 is magnetic field strength in vacuum.

(ii) Intensity of Magntisation $(\vec{M})$: It is defined as the magnetic moment per unit volume of a magnetised material

i.e., $\vec{M} = \dfrac{\vec{m}}{V}$ amp $\times$ metre

(iii) Magnetising field : It is the magnetic field used for magnetisation of a material. If I is current in solenoid, then magnetising field H = nI where n - number of turns per metre. Its unit is ampere × metre.

(iv) Magnetic susceptibility : It is defined as the intensity of magnetisation per unit magnetising field, i.e., $\chi_m = \dfrac{M}{H}$

It has no unit.

27. Classification of Magnetic Materials

Magnetic materials may be classifed into three categories :

(i) Diamagnetic substnaces : These are the substances in which feeble magnetism is produced in a direction opposite to the aplied magnetic field. These substances have small negative values of magnetism $\vec{M}$ and susceptibility χ and positive low value of relative permeability μ_r, i.e.,

$$1 \le \chi \le 0,\ 0 < \mu_r < 1$$

The example of diamagnetic substances are
bismuth, antmony, copper, lead, water, nitrogen (at STP) and sodium chloride.

(ii) Paramagnetic substances ; These are the substances in which feeble magnetism is induced in the same direction as the applied magnetic field. These substances have small positive values of M and χ and relative permeability μ_r greater than 1, i.e.,

$$0 < \chi < \varepsilon,\ 1 < \mu_r < 1 + \varepsilon$$

where ε is a small positive number. The examples of paramagnetic substances are platinum, aluminium, calcium, manganese, oxygen (at S.T.P.) and copper chloride.

(iii) Ferromagnetic substances : These are the substances in which a strong magnetism is produced in the same direction as the applied magnetic field. These substances are characterised by large positive values of M and χ and values of μ_r much greater than 1, i.e.,

$$\chi >> 1,\ \mu_r >> \chi$$

28. Curie Law

Its states that the magnetic susceptibility of **paramagnetic substances** is inversely proportional to absolute temperature i.e.,

$$\chi \propto \frac{1}{T}$$

29. Curie Temperature

When temperature is increased continuously, the magnetic susceptibility substances decreases and at a stage the substance changes to paramagnetic. The temperature of transitioin at which a ferromagnetic substance changes to paramagnetic is called Curie temperature. Itr is denoted by T_C. It is different for different materials. In paramagnetic phase the susceptibility is given by

$$\chi \propto \frac{C}{T - T_C}$$ where C is Curie constant.

30. Diamagnetism is universal properties of all substances but it is weak in para and ferromagnetic substances and hence difficult to detect.

31. Electromagnets and Permanent Magnets

Electromagnets are made of soft iron which is characterised by **high retentivity** and **low coercivity.**

IMPORTANT FORMULAE FOR NUMERICALS

1. **Biot Savart Law :** Magnetic field due to current element

$$d\vec{B} = \frac{\mu_0}{4\pi}\frac{I d\vec{l} \times \vec{r}}{r^3}$$

2. **Magnetic field due to a straight current carrying wire**

$$B = \frac{\mu_0 I}{4\pi R}(\sin\alpha + \sin\beta)$$ For infinitely long wire $B = \frac{\mu_0 I}{2\pi R}$

3. **Magnetic field due to a current carrying circular coil**

(i) At centre $B_c = \frac{\mu_0 NI}{2R}$

(ii) At axis $B_{axis} = \frac{\mu_0 NIa^2}{2(a^2 + x^2)^{3/2}}$

(where a = radius of coil)

4. **Ampere's circuital law** $\oint \vec{B}.d\vec{l} = \mu_0 I$

5. **Magnetic field strength within solenoid** B = μ_0 n I

where n = number of turns per metre length.

6. **Magnetic field due to toroid**

(i) Withing the coils $B = \frac{\mu_0 NI}{2\pi r}$

(ii) Outside the toroid B = 0

7. **Magnetic force on a moving charge** $\vec{F}_m = q\vec{v} \times \vec{B}$

8. **Magnetic force on a current carrying conductor** $\vec{F}_m = I\vec{l} \times \vec{B}$

9. **Force between parallel current :** $f = \frac{F}{l} = \frac{\mu_0 I_1 I_2}{2\pi r} N/m$

10. Torque experienced by a current loop in a uniform magnetic field

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

11. Magnetic moment of a current loop.

$$\vec{M} = NIA \text{ ampere} \times \text{metre}^2$$

12. Deflection in moving coil galvanometer

$$\phi = \frac{NAB}{k} I$$

13. For conversion of galvanometer into ammeter,

shunt required $\quad S = \frac{I_g}{I - I_g} G \approx \frac{I_g}{I} G$

14. For conversion of galvanometer into voltmeter,

series resistance required $R = \frac{V}{I_g} - G$

15. Magnetic moment of orbital electron

$$m_l = \frac{evr}{2} = \frac{e}{2m} L$$

16. Magnetic field due to a short magnetic dipole

(i) At axis $\quad B_{axis} = \frac{\mu_0}{4\pi}\frac{2M}{r^3}$

(ii) At equator $\quad B_{equal} = -\frac{\mu_0}{4\pi}\frac{M}{r^3}$

17. Element of earth's magnetic field

Horizontal compoment $\quad H = B_e \cos\theta$

Vertical component $\quad V = B_e \sin\theta$ $\quad$ Where θ is angle of dip.

$\Rightarrow \tan\theta = \frac{V}{H}$ and $\quad B_e = \sqrt{H^2 + V^2}$

18. Magnetic susceptibility $\chi_m = \frac{M}{H}$

19. Curie law $\chi_m \propto \frac{1}{T}$ for paramagnetics.

1. Draw a labelled diagram of a moving coil galvanometer. State the priciple on which it works.
Derive an expression for torque acting on a rectangular current carrying loop kept in a uniform magnetic field B.

OR

Derive an expression for the torque on a rectangular coil of area a carrying current I placed in a magnetic field B at an angle θ to the direction of the field.

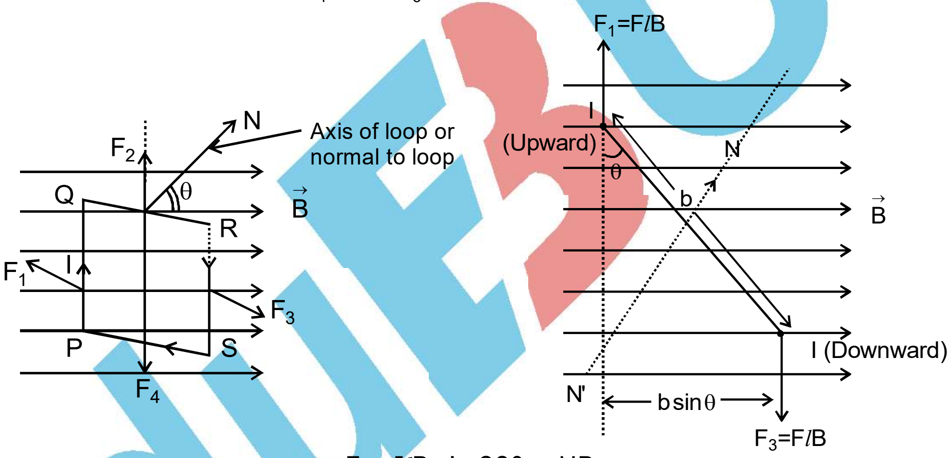
Sol. For 1st part refer point 19 of Basic Concepts and Formulae

Torque on a current carrying loop : Consider a rectangular loop PQRS of length l, breadth b

SOLVED PROBLEMS

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 θ 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 $(90° - \theta)$ 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 $F' = BIb \sin (90° - \theta) = BIb\cos\theta$. 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 cacel 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 :



$F = IlB \sin 90° = HB.$

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 forces 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 θ with the direction of magnetic field B, the perpendicualr distance between F_1 and F_3 is b sin θ.

$\therefore$ Momentum of couple or Torque,

τ = (Magnitude of one force F) × perpendicualr distance = (BIl). (b $\sin\theta$) = $I(lb)$ B $\sin\theta$

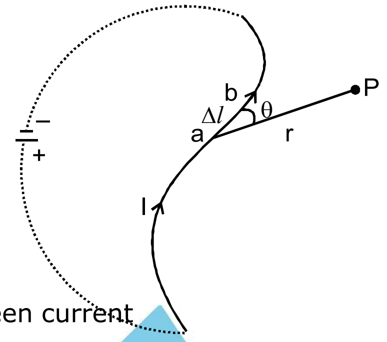
But lb = area of loop = A (say)

$\therefore$ Torque, $\tau = IAB \sin\theta$

If the loop contains N-turns, then $\tau = NIAB \sin\theta$

2. Derive an expression for the magnetic field produced at a point near long current carrying wire.

Sol. **Biot Savart law :** Suppose the current I is flowing in a conductor and there is a small current element



'ab' of length Δl. According to Biot Savart the magnetic field (ΔB) produced due to this current element at a point P distance r from the element is

(i) directly proportional to the curent flowing in the element i.e., $\Delta B \propto I$

(ii) directly proportional to the length of element, i.e., $\Delta B \propto \Delta l$.

(iii) directly proportional to sin θ, where θ is the angle between current element and the line joining current element to point P.

(iv) Inversely proportional to the square of the distance of the element from point P.

i.e, $$\Delta B \propto \frac{1}{r^2}$$

Combining all these laws $$\Delta B \propto \frac{I \Delta l \sin\theta}{r^2}$$

where $\frac{\mu}{4\pi}$ is a constant of proportional. It depends on the medium between the current element and point of observation (P). μ is called the permeability of medium. Equation (1) is called Biot-Savart law. The product of current (I) and length element (Δl) (i.e, I Δl) is called the current element. Current element is vector quantity, its direction is along the direction of current. If the conductor be placed in vacuum (or air), then μ is replaced by μ_0 ; where μ_0 is called the permeability of free space (or air). In S.I. system $\mu_0 = 4\pi \times 10^{-7}$ weber/ampere-metre (or newton/ampere^2)

Thus $\frac{\mu_0}{4\pi} \times 10^{-7}$ weber/ampere × metre.

As in most cases the medium surrounding the conductor is air, therefore, in general, Biot Savart law is written as

$$\Delta B = \frac{\mu_0}{4\pi} \frac{I \Delta l \sin\theta}{r^2}$$

The direction of magnetic field is perpendicualr to the plane containing current element and the line joining point of observation to current element. So in vactor from the expression for magnetic field takes the form

$$\Delta \vec{B} = \frac{\mu_0}{4\pi} \frac{I D \vec{l} \times \vec{r}}{r^3}$$

Derivation of formula for magnetic field due to a current carrying wire using Biot Savart law :

Consider a wire EF carrying current I in upward direction. The point of observation is P at a finite disance R from the wire. If PM is perpendicular dropped from P on wire; then PM = R. The wire may be supposed to be formed of a large number of small current elements. Consider a small element CD of length δl at a distance l from M.

Let $\angle CPM = \phi$

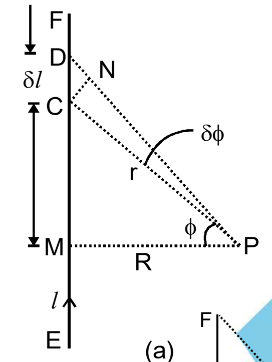
and $\angle CPD = \delta\phi$, $\angle PDM = \theta$

The length δl is very small, so that $\angle PCM$ may also be taken equal to θ.

The perpendicular dropped from C on PD is CN. The angle formed between element $I d\vec{l}$ and

$\vec{l}(= \vec{CP})$ is

$(\pi - \theta)$. Therefore according to Biot-Savart law, the magnetic field due to current element



$Id\vec{l}$ at P is

$$\delta B = \frac{\mu_0}{4\pi} = \frac{I\delta l \sin(\pi - \theta)}{r^2} = \frac{\mu_0}{4\pi}\frac{I\delta l \sin\theta}{r^2} \quad ...(1)$$

But in ΔCND, $\sin\theta = \sin(\angle CDN) = \frac{CN}{CD} = \frac{r\delta\phi}{\delta l}$

or $\delta l \sin\theta = r\delta\phi$

$\therefore$ From equation (1)

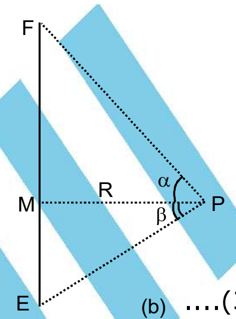
$$\delta B = \frac{\mu_0}{4\pi}\frac{Ir\delta\phi}{r^2} = \frac{\mu_0}{4\pi}\frac{I\delta\phi}{r} \quad ....(2)$$

Again from fig.

$$\cos\phi = \frac{R}{r} \Rightarrow r = \frac{R}{\cos\phi}$$

$\therefore$ From equation (2)

$$\delta B = \frac{\mu_0}{4\pi}\frac{I\cos\phi\,\delta\phi}{R}$$



....(3)

If the wire is of finite length and its ends make angles α and β with line MP, then net magnetic field (B) at P is obtained by summing over magnetic field due to all current elements, i.e.,

$$B = \int_{-\beta}^{\alpha} \frac{\mu_0}{4\pi}\frac{I\cos\phi\,d\phi}{R} = \frac{\mu_0 I}{4\mu R}\int_{-\beta}^{\alpha}\cos\phi\,d\phi$$

$$= \frac{\mu_0 I}{4\pi R}[\sin\phi]_{-\beta}^{\alpha} = \frac{\mu_0 I}{4\pi R}[\sin\alpha - \sin(-\beta)]$$

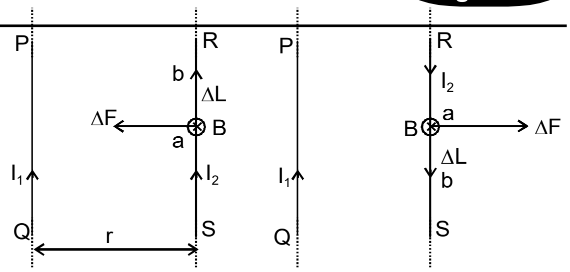
i.e., $$B = \frac{\mu_0 I}{4\pi R}(\sin\alpha + \sin\beta)$$

This is expression for magnetic field due to current carrying wire of finite length.
If the wire is of infinite length (or very long), then $\alpha = \beta \Rightarrow \pi/2$

$$\therefore \quad B = \frac{\mu_0 I}{4\pi R}\left(\sin\frac{\pi}{2} + \sin\frac{\pi}{2}\right) = \frac{\mu_0 I}{4\pi R}[1+1] \quad \text{or} \quad B = \frac{\mu_0 I}{2\pi R}$$

3. Derive an expression for the force betwen two longthin wires carrying currents. Define 'ampere'.

Sol. Force Between Two Parallel Current Carrying Conductors : We know that a magnetic field is produced around a conductor when a current is passed thorugh it and a current carrying conductor experiences a force when placed in an external magnetic field. Therefore if two current carryingf conductors are placed near each other, then either currrent carrying conductor will experience a force due to the magnetic field caused by the other. A a result the two current carrying conductors placed near other experience a mutual interaction.
Suppose two long wires PQ and RS are placed parllel to each other in vacuum (or air) carrying currents I_1 and I_2 respectively. It has been observed experimentally that when the currents in the wire are in the same direction, they experience an attractive force (fig.a) and when they carry currents in opposite directions, they experience a repulsive force (fig b)
Let the wires PQ and RS carry currents I_1 and I_1 in same direction and placed at separation r. (fig).



Consider a current - element 'ab' of lenth ΔL of wire RS. The magnetic field produced by current - carrying conductor PQ at the location of other wire RS

$$B_1 = \frac{\mu_0 I_1}{2\pi r} \qquad ..(1)$$

According to Maxwell's right hand rule or fight hand plam rule no. 1, the direction of B_1 will be perpendicular to the plane of paper and directed downward. Due to this magnetic field, each element of other wire expereiences a force. The direction of current element is pependicular to the magnetic field ; therefore the magnetic force on element ab of length ΔL.

$$\Delta F = B_1 I_2 \Delta L \sin 90°$$

$$\therefore \qquad = \frac{\mu_0 I_1}{2\pi r} I_2 \Delta L$$

∴ The total force on wire of length L will be

$$F = \frac{\mu_0 I_1 I_2}{2\pi r} \Sigma \Delta L = \frac{\mu_0 I_1 I_2}{2\pi r} L$$

∴ Force acting on per unit length of wire

$$f = \frac{F}{L} = \frac{\mu_0 I_1 I_2}{2\pi r} \text{N/m} \qquad ...(2)$$

According to Fleming's left hand rule, the direction of magnetic force will be towards PQ i.e., the force will be attractive.
On the other hand if the currents I_1 and I_2 in wires are in opposite directions, the force will be repulsive. The magnitude of force in each case remains the same.

Definition of Ampere : In S.I. system of fundamental unit of current 'ampere' has been defined assuming the force between the two current carrying wires as standard.
The force between two parallel current carrying wires of separation r is

$$f = \frac{F}{L} = \frac{\mu_0 I_1 I_2}{2\pi r} \text{N/m}$$

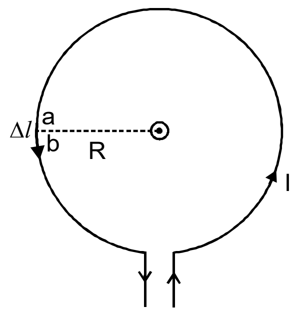
If $I_1 = I_2 = 1$ A, r = 1m, then

$$f = \frac{\mu_0}{2\pi r} = 2 \times 10^{-7} \text{ N/m}$$

Thus 1 ampere is the current which when flowing in each of parallel wires placed at separation 1 m in vacuum exert a force of 2×10^{-7} on 1 m length of either wire.

4. State Biot Savart Law. Using this law, find an expression for the magnetic field at the centre of a circular coil of N-turns, radius r, carrying current I.
Sketch the magnetic field for a circular current loop, clearly indication the direction of the field.

Sol. Magnetic Field at the centre of circular loop :



Consider a circular coil of radius R carrying current I in anticlocwise direction. Say, O is the centre of coil, at which magnetic field is to be compouted. The coil may be supposed to be formed of a large number of current element. Consider a small current element 'ab' of length Δ*l*. According to Biot Savart law the magnetic field due to current element 'ab' at centre O is :

$$\Delta B = \frac{\mu_0}{4\pi} \frac{I \Delta l \sin\theta}{R^2}$$

Where θ is angle between current element ab and the line joining the element to the centre

O. Here θ = 90°. because current element at each point of circular path is perpendicular to the radius. Therefore magnetic field produced at O, due to current element ab is

$$\Delta B = \frac{\mu_0}{4\pi}\frac{I\Delta l}{R^2}$$

According to Maxwell's right hand rule, the direction of magnetic field at O is upward, perpendicular to the planeof coil. The direction of magnetic field due to all current element is the same. therefore the resultant magnetic field at the centre will be the sum of magnetic fields due to all current elements. Thus

$$B = \sum \Delta B = \sum \frac{\mu_0}{4\pi}\frac{I\Delta l}{R^2} = \frac{\mu_0}{4\pi}\frac{I}{R^2}\sum \Delta l$$

But $\sum \Delta l$ = total length o circular coil = $2\pi R$ (for one - turn)

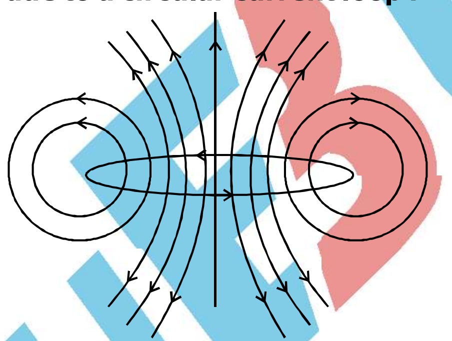
$\therefore$ $B = \frac{\mu_0}{4\pi}\frac{I}{R^2}.2\pi R$ or $B = \frac{\mu_0 I}{2R}$

If the coil contains N-turns, then $\sum \Delta l$ = N. 2 π R

$\therefore$ $B = \frac{\mu_0 I}{4\pi R^2}.N.2\pi R$ or $B = \frac{\mu_0 NI}{2R}$

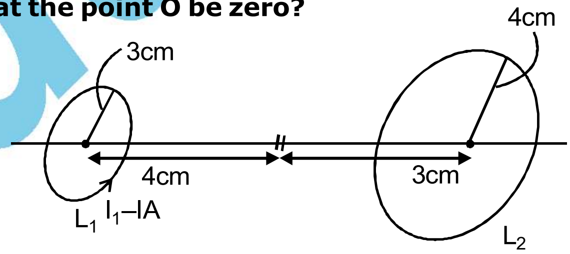
Here current in the coil is anticlockwise and the direction of magnetic field is perpendicular to the plane of coil upward; but if the current in the coil is clockwise, then the direction of magnetic field will be perpendicular to the plane of coil downward.

Magnetic field lines due to a circular current loop :

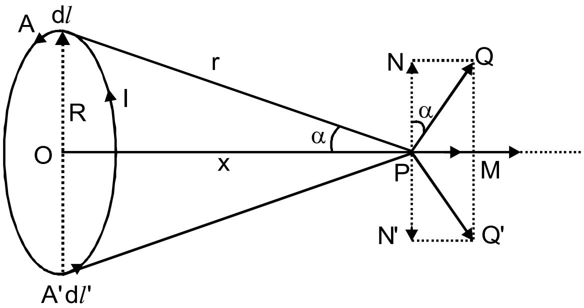


5. (i) Describe an expression for the magnetic field at a point on the axis of a current carrying circular loop.

(ii) Two co-axial circular loops L_1 and L_2 of radii 3 cm and 4 cm are placed as shown. What should be the magnitude and direction of the current in the loop L_2 so that the net magnetic field at the point O be zero?



Sol.



(i) Magnetic Field at the axis of a Circular loop : Consider a circular loop of radius R carrying current I, with its plane perpendicualr to the plane of paper. Let P be a point of observation on the axis of this circular loop at a distance x from its centre O. Consider a small element of length δl of the coil at point A. The magnitude of the magnetic induction $\delta\vec{B}$ at point P due to this element is given by

$$\delta B = \frac{\mu_0}{4\pi}\frac{I\delta l \sin\alpha}{r^2} \qquad ...(1)$$

The direction of $\delta\vec{B}$ is perpendicular to the plane containing $\vec{\delta l}$ and $\vec{r}$ and is given by right hand screw rule. As the angle between I $\vec{\delta l}$ and $\vec{r}$ is 90°, the magnitude of the magneic induction $\delta\vec{B}$ is given by,

$$\delta B = \frac{\mu_0 I}{4\pi}\frac{\delta l \sin 90°}{r^2} = \frac{\mu_0 I\delta l}{4\pi r^2} \qquad ...(2)$$

In figure $\delta\vec{B}$ has been represented by $P\vec{Q}$. The vector $\delta\vec{B}$ or $(P\vec{Q})$ can be resolved into two components, namely PM and PN along and perpendicular to the axis respectively. Now consider another small current element of length $\delta I'$ at A′. The magnetic induction $\delta\vec{B}$ due to this element has been represented by $P\vec{Q}'$ whose magnitude is $\frac{\mu_0 I\delta l'}{4\pi r^2}$ and which can also be resolved into two components ; PM and PN′ along the axis and perpendicular to the axis respectively. Thus if we consider the magnetic induction produced by the whole of the circular coil, then by symmetry the components of magnetic induction pependiculr to the axis will be cancelled out, while those parallel to the axis will be added up. Thus the resultant magnetic induction $\vec{B}$ at axis point P is along the axis and may be evaluated as follows :

The component of $\delta\vec{B}$ along the axis,

$$\delta B_x = \frac{\mu_0 I\delta l}{4\pi r^2}\sin\alpha \qquad ...(3)$$

But $\sin\alpha = \frac{R}{r}$ and $r = (R^2 + x^2)^{1/2}$

$$\therefore \qquad \delta B_x = \frac{\mu_0 I dl}{4\pi r^2}\cdot\frac{R}{r} = \frac{\mu_0}{4\pi}\frac{IR}{r^3}\delta l = \frac{\mu_0 IR}{4\pi(R^2+x^2)}\delta l \qquad ...(4)$$

Therefore the magnitude of resultant magnetic induction at axial point P due to the whole circular coil is given by

$$B = \oint \frac{\mu_0 IR}{4\pi r^2}\cdot\frac{R}{r} = \frac{\mu_0 IR}{4\pi r^3}\delta l = \frac{\mu_0 IR}{4\pi(R^2+x^2)}\delta l$$

But $\oint dl = \text{length of the loop} = 2\pi R$

Therefore, $B = \frac{\mu_0 IR^2}{2(R^2+x^2)^{3/2}}$ tesla.

If the coil contains N turns, then

$$B = \frac{\mu_0 NIR^2}{2(a^2+x^2)^{3/2}} \text{ tesla.} \qquad ...(6)$$

(ii) Magnetic field at the axis of a circular coil is :

$$B = \frac{\mu_0 NIa^2}{2(a^2+x^2)^{3/2}}$$

Here N = 1, a_1 = 3 cm, x_1 = 4 cm, I_1 = 1 A

∴ Magnetic field at O due to coil L_1 is

$$B_1 = \frac{\mu_0 \times I \times (3\times10^{-2})^2}{2[(3\times10^{-2})^2 + (4\times10^{-2})^2]^{3/2}} = \frac{\mu_0(9\times10^{-4})}{2\times125\times10^{-6}}$$

Magnetic field at O due to coil L_2 is

$$B_2 = \frac{\mu_0 \times I_2(4\times10^{-2})}{2[(4\times10^{-2})^2 + (3\times10^{-2})^2]^{3/2}}$$

Here a_2 = 4 cm

$$x_2 = 3\text{ cm} = \frac{\mu_0 I_2 \times 16\times10^{-4}}{2\times125\times10^{-6}}$$

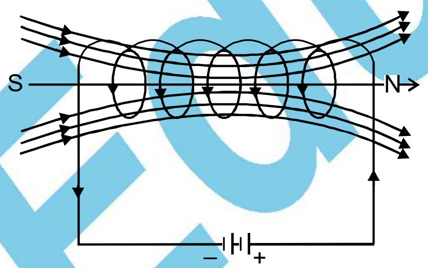
For zero magnetic field at O, the currents I_1 and I_2 should be in same direction, so current I_2 should be in opposite directions and satisfy the condition $B_1 = B_2$

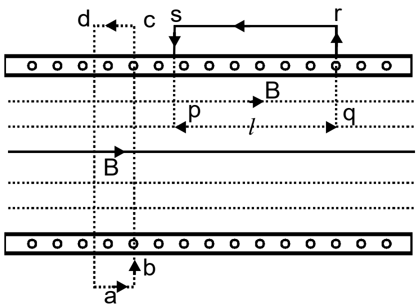
i.e., $$\frac{\mu_0 \times 9\times10^{-4}}{2\times125\times10^{-6}} = \frac{\mu_0 I_2 \times 16\times10^{-4}}{2\times125\times10^{-4}} \Rightarrow I_2 = \frac{9}{16}\text{A}$$

6. Using Ampere's circuital law find an expression for the magnetic field at a point on the axis of a long solenoid with closely wound turns.

Sol. Magnetic field Due to a Current Carrying Long Solenoid :

A solenoid is a long wire wound in the form of a close-packed helix, carrying current. To construct a solenoid a large number of closely packed turns of insulated copper wire are wound on a cylindrical tube of car-board or china clay. When an electric current is passed through the solenoid, a magnetic field is produced within the solenoid. If the solenoid is long and the successive insulated copper turns have no gaps, then the magnetic field within the solenoid is uniform; with practically no magnetic field outside it. The reason is that the solenoid may be supposed to be formed of a large number of circular current elements. The magnetic field due to a circular loop is along its axis and the current in upper and lower straight parts of solenoid is equal and opposite. Due to this the magnetic field in a direction perpendicular to the axis of solenoid is zero and so the resultant field is along the axis of the solenoid.





If there are 'n' number of turns per metre length of solenoid and I amperes is the current flowing, then magnetic field at axis of long solenoid.

$$B = \mu_0 n I$$

If there are N turns in length I of wire, then

$$n = \frac{N}{l} \quad \text{or} \quad B = \frac{\mu_0 N I}{l}$$

Derivation : Consider a symmetrical long solenoid having number of turns per unit length equal to n.

Let I be the current flowing in the solenoid, then by right hand rule, the magnetic field is parallel to the axis of the solenoid.

Field outside the solenoid : Consider a closed path *abcd*. Applying Amere's law to this path

$\oint \vec{B}.\vec{dl} = \mu \times 0$ (since net current enclosed by path is zero)

As $dl \neq 0 \quad \therefore B = 0$

This means that the magnetic field outside the solenoid is zero.

Field Inside the solenid : Consider a closed path *pqrs.* The line integral of magentic field $\vec{B}$ along path *pqrs* is

$$\int_{pqrs} \vec{B}\bullet\vec{dl} = \int_{pq} \vec{B}\bullet\vec{dl} + \int_{qr} \vec{B}\bullet\vec{dl} + \int_{sp} \vec{B}\bullet\vec{dl} \qquad ...(1)$$

For path pq. $\vec{B}$ and $\vec{dl}$ are along the same direction.

$$\therefore \qquad \int_{pq} \vec{B}\bullet\vec{dl} = \int B\,dl = Bl \qquad (pq = 1 \text{ say})$$

For paths qr and sp, $\vec{B}$ and $\vec{dl}$ are mutually perpendicular.

$$\int_{qr} \vec{B}\bullet\vec{dl} = \int_{sp} \vec{B}\bullet\vec{dl} = \int B\,dl\cos 90° = 0$$

For path rs, B = 0 (since field is zero outside a solenoid)

$$\therefore \qquad \int_{rs} \vec{B}\bullet\vec{dl} = 0$$

In view of these, equation (1) gives

$$\oint_{pqrs} \vec{B}\bullet\vec{dl} = \int_{pq} \vec{B}\bullet\vec{dl} = Bl \qquad ...(2)$$

By Ampere's law $\int \vec{B}\bullet\vec{dl} = \mu_0 \times$ net current enclosed by path

$\therefore \qquad Bl = \mu_0 (nl\,l) \quad \therefore \; B = \mu_0 n I$

This is the well know result.

7. Using Ampere's circuital law, derive an expression for the magnetic field along the axis of a toroidal solenoid.

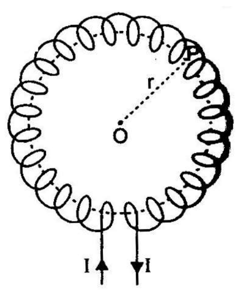
Sol. Magnetic field due to a toroidal solenoid : A long solenoid shaped in the form of closed ring is called a toroidal solenoid (or endless solenoid). Let n be the number of turns per unit length of toroid and I the current flowing through it. The current causes the magnetic field inside the turns of the solenoid. The magnetic lines of fore inside the toroid are in the form of concentric circles. By symmetry the magneic field has the same magnitude at each point of circle and is along the tangent at every point on the circle.

For points inside the core of toroid

Consider a circle of radius r in the region enclosed by turns of toroid. Now we apply Ampere's circuital law to tis circular path, i.e,

$$\int \vec{B}\bullet\vec{dl} = \mu I \qquad ....(1)$$

$$\int \vec{B}\bullet\vec{dl} = \oint B\,dl\cos 0 = B.2\pi r$$



Length of toroid = $2\pi r$

Number of turns in toroid = $n (2\pi r)$

current in one-turn = I

$\therefore$ Current enclosed by circular path = $(n\, 2\pi r) \bullet I$

$$B\, 2\pi r = \mu_0 (n\, 2\pi r\, I)$$

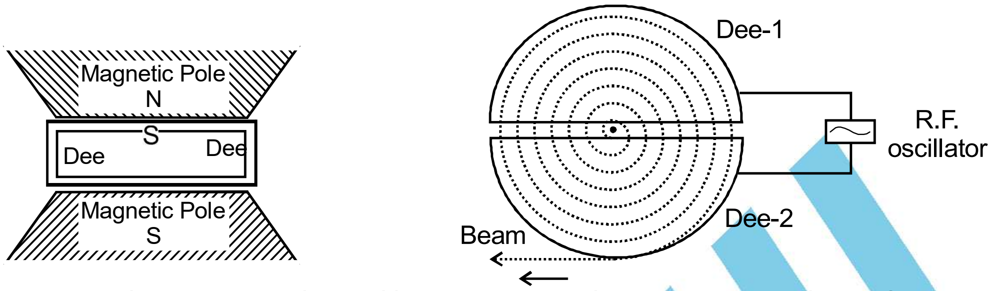
$$\Rightarrow \qquad B = \mu_0 n I$$

8. (a) Explain with the help of a labelled diagram construction, principle and working of

cyclotron stating clearly the functions of electric and magnetic fields on a charged particle. Derive an expression for the period of revolution and cyclotron frequency. Show that it is independent of the speed of the charged particles.

(b) Also find the total K.E. attained by the charged particle.

Sol.



(a) Cyclotron : The cyclotron, devised by Lawrence and Livingston, is a device for accelerating ions to high speed by the repeated application of accelerating potentials.
Construction : The cyclotron consists of two flat semi-circular metalboxes called 'dees' and are arranged with a small gap between them. A source of ions is located near the mid-point of the gap between the dees (fig). The dees are connected to the terminals of a radio frequency oscillator, so that a high frequency alternating potential of several million cycles per second exists between the dees. Thus dees acts as electrondes, The dees are enclosed in an insulated metal box containing gas at low pressure. The whole apparatus is placed between th poles of a strong electromagnet which provides a magnetic field perpendicular to the plane of the dees.
Principle : Resonance Condition : The condition of working of cyclotronis that the frequency ofradio frequency alternating potential must be equal to the frequency of revolution of charged particles within the dees. This is called resonance condition.
Working : The principle of action of the apparatus is shown in fig. The positive ions produced from a source S at the centre are accelerated by a dee which is at negative potential at that moment. Due to the presence of perpendicular magnetic field the ion will mvoe in circular path inside the dees. The magnetic field and the frequency of the applied voltages are so chosen that as the ion comes out of a dee, the dees change their polarity (positive becoming negative and vice-versa) and the ion is further accelerated and moves with higher velocity along a circular path of greater radius. The phenomenon is continued till the ion reaches at the periphery of the dees whee an auxiliary negative electrode (deflecting plate) deflects the accelerated ion on the the target to be bombarded.
The **function of electric field** is to accelerate the charged particle and so to impact energy to the charged particle.
The function of magnetic field is to provide circular path to charged particle and so to provide the location whre charged particle is capable of gaining energy from electric field.
Expression for Period of Revolution and Frequency :
Suppose the positive ion with charge q moves in a dee with a velocity v, then,

$$qvB = \frac{mv^2}{r} \quad \text{or} \quad r = \frac{mv}{qB} \qquad ...(1)$$

where m is the mass and r the radius of the path of ion in the dee and B is the strength of the magnetic field. The angular velocity ω of the ion is given by,

$$\omega = \frac{v}{r} = \frac{qB}{m} \text{(from eq.1)} \qquad ...(2)$$

The time tkaen by the ion in describing a semi-circle, i.e., in turning through an angle π is ,

$$t = \frac{\pi}{\omega} = \frac{\pi m}{Bq} \qquad ...(3)$$

Thus the time is independent of the speed of the ion i.e., although the speed of the ion goes on increasing with increase ion the radius (from eq. 1) when it moves from one dee to the other, yet it takes the same time in each dee.

From eq.(3) it is clear that for a particular ion, $\frac{m}{q}$ being known, B can be calculated for producing resonance with the high frequency alternating potential.

Now for the cyclotron to work, the applied alternating potential should also have the same semi-periodic time (T/2) as that taken by thehion to cross either dee, i.e.,

$$\frac{T}{2} = t = \frac{\pi m}{qB} \qquad ...(4)$$

or
$$T = \frac{2\pi m}{qB} \qquad ....(5)$$

This is the expression for period of revolution.

$\therefore$ Frequency of revolution of particles

$$f = \frac{1}{T} = \frac{qB}{2\pi m}$$

This frequency is called the cyclotron frequency. Clearly the cyclotron frequency (or period of revolution) is independent of speed of particle.

Expression for K.E. Attained

(b) The frequency o the applied alternating potential will be

$$f = \frac{1}{T} = \frac{qB}{2\pi m}$$

If R be the radius of the path and v_{max} the velocity of the ion when it leaves the periphery, then in accordance with eq. (2)

$$v_{max} = \frac{qBR}{m} \qquad ...(6)$$

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

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

when charged particle crosses the gap between dees it gains KE $= qV$ ...(7)

In one revolution, it crosses the gap twice, therefore it it completes n-revolutions before emerging the doees, the kinetic energy gained

$$= 2n\,q\,V$$

Thus
$$K.E. = \frac{q^2B^2R^2}{2m} = 2nqV \qquad ....(8)$$

9. **Draw the labelled diagram of a moving coil galvanometer. Prove that in a radial magnetic field, the deflection of the coil is directly proportional to the current flowing in the coil.**

OR

(a) With the help of a neat and labelled diagram, explain the underlying principle and working of a moving coil galvanometer.

(b) What is the function of

(i) uniform radial field (ii) uniform radial field

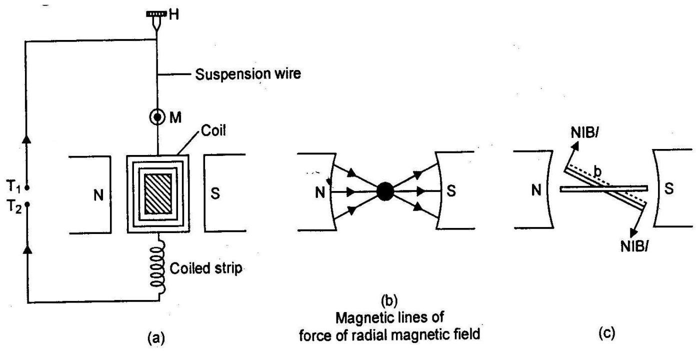
(ii) soft iron core, in such a device.

Sol. (a) **Moving coil Gavanometer :** A galvanometer is used to detect current in a circuit. suspended by phosphor bronze strip between the pole-pieces (N and S) of a strong permanent magnet.

A soft iron core in cylindrical form is placed between the coil.

One end of coil is attached to suspension wire which also servers as one terminal (T_1)

galvanometer. The other end of coil is connected to a loosely coiled strip, whcih serves as the other terminal (T_2). The other end of the suspension is attached to a torsion head which can be rotated to set the coil in zero position. A mirror (M) is fixed on the phosphor bronze strip by means of which the deflection of the coil is measured by the lamp and scale arrangement. The levelling screws are also provided at the base of the instrument.



The pole pieces of the permanent magnt are cylindrical so that the magnetic field is radial at any position of the coil.

Theory : When current (I) is passed in the coil, torque τ acts on the coil, given by

$$\tau = NIAB\sin\theta$$

where θ is the angle between the normal to plane of coil and the magnetic field of strength B, N is the number of turns in a coil.

When the magnetic field is radial, as in the case of cylindrical pole pieces and soft iron core, then in every position of coil the plane of the coil, is parallel to the magnetic field lines, so that θ = 90° and sin 90° = 1

Deflecting torque, $\tau = NIAB$

If k is the torsional rigidity of the wire and θ is the twist of suspension strip, then restoring torque = $C\theta$

For equilibrium, deflecting torque = restoring torque

i.e., $NIAB = k\theta$

$\therefore$ $\theta = \frac{NAB}{k}I$ ....(1)

i.e., $\theta \propto I$

deflection of coil is directly proportional to current flowing n the coil and hence we can construct a linear scale.

(b) (i) Function of uniform Radial Magnetic field : Torque as current carrying coil in a magnetic field is

τ = NIAB sin θ

In radial magnetic field sin θ = 1, so torque is τ = N I A B.

This makes the deflection (θ) proportional to current. In other words, the radial magnetic field makes the scale linear.

(ii) **Function of soft iron core** : The soft iron core helps in making the field radial and reduce energy losses produced due to eddy currents.

10. With the help of a circuit, show how a moving coil galvanometer can be converted into an ammter of an given range. Write the necessary mathematical formula.

Sol. An ammeter is a low resistance galvanometer and is connected in sereis in a circuit to read current directly in 'a'.

The resistance of an ammeter is to be made as low as possible so that it may read current without any appriciable error. therefore to convert a galvanometer into ammeter a shunt resistance. (i.e., small resistance in parllel) is connected across the coil of galvanometer. Let G be the resistance of galvanometer and I_g the current required for full scale deflection. Suppose this galvanometer is to converted into ammeter of range I ampere and the value of shunt required is S. If I_S is current in shunt, then from fig.

$$I = I_g + I_S \quad \Rightarrow \quad I_S = (I - I_g) \quad ...(1)$$

Also potential difference across A and B

$$(V_{AB}) = I_S . S = I_g . G$$

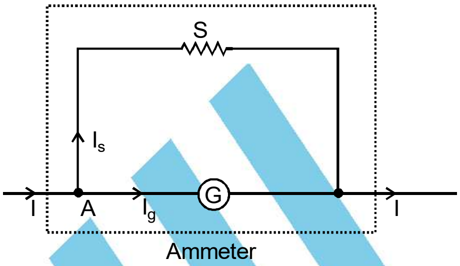
Substituting value of I_S from (1), we get

or $(I - I_g) S = I_g G$

or $IS - I_g S = I_g G$

or $IS = I_g (S + G)$

or $$I_g = \frac{S}{S+G} I \quad ....(2)$$



i.e., shunt required $S = \frac{GI_g}{I - I_g}$

This is the working equation of conversion of galvanometer into ammeter.

The resistance (R_A) of ammeter so formed is given by

$$\frac{1}{R_A} = \frac{1}{S} + \frac{1}{G} \quad \text{or} \quad \frac{1}{R_A} = \frac{S+G}{SG} \quad \Rightarrow \quad R_A = \frac{SG}{S+G}$$

If k is figure of merit of the galvanometer and n is the number of scale division, then I_g = nk. Out of the total main current I amperes, only a small permissible value I_g flows through the galvanometer and the rest $I_s = (I - I_g)$ passes through the shunt.

Remark : An ideal ammete has zero resistance.

11. Distinguish the magnetic properties of dia-,para- and ferromagnetic substances in terms of

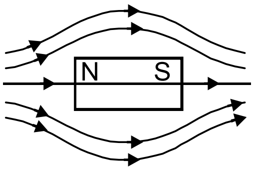
(i) Susceptibility (ii) Magnetic permeability (iii) Coercivity.

Give an example of each of these materials. Draw the field line due to an external magnetic field near a (i) diamagnetic (ii) paramagnetic substance.

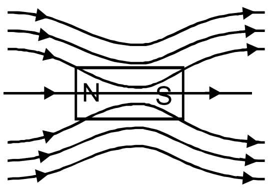
Sol. Distinction between diamagnetic, paramagnetic and feeromagnetic substances

	Property	Diamagntic	Paramagnetic	Ferromagneic
(i)	Susceptibility (χ)	$- \le \chi < 0$ (negative and small)	$0 < \chi < \varepsilon$ (positive and small)	$\chi >> 1$ (positive and large)
(ii)	Permeability (μ_r)	$0 \le \mu_r < 1$ (less than 1)	$1 < \mu_r < 1 + \varepsilon$ (slightly greater than 1)	$\mu_r >> 1$ (much greater than 1)
(iii)	Coercivity Example	High Gold	Low Platinum	Very low Iron

The magnetic field lines near a diamagnetic substance and a paramagntic substance are shown below :



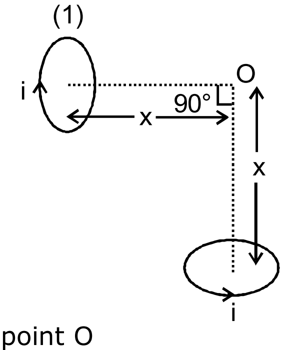
(i) Field linear near a Diamagnetic



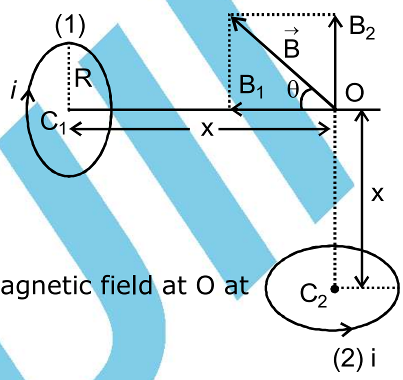
(ii) Field lines near a Paramagnetic

1. Two small identical circular loops, maked (1) and (2), carrying equal currents, are placed with the geometrical axes perpendicualr to each other as shown in the figure.

Find the magnitude and direction of the net magnetic field produced at the point O.



Sol. Magnetic field due to coil 1 at point O



$$\vec{B}_1 = \frac{\mu_0 iR^2}{2(R^2+x^2)^{3/2}} \text{ along } \vec{OC_1}$$

Magnetic field due to coil 2 at point O

$$\vec{B}_2 = \frac{\mu_0 iR^2}{2(R^2+x^2)^{3/2}} \text{ along } \vec{C_2O}$$

Both $\vec{B}_1$ and $\vec{B}_2$ are mutually perpendicular, so the net magnetic field at O at

$$B = \sqrt{B_1^2 + B_2^2} = \sqrt{2}B_1 (\text{as } B_1 = B_2) = \sqrt{2}\frac{\mu_0 iR^2}{2(R^2+x^2)^{3/2}}$$

As R << x

$$B = \frac{\sqrt{2}\mu_0 iR^2}{2.x^3} = \frac{\mu_0}{4\pi}.\frac{2\sqrt{2}\mu_0 i(\pi R^2)}{x^3} = \frac{\mu_0}{4\pi}\frac{2\sqrt{2}\mu_0 iA}{x^3}$$

where A = πR^2 is area of loop.

$$\tan\theta = \frac{B_2}{B_1}$$

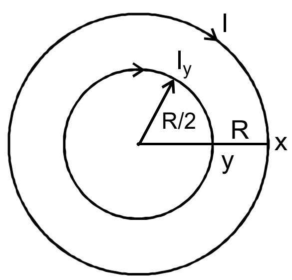
$\Rightarrow$ $\tan\theta = 1$ $(\because B_2 = B_1)$

$\Rightarrow$ $\theta = \frac{\pi}{4}$

$\therefore$ $\vec{B}$ is directed at an angle $\frac{\pi}{4}$ with the direction of magnetic field $\vec{B}_1$

2. Two circular coils X and Y having radii R and R/2 respectively are placed in horizontal plane with their centres coinciding with each othe. Coil X has current I flowing through it in the clockwise sense. What must be the current incoil Y to make the total magneic field at the common centres of the two coils, zero ? With the same currents flowing in the two coils, if the coil Y is now lifted vertically upwards through a distance R, what would be the net magnetic field at the centre of coil Y ?

Sol. For current at common centre O to be the zero; the current in coil Y must be anticlockwise. Net magnetic field at centre O is $B_1 - B_2 = 0$



$\Rightarrow$ $B_1 = B_2$ or $\frac{\mu_0 I}{2R} = \frac{\mu_0 I_4}{2(R/2)}$

$\Rightarrow$ $I_y = \frac{I}{2}$ i.e., current in coil Y is $\frac{I}{2}$ in anticlockwise direction.

Magneic field at the centre of coil Y is

$$B_1 = \frac{\mu_0 (I/2)}{2(R/2)} = \frac{\mu_0 I}{2R} (\text{upward})$$

Now centre of coil Y at a distance x = R on the axis of coil X, so magnetic field due to X at the centre of coil Y is

$$B_2 = \frac{\mu_0 IR^2}{2(R^2 + x^2)^{3/2}} = \frac{\mu_0 IR^2}{2(R^2 + R^2)^{3/2}} = \frac{\mu_0 IR^2}{4\sqrt{2}R^3}$$

$\Rightarrow$ $$B_2 = \frac{\mu_0 I}{4\sqrt{2}R}\text{(downward)}$$

$\therefore$ Net magnetic field, $B = B_1 - B_2$

$$= \frac{\mu_0 I}{2R} - \frac{\mu_0 I}{4\sqrt{2}R} = \frac{\mu_0 I}{R}\left[\frac{1}{2} - \frac{1}{4\sqrt{2}}\right] = \frac{\mu_0 I}{R}\left(\frac{2\sqrt{2}-1}{4\sqrt{2}}\right) = \frac{\mu_0 I}{R}\left(\frac{1.828}{5.657}\right) = 0.323\ \frac{\mu_0 I}{R}$$

3. A straight horizontal conducting rod of elgnth 0.45 m and mass 60 g is suspended by two vertical wires at its ends. A current of 5.0 A is set up in the rod through the wires.
(a) What magnetic field should be set up normal to the conductor in order that the tensions in the wire is zero ?
(b) What will be the total tension in the wires if the direction of current is reversed, keeping the magnetic field same as before ?
(Neglect the mass of wires, g = 9.8 m/s²).

Sol. **(a)** If tension in wires be zero, then the weight of rod and magnetic force on rod must be equal and opposite.
Weight of rod acts vertically downward. For magnetic force to act upward, the magnetic field should be normal to the length of current as shown in figure.(a).

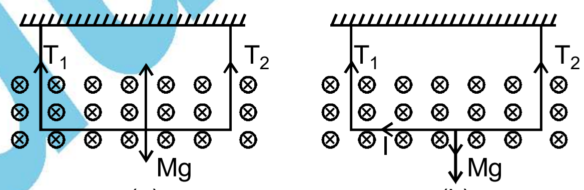
Magnetic force = weight of rod

BIL = mg

Magnetic field, $B = \frac{Mg}{IL}$

Given M = 60 g = 60 × 10^{-3} kg, I = 5.0 A, L = 0.45 m

$\therefore$ $$B = \frac{60 \times 10^{-3} \times 9.8}{5.0 \times 0.45} = 0.26\,T$$



(a) (b)

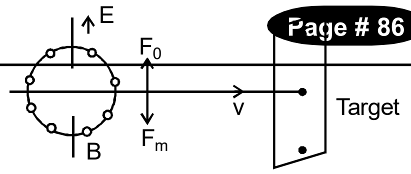
(b) When the direction of current is reversed, the magnetic force also reverse the direction; so that now weight Mg and magnetic force BIL act in the same direction.

$\therefore$ Total tension in wires T $(= T_1 + T_2)$ = Mg + BIL = 2Mg

= 2 × 60 × 10^{-3} × 9.8 = 1.176 N

4. A beam of protons passes undeflected with a horizontal velocity v, through a region of electric and magnetic fields, mutually pependicualr to each other and normal to the direction of the beam. If the magnitudes of the electric and magnetic fields are 50 kV/m and 1`00 mT respectively; calculate the
(i) velocity v of the beam.
(ii) force with which it strikes a target on the screen, if the proton beam current is equal to 0.80 mA.

Sol. (i) For a beam of charged particles to pass undeflected crossed electric and magnetic fields, the condition is that electric and magnetic forces



on the beam must be equal and opposite i.e.,

$$eE = evB$$

$$\Rightarrow \qquad v = \frac{E}{B}$$

Given, $E = 50$ kV/m $= 50 \times 10^3$ V/m, $B = 100$ mT $= 100 \times 10^{-3}$ T

$$\therefore \qquad v = \frac{50 \times 10^3}{100 \times 10^{-3}} = 5 \times 10^5\ ms^{-1}$$

(ii) The beam strikes the target with a constant velocity, so force exerted on the target is zero.

However, if proton beam comes to rest, it exerts a force on the target, equal to rate of charge of linear momentum of the beam i.e.,

$$F = \frac{\Delta p}{\Delta t} = \frac{mv}{\Delta t} = \frac{mv}{q/i} = \frac{mvi}{q} = \frac{mvi}{ne}$$

5. In a galvanometer there is a deflection of 10 V division per mA. The internal resistance of the galvanometer is 50 Ω. If a shunt of 2.5 Ω is connected to the galvanometer and there are 50 divisions in all on the scale of the galvanometer, calculate the maximum current which the galvanometer can read.

Sol. Current for full scale deflection

$$I_g = \frac{1}{10} \times 50 = 5\text{mA}$$

Resistance of galvanometer, $G = 60\ \Omega$

Shunt, $S = 2.5\ \Omega$

If I is the range of converted Ammeter, then working equation of conversion of Galvanometer into Ammeter is

$$I_g = \frac{S}{S+G} I \Rightarrow I = \frac{S}{S+G} I_g$$

Substituting given values

$$I = \frac{2.5+60}{2.5} \times 5\text{mA} = 125\text{mA}$$

6. A voltmeter reads 5.0 V at ful scale deflection and is graded according to its resistance per volt at full scale deflection as 5 kΩ/v. How will you convert it into a voltmeter that reads 20 V at full scale deflection ?

Sol. Initial range of voltmeter, $V_0 = 5$ V

Resistance per volt at full scale deflection $= 5$ k Ω/V

$\therefore$ Resistance of voltmeter, $R_v = 5\frac{k\Omega}{V} \times 5\ V = 25\ k\Omega = 25 \times 10^3\ \Omega$

Final range of voltmeter, $V = 20$ V

If R is the required series resistance, then

$$R = \left(\frac{V}{I_g} - R_v\right)$$

Here I_g = current for full scale deflection $= \frac{V_0}{R_v}$

$$\therefore \qquad R = \left(\frac{V}{V_0}R_v - R_v\right) = R_v\left(\frac{V}{V_0} - 1\right) = 25 \times 10^3\left(\frac{20}{5} - 1\right) = 75 \times 10^3\ \Omega = 75\text{k}\Omega$$

7. At a place the horizontal and vertical components of earth's magnetic field are equal. What is the angle of dip of that place ?

Sol. Given $H = V$ or $\frac{V}{H} = 1$

$\therefore$ Angle of dip θ is given by $\tan\theta = \frac{V}{H} = 1 \Rightarrow \theta = 45°$

8. The vertical component of the earth's magnetic field at a given place in $\sqrt{3}$ times its horizontal component. If total intensity of earth's magnetic field at the place of 0.4 G find the value of :
(i) angle of dip (ii) the horizontal component of earth's magnetic field.

Sol. Given $V = \sqrt{3}H$

$B_e = 0.4$ G

(i) Angle of dip θ is given by

$$\tan\theta = \frac{V}{H} = \frac{\sqrt{3}H}{H} \Rightarrow \tan\theta = \sqrt{3} \text{ or } \theta = 60°$$

(ii) Horizontal component of earth's magnetic field is

$H = B_e \cos\theta = (0.4 \text{ G}) \times \cos 60° = 0.2$ G

9. The horizontal component of earth's magnetic field at a given place is 0.4×10^{-4} Wb/m² and angle of dip is 30°. Calculate the value of (i) Vertical component (ii) Total intensity of earth's magnetic field.

Sol. (i) Given $H = 0.4 \times 10^{-4}$ Wb/m², $\theta = 30°$

$\tan\theta = \frac{V}{H} \Rightarrow$ vertical compnent $V = H\tan\theta$

$= 0.4 \times 10^{-4} \times \tan 30°$

$$= \frac{0.4 \times 10^{-4}}{\sqrt{3}} = 0.23 \times 10^{-4} \text{ Wb/m}^2$$

(ii) Total intensity of earth's magnetic field

$$B_e = \sqrt{H^2 + V^2} = \sqrt{(0.4 \times 10^{-4})^2 \left(\frac{0.4 \times 10^{-4}}{\sqrt{3}}\right)^2} = 0.46 \times 10^{-4} \text{ Wb/m}^2$$

10. A short bar magneti placed with its axis at 30° to a uniform magnetic field of 0.2 T experiences a torque of 0.06 N-m. (i) Calculate magnetic moment of the magnet and (ii) Find out what orientation of the magneticorresponds to a stable equilibrium in the magnetic field.

Sol. (i) Torque, $\tau = MB\sin\theta$

Here $B = 0.2$ T, $\theta = 30°$, $\tau = 0.06$ Nm

$\therefore$ Magnetic moment, $M = \frac{\tau}{B\sin\theta} = \frac{0.06}{0.2\sin 30°} = \frac{0.06}{0.2 \times 1/2} = 0.6 \text{ Am}^2$

(ii) Potential energy of magnetic dipole in a uniform magnetic field is

$U = -MB\cos\theta$

In a stable equilibrium potential energy is the minimum. For minimum potential energy $\cos\theta = 1$.

$\Rightarrow \theta = 0$.

That is, for stable equilibrium the magnet must be aligned with its magnetic moment parallel to the field.

11. A long straight wire carries a current of 50 A. An electron moving at 10^7 m/s, is 5.0 cm from the wire. Find the force acting on the electron if its velocity is directed,
(i) towards the wire (ii) parallel to the wire
(iii) perpendicular to the direction defined by (i) and (ii).

Sol. The magnetic field produced by a current carrying long wire at a distance

$R = 5 \text{ cm} = 5 \times 10^{-2}$ m is

$$B = \frac{\mu_0 I}{2\pi r} = \frac{\mu_0 I}{2\pi r} = \frac{4\pi \times 10^{-7}}{2\pi} \cdot \frac{50}{5 \times 10^{-2}} = 2.0 \times 10^{-4} \text{N/Am}$$

This field is directed downward perpendiculr to the plane of paper.

(i) The velocity v_1 is towards the wire i.e., angle between B and v_1 is 90°, therefore force on particle

$F = evB \sin 90° = evB$

i.e., $F = 1.6 \times 10^{-19} \times 10^{7} \times 2.0 \times 10^{-4} = 3.2 \times 10^{-16}$ N.

By Fleming's left hand rule this force is parallel to current.

(ii) When the electron is moving parallel to wire, v is again perpendiculr to B, therefore the force is again 3.2×10^{-16} N; but by Fleming left hand rule it is now directed radially away from the wire.

(iii) When the electron is moving pependicular to direction defined by (i) and (ii), angle between v and B will be 0 to π; therefore $\sin\theta = 0$; consequenctly the force will be zero.

Q.1 A long straight wire carries a current of 10 A. What is the value of magnetic field at a point 20 cm from the wire.

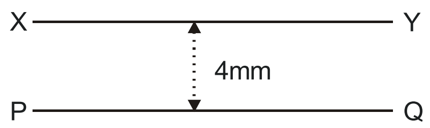
Q.2 How much current should be passed through a long wire so as to produce a magnetic field of 0.5×10^{-4} T at distance 10 cm from it.

Q.3 Find the magnetic field strength at the centre of a circular loop of radius 6.28 cm carrying a current of 2A.

Q.4 In Bohr model of hydrogen atom, the electron circulates around the nucleus in a circular orbit of radius 00.51 Å at a frequency of 6.8×10^{15} rv/sec. What is the magnetic field produced at the centre ?

Q.5 Two parallel wires at separation 10 cm carry current of 10 A and 20 A respectively in the time direction. Calculate the force of interaction per unit length.. Is this force attractive or repulsive?

Q.6 A long straight conductor PQ, carrying a current of 60 A is fixed horizontally. Another long conductor XY is kept parallel to PQ at a distance of 4 mm in air. Conductor XY is free to move and carries a current 'I.'. Calculate the magnitude and direction of current I for which the magnetic repulsion just balances the weight of conductor XY. Mass per unit length of conductor XY is 10^{-2} kg m^{-1}.



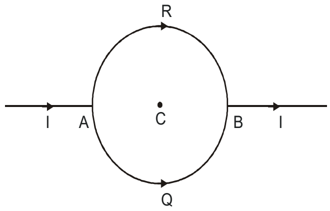
Q.7 A galvanometer has a current range 15 mA and voltage range 750 mV. How will you convert a into an ammeter of range 25 A.

Q.8 An electron travels in a circular path of radius 10 cm in a magnetic field of 2×10^{-5} T. Calculate the speed of electrons.

Q.9 A beam of protons enters a uniform magnetic field of 0.3 T with a velocity of 4×10^{5} m/s at an angle of 60º to the magnetic field. Find the radius of the helical path taken by the beam. Also find the pitch of the helix.

1. (a) With the help of a diagram, explain the principle and working of moving coil galvanometer
(b) What is the importance of a radial magnetic field and how is it produced ?
(c) Why is it that while using a moving coil galvanometer as a voltmeter a high resistance in series in required, wherever in an ammeter a shunt is used ?

Q.10 A long wire is bent as shown in fig.
What is the value of magnetic field at centre O.



Q.11 A straight wire of length $\frac{\pi}{2}$ metre is bent into a circular shape. If the wire were to carry a current of 5 A, calculate the magnetic field due to it before bending, a point distant 0.01 times the radius of circle formed from it. Also calculate the magnetic field at the centre of the circular loop formed for the same value of the current.

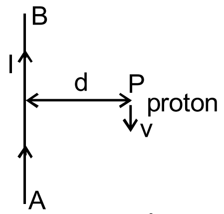
Q.12 Calculate the value of resistance needed to convert a galvanometer of resistance 100 Ω with a full scale deflection for a current of 5 mA., (i) into a voltmeter of range 0–10 V. (ii) into an ammeter of range 0–1 A.

Q.13 The frequency of r.f. voltage source applied across the cyclotron. Dees is 10MHz. What should be the value of the operating magnetic field. If the radius of the Dees be 0.60 m, what is the maximum kinetic energy (in MeV) of beam of protons accelerated in cyclotron.
Given $m_p = 1.67 \times 10^{-27}$ m.

Q.14 Deuterons ($q = 1.6 \times 10^{-19}$ C, $m = 3.3 \times 10^{-27}$ kg) are being accelerated by a cyclotron.
(i) What is cyclotron frequency if magnetic field used has a strength 1.5 T ?
(ii) The p.d. across the gap of Dees is 50 kV. If K.E. attained is 20 MeV, calculate the number of revolutions of deutrons inside the Dees.

EXERCISE - I UNSOLVED PROBLEMS

2. (a) Derive an expression for the force between two long parallel current carrying conductors
(b) use this expression to define SI unit of current
(c) A long straight wire AB carries a current I. A proton P travels with a speed v, parallel to the wire, at a distance d from it in a direction opposite to the current as shown in figure. What is the force experienced by the proton and what is its direction ?



3. A beam of electrons projected along + x axis, experience a force due to a magnetic field along +y-axis. What is the direction of magnetic field.

4. Deduce the expression for the magnetic dipole moment of an electron orbiting around the central nucleus

5. Use expression : $\vec{F} = q(\vec{v} \times \vec{B})$, to define the SI unit of magnetic field

6. The horizontal component, of the earth's magnetic field at a place is 50% of the earth's total field there. Find the value of the angle of dip at that place. What is the ratio of the vertical component of the total magnetic field of the earth at that place ?

7. What does a toroid consist of ? Show that for an ideal toroid of closely wound turns, the magnetic field
(1) inside the toroid is constant and (2) in the open space inside and exterior is zero.

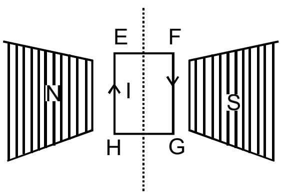
8. State Ampere's circuital law. Show through an example, how this law enabler an easy evaluation of the magnetic field when there is a symmetry in the system.

9. Define current and voltage sensitivity of a galvanometer. Increasing the current sensitivity may not necessarily increases the voltage sensitivity of galvanometer, justify.

10. An electron does not suffer any deflection while passing through a region of uniform magnetic field. Give direction of magnetic field.

11. Draw a schematic sketch of a cyclotron. Explain briefly how it works and how it is used to accelerate the charged particles.
(1) Show that time period of ions is independent of both the speed and radius of circular path
(2) What is resonance condition ? How is it used to accelerate the charged particle ?

12. (a) Two straight long parallel conductors carry currents I_1 and I_2 in the same direction. Deduce the expression for the force per unit length between them and Depict the pattern of magnetic lines of force around them.
(b) Rectangualr current carrying loop E F G H is kept in a uniform magnetic field as shwon in the figure.



(i) What is the direction of the magnetic moment of the current loop ?
(ii) When is the torque acting on the loop
(A) maximum (B) maximum

EXERCISE - II BOARD PROBLEMS

13. A galvanometer has a resistance 30 Ω and gives full scale deflection for a current of 2 mA. How much resistance and in what way must be conected to convert it into :
(i) an ammeter of range 0.3 A (ii) a voltmeter of range 0.2 A

14. A circular coil of 200 turns, radius 5 cm carries a current of 2.5 a. It is suspended vertically in a uniform horizontal magnetic field of 0.25 T, with the plane of the coil making an angle of 60° with the field lines. Calculate the magnitude of the torque that must be applied on it to prevent it from turning.

15. A rectangular loop of sides 25 cm and 10 cm carrying a current of 15 a is placed with its longer side parallel to a long straight conductor 2.0 cm apart carrying a current of 25 A (fig). What is the net force on the loop ?

16. A cyclorton oscillator frequency is 10 MHz. What should be the operating magnetic field for acceleration proton ? If the radius of its blees is 60 cm, what is the kinetic energy of the proton beam produced by the acceleration ? Express your answer in Mev.($e = 1.60 \times 10^{-19}$ C, $M_p = 1.67 \times 10^{-27}$ kg, 1 MeV = 1.6×10^{-13} J)

17. A magnetising field of 1500 A/m produces a flux of 2.4×10^{-5} Wb in a bar of iron of cross-sectional area 0.5 cm^2. Calculate the permeability and susceptibility of the iron-bar used.

18. A solenoid of length 1 m has radius of 1 cm and is made up of 1000 turns. It carries a current of 10 A. What is the magnitude of the magnetic field inside the solenoid ?

19. A bar magnet of magnetic moment of 1.5 JT^{-1} lies aliged with the direction of a uniform magnetic field of 0.22 T. Calculate the amount of work done to turn of the magnet so as to align its magnetic moment (i) normal to field direction and (ii) opposite to field direction.

20. A semi-circular arc of radius 20 cm carries a current of 10 A. Calculate the magnitude of magnetic field at the centre of the arc.

21. A long straight wire AB carries current of 4a. A proton P travels at 4×10^6 m/s, parallel to the wire, 0.2 m from it and in a direction opposite to the current as shwon in fig. Calculate the force which the magnetic field of current exerts on the proton. Also specify the direction of the force.

22. To increase the current sensitivity of a moving coil galvanometer by 50%, its resistance is increased so that the new resistance becomes twice its initial resistance. By what factor does its voltage sensitivity change ?

23. A solenoid 1.5 m long and 4.0 cm in diameter posses 10 turns/cm. A current of 5.0 ampere is flowing through it. Calculate the magnetic induction (a) inside and (b) at one end, on the axis of solenoid.

24. Mention the two characterisitic properties of the material suitable for making core of a trasformer.

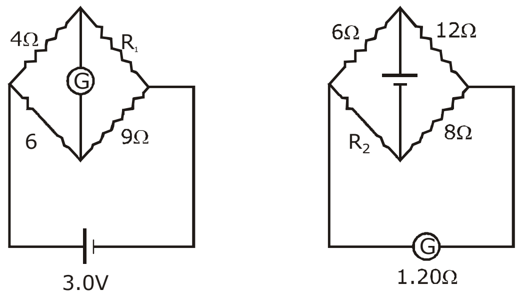
25. (a) Write the experession for the force, $\vec{F}$, acting on a charged particle of charge 'q', moving with a velocity $\vec{\upsilon}$ in the presence of both electric field $\vec{E}$ and magnetic field $\vec{B}$. Obtain the condition under which the particle moves undeflected through the fields.
(b) A rectangular loop of size $\ell \times b$ carrying a steady current I is placed in a uniform magnetic field $\vec{B}$. Prove that the torque $\vec{\tau}$ acting on the loop is given by $\vec{\tau} = \vec{m} \times \vec{B}$, where $\vec{m}$ is the magnetic moment of the loop.

OR

(a) Explain, giving reasons, the basic difference in converting a galvanometer into (i) a voltmeter and (ii) and ammeter.
(b) Two long straight parallel conductors carrying steady currents I_1 and I_2 are separated by a distance 'd'. Explain briefly, with the help of a suitable diagram, how the magnetic field due to the force acting between the two conductors. Mention the natureof this force.

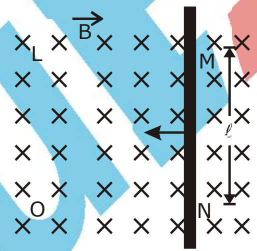
26. Define the current sensitivity of a galvanometer. Write its S.I. unit
Figure shows two circuits each having a galvanometer and a battery of 3 V.

When the galvanometers in each arrangment do not show any deflection, obtain the ratio R_1/R_2.



27. A wire AB is carrying a steady current of 10 A and is lying on the table. Another wire CD carrying 6 A is held directly above AB at a height of 2 mm. Find the mass per unit length of the wire CD so that it remains suspended at its position when left free. Give the direction of the current flowing in CD with respect in AB. [Take the value of g = 10 ms^{-2}]

28. A rectangular conductor LMNO is placed in a uniform magnetic field of 0.5 T. The field is directed perpendicular to the plane of the conductor. When the arm MN of length of 20 cm is moved towards left with a velocity of 10 ms^{-1}, calculate the emf induced in the arm. Given the resistance of the arm to be 5 Ω (assuming that other arms are of negligible resistance) find the value of the current in the arm.



A wheel with 8 metallic spokes each 50 cm long is rotated with a speed of 120 rev/min in a plane normal to the horizontal component of the Earth's magnetic field. The Earth's magnetic field at the place is 0.4 G and the angle of dip is 60°. Calculate the emf induced between the axle and the rim of the wheel. How will the value of emf be affected if the number of spokes were increased ?

ANSWER KEY

EXERCISE - I — UNSOLVED PROBLEMS

1. 10^{-5} T **2.** 25 A **3.** 2×10^{-5} T

4. 13.4 T

5. 4×10^{-4} Nm^{-1}, attractive

6. 32.7 A, opposite to current in PQ

7. We shall use a shunt of 0.03 Ω

8. 3.5×10^{7} m/s **9.** 1.2 cm, 4.35 cm

10. $\frac{\mu_0 I}{2\pi R}(\pi + 1)$ Wb/m^2 **11.** 4×10^{-4} T, 12.56×10^{-5} T

12. 1900 Ω in series, 0.5 Ω is parallel **13** B = 0.67 T, KE = 7.4 MeV

14. 11.6 MHz, 400

EXERCISE - II — BOARD PROBLEMS

6. $\delta = 60°$, $\sqrt{3}/2$

12. (i) M is perpendicular to plane and directed downward

(ii) M is perpendicular to B

M is parallel to B

13. (i) 0.2 Ω (ii) 70 Ω **14.** $\tau = 0.4$ g Nm **15.** $F = F_1 - F_2 = 7.812 \times 10^{-4}$ N (repulsive)

16. B = 0.66 T, $K.E_{max}$ = 7.5 MeV **17.** $\chi = \mu_r - 1 = 254$.

18. $B = 1.256 \times 10^{-2}$ T **19.** M_B, 2MB

20. $B = 1.57 \times 10^{-5}$ T **21.** $F_m = 25.6$ N

22. % decreases in voltage sensitivity = 25% **23.** (a) B inside = $2\pi \times 10^{-3}$ T, (b) B at one end = $\pi \times 10^{-3}$ T