Date: 20/10/2021

Q1. **Write one condition under which an electric charge does not experience a force in a magnetic field.**

Q2. **Write an expression for the force experienced by a charged particle moving in a uniform magnetic field *B*.**

Q3. **An electron moving through a magnetic field does not experience any force. Under what condition is this possible?**

Q4. **What is the direction of the force acting on a charged particle *q*, moving with a velocity $\vec{v}$ in a uniform magnetic field $\vec{B}$?**

Q5. **What is magnetic Lorentz force?**

Q6. **Is the source of magnetic field analogue to the source of electric field?**

Q7. **What is the magnitude of force on a charge moving with a velocity $\vec{v}$ in a magnetic field $\vec{B}$?**

Q8. **Under what conditions will the force exerted by the magnetic field on a charged particle be (a) Maximum and (b) minimum?**

Q9. **In a certain arrangement a proton does not get deflected while passing through a magnetic field region. Under what condition is this possible?**

Q10. **Why can neutrons be accelerated in a cyclotron?**

Q11. **In which condition, an electron moving through a magnetic field experiences maximum force?**

Q12. **What are the primary functions of electric field and the magnetic field in a cyclotron?**

Q13. **A 30 μC charge is placed in same direction of uniform magnetic field of 4 tesla. How much force does the charge experience?**

Q14. **A certain proton moving through a magnetic field region experiences maximum force. When does this occur?**

Q15. **Why the frequency of a charge circulating inside the dees of a cyclotron does not depend upon the speed of the charge?**

Q16. **Which one of the following will experience maximum force, when projected with the same velocity '*v*' perpendicular to the magnetic field '*B*' : (a) α-particle, and (b) β-particle?**

Q17. **Write down the expression for the Lorentz force on a charge particle.**

Q18. **A particle carrying a charge of 5 μC is moving with a velocity $\vec{v} = (4\hat{i} + 3\hat{k})\text{ms}^{-1}$ in a magnetic field $\vec{B} = (3\hat{k} + 4\hat{i})\text{Wbm}^{-2}$. Calculate the force acting on the particle.**

Q19. **An electron is not deflected, while moving through a certain region of space. Can we be sure that there is no magnetic field in the region?**

Q20. In a field, the force experienced by a charge depends upon its velocity and becomes zero, when it is at rest. What is the nature of the field?

Q21. State the principle of cyclotron.

Q22. What is the direction of the force acting on a charged particle q, moving with a velocity $\vec{v}$ in a uniform magnetic field $\vec{B}$?

Q23. Does time spent by a proton inside the dee of the cyclotron depend upon (a) the radius of the circular path (b) the velocity of the proton?

Q24. In a field, the force experienced by a charge depends only upon the magnitude of the field and does not depend upon the velocity. Is field electric or magnetic in nature?

Q25. A test charge of 1.6×10^{-19} C moving with a velocity $\vec{v} = (2\hat{i} + 3\hat{j})\text{ms}^{-1}$ in a magnetic field $\vec{B} = (2\hat{i} + 3\hat{j})\text{Wbm}^{-2}$. Find the force acting on the test charge.

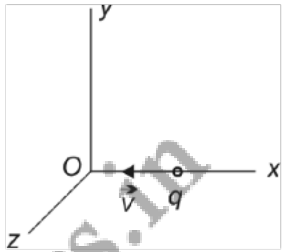
Q26. Two protons P and Q, moving the same speed enter magnetic fields B_1 and B_2 respectively at right angles to the field directions. If B_2 is greater than B_1, for which of the protons P and Q, the circular path in the magnetic field will have a smaller radius?

Q27. A charged particle in a plasma trapped in a magnetic bottle leaks out after a millisecond. What is the total work done by the magnetic field during the time, the particle is trapped?

Q28. As shown in figure. a charge q moving along the X-axis with a velocity $\vec{v}$ is subjected to a uniform magnetic field $\vec{B}$ acting along the Z-axis as it crosses the origin O.

(a) Trace its trajectory.

(b) Does the charge gain kinetic energy, as it enters the magnetic field? Justify your answer

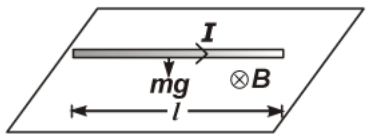


Q29. An electron and a proton moving with the same speed enter the same magnetic field region at right angles to the direction of the field. For which of the two particles will the radius of circular path be smaller.

Q30. What is the magnitude of magnetic force per unit length on a wire carrying a current of 8 A and making an angle of 30° with the direction of a uniform magnetic field of 0.15 T?

Q31. A 3.0 cm wire carrying a current of 10 A is placed inside a solenoid perpendicular to its axis. The magnetic field inside the solenoid is given to be 0.27 T. What is the magnetic force on the wire?

Q32. A straight wire of mass 200 g and length 1.5 m carries a current of 2A. It is suspended in mid-air by a uniform horizontal magnetic field B (see figure). What is the magnitude of the magnetic field?



Q33. An electron beam passes through a region of crossed electric and magnetic fields of intensities E and B respectively. For what value of electron speed will the beam remain undeflected?

Q34. Why does not a charged particle moving at right angle to the direction of magnetic field undergo any change in kinetic energy?

Q35. Two particles *M* and *N* masses *m* and 2*m* have charges *q* and 2*q* respectively. Both these particles moving with velocities v_1 and v_2 respectively in the same direction enter the same magnetic field *B* acting normally to their direction of motion. If the two forces F_M and F_N acting on them are in the ratio of 2 : 1, find the ratio of their velocities.

Q36. A charge $q = -4\,\mu C$ has an instantaneous velocity $\vec{v} = (2\hat{i} - 3\hat{j} + \hat{k}) \times 10^6\, ms^{-1}$ in a uniform magnetic field $\vec{B} = (2\hat{i} + 5\hat{j} - 3\hat{k}) \times 10^{-2} T$. What is the force on the charge?

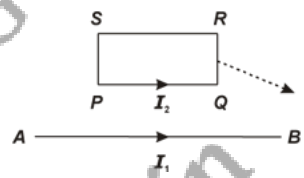
Q37. State and explain Lorentz force.

Q38. A beam of α-particles and of protons, of the same velocity *v*, enters a uniform magnetic field at right angles to the field lines. The particles describe circular paths, find the ratio of their radii of the circular path.

Q39. An electron is moving at $10^6\, ms^{-1}$ in a direction parallel to a current of 5 A, flowing through an infinitely long straight wire, separated by a perpendicular distance of 10 cm in air. Calculate the magnitude of the force experienced by the electron.

Q40. An electron after being accelerated through a potential difference of 100 eV enters a uniform magnetic field of 0.004 T perpendicular to its direction of motion. Calculate the radius of the path described by the electron. Given, $m = 9.1 \times 10^{-31}$ kg and $e = 1.6 \times 10^{-19}$ C.

Q41. As shown in the figure below, the straight wire *AB* is fixed, while the loop is free to move under the influence of the electric currents flowing in them
In which direction does the loop begin to move?
Give reason for your answer



Q42. A straight wire, of length *l*, carrying a current ***I***, stays suspended horizontally in mid air in a region where there is a uniform magnetic field $\vec{B}$. The linear mass density of the wire is λ. Obtain the magnitude and direction of this magnetic field.

Q43. A cyclotron's oscillator frequency is 10 MHz. What should be the operating magnetic field for accelerating protons? If the radius of its 'dees' is 60 cm, what is the kinetic energy (in MeV) of the proton beam produced by the accelerator. ($e = 1.60 \times 10^{-19}$ C, $m_p = 1.67 \times 10^{-27}$ kg, 1 MeV = 1.6×10^{-13} J).

Q44. A circular coil of 200 turns and radius 10 cm is placed in a uniform magnetic field of 0.5 T, normal to the plane of the coil. If the current in the coil is 3.0 A, calculate the

(a) total torque on the coil.

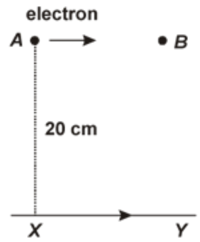
(b) total force on the coil.

(c) average force on each electron in the coil, due to the magnetic field.

Assume the area of cross-section of the wire to be $10^{-5}\, m^2$ and the free electron density is $10^{29}/m^3$.

Q45. Derive an expression for the force acting on a straight current carrying conductor placed in a uniform magnetic field.

Q46. An infinitely long straight conductor '*XY*' is carrying a current of 5 A. An electron is moving with a speed of 10^5 m/s parallel to the conductor in air from point *A* to *B*, as shown in the figure below. The perpendicular distance between the electron and the conductor '*XY*' is 20 cm. Calculate the magnitude of the force experienced by the electron. Write the direction of this force.



Q47. Find the expression for magnetic dipole moment of a revolving electron. What is 'Bohr magneton'?

Q48. An electron moves around the nucleus in a hydrogen atom of radius 0.51 Å with a velocity of 2×10^5 m/s. Calculate the following

(a) The equivalent current due to orbital motion of electron.

(b) The magnetic field produced at the centre of the nucleus.

(c) The magnetic moment associated with the electron.

Q49. (a) Explain, giving reasons, the basic difference in converting a galvanometer into (i) voltmeter and (ii) an 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 one conductor acts on the other. Hence deduce the expression for the force acting between the two conductors. Mention the nature of this force.

Q50. (a) Write an expression for the force experienced by a charge *q*, moving with a velocity *v*, in a magnetic field B.

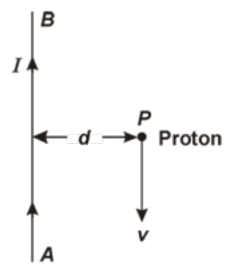
Use expression to define the unit of magnetic field.

(b) Obtain an expression for the force experienced by a current carrying wire in a magnetic field.

Q51. (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 the figure. What is the force experienced by the proton and what is its direction?

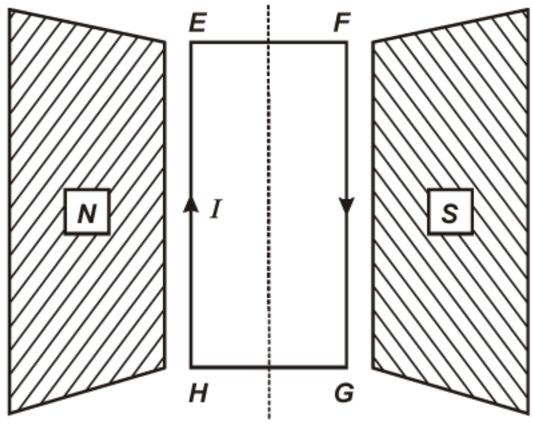


Q52. (a) Two straight long parallel conductors carry currents I_1 and I_2 in the same direction. Deduce the expression for the force per unit length between them. Depict the pattern of magnetic field lines around them.

(b) A rectangular current carrying loop *EFGH* is kept in a uniform magnetic field as shown in the figure.

(i) What is the direction of the magnetic moment of the current loop?

(ii) What is the torque acting on the loop maximum and zero?



Date: 20/10/2021

S1. We know,

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

where θ is angle between velocity (v) and $\vec{B}$.

$\theta = 0°$ *i.e.*, charge of velocity and magnetic field both are same, Hence no force exert on the charge.

S2. It is given by

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

Te magnitude of force is given by

$$F_m = qvB\sin\theta.$$

where θ angle between v and B.

S3. It is moving parallel/antiparallel to magnetic field.

S4. The direction force of a charge particle will be perpendicular both velocity $\vec{v}$ and magnetic field $\vec{B}$

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

if v and B both are perpendicular then force acting on charge particle.

S5. The force experienced by a charged particle, when moving inside magnetic field is called magnetic Lorentz force.

It is given by

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

S6. No. The source of magnetic field is not a magnetic charge. In case of electric field, the source of electric field is electric charge.

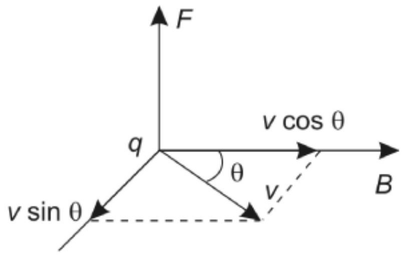
S7. The magnitude of force on the moving charge due to magnetic field is given by

$$F = q(\vec{v} \times \vec{B}) = qvB\sin\theta.$$

If the charged particle moves at right angle to the direction of the field, then

$$\theta = 90°$$

$$F = qvB.$$



If the charged particle moves in parallel to the direction of the field, then

$\theta = 0°$

$F = 0.$

S8. (a) The force is maximum when the velocity of charge particle and magnetic field both are perpendicular *i.e.*, $\vec{v} \perp \vec{B}$.

We know $\vec{F} = qvB\sin\theta$

when $\theta = 90°$ then F is maximum.

(b) The force is minimum when the angle between velocity moving charge particle and magnetic field will parallel or antiparallel.

S9. It is possible when proton move parallel or antiparallel the direction of magnetic field

Explanation: $\theta = 0^\circ$ or 180°

$\vec{F} = qvB\sin\theta$

$\vec{F} = 0$ (in both cases)

Hence, the proton does not deflected.

S10. No, neutrons cannot be accelerated by using a cyclotron. This because, a cyclotron can accelerate charged particles and is particularly suitable for protons and positive ions.

S11. An electron moving through a magnetic field experiences maximum force, when it moves 90° to the direction of magnetic field.

S12. The magnetic field makes the charged particle to cross the gap between the dees again and again by making it to move along circular path, while the oscillating electric field, applied across the dees, accelerates the charged particle again and again.

S13. Given, $q = 30\ \mu C = 3.0 \times 10^{-5}$ C

$B = 4$ tesla

$\theta = 0$

$F = qvB\sin\theta \Rightarrow qvB\sin 0$

$F = 0$

Hence, no force experience on charge particle.

S14. From Lorenz force,

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

Obviously, magnitude of $\vec{F}$ will be maximum, if the direction of $\vec{v} \perp \vec{B}$.

S15. The radius of the circular path inside the dee increases in direct proportion to the velocity of the charge. As a result, the time period of the charge and hence its frequency remains independent of the speed of the charge.

S16. We know,

$$\vec{F} = qvB\sin\theta$$

α-particle more force experience.

S17. The force experienced by a charge, when moving inside the electric and magnetic fields is called Lorentz force. It is given by

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

where q is electric charge, $\vec{E}$ is electric field, $\vec{v}$ is velocity of charge and $\vec{B}$ is magnetic field.

S18. Given, $q = 5\,\mu\text{C} = 5 \times 10^{-6}\,\text{C}$; $\vec{v} = (4\hat{i} + 3\hat{k})\,\text{ms}^{-1}$

and $\vec{B} = (3\hat{k} + 4\hat{i})\,\text{Wbm}^{-2}$

Now,
$$\vec{F} = q(\vec{v} \times \vec{B})$$
$$= 5 \times 10^{-6}\,[(4\hat{i} + 3\hat{k}) \times (3\hat{k} + 4\hat{i})]$$
$$= 5 \times 10^{-6}\,(-12\hat{j} + 12\hat{j}) = 0.$$

S19. No. The electron may be moving parallel or antiparallel to the direction of magnetic field. In such a case, the force

$$\vec{F} = e(\vec{v} \times \vec{B}) = 0.$$

S20. The field is magnetic in nature. It is because, force due to electric field is not affected, whether the charge is at rest or is in motion.

S21. It states that the positive ions can acquire a large amount of energy with a comparatively smaller alternating potential difference by making them to cross the same electric field time and again by making use of a strong magnetic field.

S22. We know,

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

the force acts in the direction of $\vec{v} \times \vec{B}$ *i.e.*, perpendicular to both $\vec{v}$ and $\vec{B}$ from right hand rule.

S23. The time spent by a proton inside the dee of a cyclotron is independent of both the radius of circular path and the velocity of the proton.

S24. The field is electric in nature.

S25. Given, $q = 1.6 \times 10^{-19}$ C; $\vec{v} = (2\hat{i} + 3\hat{j})$ ms^{-1}

and $\vec{B} = (2\hat{i} + 3\hat{j})$ Wbm^{-2}

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

$= 1.6 \times 10^{-19} [(2\hat{i} + 3\hat{j}) \times (2\hat{i} + 3\hat{j})]$

$= 1.6 \times 10^{-19} (6\hat{k} - 6\hat{k}) = 0$

S26. From the expression:

$$B = \frac{mv}{er},$$

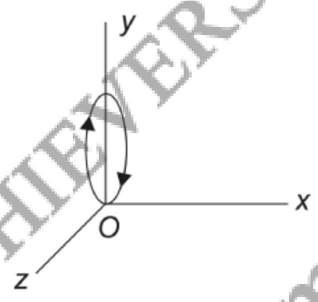
where m, v and e are constant for both protons p and q

Now, $B \propto \frac{1}{r}$.

Since $B_2 > B_1$, $r_2 < r_1$. Hence, the proton Q (moving inside the magnetic field B_2) will have a circular path of smaller radius.

S27. As the force due to magnetic field on a moving charged particle always acts perpendicular to its direction of motion (velocity), no work is done by the magnetic field.

S28. (a) As the charged particle crosses the origin O with velocity $\vec{v}$ (along negative X-axis), it comes under the effect of magnetic field $\vec{B}$ (acting along positive Z-axis). A force equal to $\vec{F} = q(\vec{v} \times \vec{B})$ acts on the charged particle positive Y-axis. As a result, the particle moves along a circular path in XY-plane as shown in figure.



(b) The force on the charged particle due to magnetic field is always perpendicular to its path and therefore, work done by magnetic field on the moving charge is zero. Hence, the charged particle will not gain kinetic energy.

S29. As mass of electron is less than that of proton, radius of circular path of the electron will be smaller.

Explanation: From the expression,

$$Bev = \frac{mv^2}{r}$$

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

where v, q and B are constant for electron and proton.

Now, $r \propto m$.

S30. Current in the wire, $I = 8$ A

Magnitude of the uniform magnetic field, $B = 0.15$ T

Angle between the wire and magnetic field, $\theta = 30°$.

$$\text{Magnetic force } f = IBl \sin\theta$$

$$\therefore \quad \text{Magnetic force/length } f = \frac{IBl \sin\theta}{l}$$

Magnetic force per unit length on the wire is given as:

$$f = BI \sin\theta$$

$$= 0.15 \times 8 \times 1 \times \sin 30°$$

$$= 0.6 \text{ N m}^{-1}$$

Hence, the magnetic force per unit length on the wire is 0.6 N m^{-1}.

S31. Length of the wire, $l = 3$ cm $= 0.03$ m

Current flowing in the wire, $I = 10$ A

Magnetic field, $B = 0.27$ T

Angle between the current and magnetic field, $\theta = 90°$

Magnetic force exerted on the wire is given as:

$$F = BIl \sin\theta$$

$$= 0.27 \times 10 \times 0.03 \sin 90°$$

$$= 8.1 \times 10^{-2} \text{ N}$$

Hence, the magnetic force on the wire is 8.1×10^{-2} N. The direction of the force can be obtained from Fleming's left hand rule.

S32. We find that there is an upward force $\boldsymbol{F}$, of magnitude IlB,. For mid-air suspension, this must be balanced by the force due to gravity:

$$mg = IlB \sin\theta \qquad [\theta = 90°]$$

$\therefore \qquad m\,g = IlB$

$$B = \frac{mg}{Il} = \frac{0.2 \times 9.8}{2 \times 1.5} = 0.65\ \text{T}$$

S33. Suppose, v be the electron speed, for which the beam remains undeflected, while crossing through the crossed electric and magnetic fields. For the beam to remain undeflected, the force on an electron due to the two fields should be equal and opposite

Magnetic force = Electric force

Therefore, $\qquad B\,e\,v = e\,E$

or $\qquad v = \frac{\boldsymbol{E}}{\boldsymbol{B}}.$

S34. The force on a charged particle moving in a uniform magnetic field always acts in a direction perpendicular to the direction of motion of the charge. As work done by the magnetic field on the charge is zero, the energy of he charged particle does not change.

S35. Given, $F_M : F_N = 2 : 1$

Mass of the two particles are m and $2m$

Charge of the particles are q and $2q$

Velocity of the both particles are v_1 and v_2

Force acting on particles due to magnetic field is given by

$$F = q\,v\,B$$

$$F_M = q\,v_1\,B; \qquad F_N = q\,v_2\,B$$

$$\frac{F_M}{F_N} = \frac{\cancel{q}\,v_1\,\cancel{B}}{2\cancel{q}\,v_2\,\cancel{B}} = \frac{v_1}{2v_2}$$

$$\frac{2}{1} = \frac{1v_1}{2v_2} \quad \Rightarrow \quad \boldsymbol{v_1 : v_2 = 4 : 1}$$

S36. $\vec{F} = q\vec{v} \times \vec{B}$

$$\vec{F} = (-4 \times 10^{-6})[(2\hat{i} - 3\hat{j} + \hat{k}) \times 10^{6}] \times [(2\hat{i} + 5\hat{j} - 3\hat{k}) \times 10^{2}]$$

$$= -(-16\hat{i} - 32\hat{j} - 64\hat{k}) \times 10^{-2}\,N$$

$$\vec{F} = -16(\hat{i} + 2\hat{j} + 4\hat{k}) \times 10^{-2}\,N.$$

S37. **Lorentz force:** Total force experienced by a charged particle moving in a region where both electric and magnetic fields exist, is called Lorentz force.

Let us consider a charged particle having charge q and moving with velocity $\vec{v}$ in a region having electric field $\vec{E}$ and magnetic field $\vec{B}$. The Lorentz force experienced by the particle is given by

$$\vec{F} = \vec{F_m} + F_e$$

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

or $$F = qvB \sin\theta + qE$$

where θ is angle between $\vec{v}$ and $\vec{B}$.

S38. Let m_1 and q_1 be the mass and the charge of an α-particle respectively. Let r_1 be the radius of the circular path described by the α-particle, when it moves in a uniform magnetic field B with a velocity v. Then,

Magnetic force = Centrifugal force

$$Bq_1 v = \frac{m_1 v^2}{r_1}$$

or $$r_1 = \frac{m_1 v}{Bq_1} \quad \text{... (i)}$$

Similarly, m_2 and q_2 be the mass and charge of proton. Then, the radius of the circular path described by the proton, when moving with same velocity v in a magnetic field B, is given by

$$r_2 = \frac{m_2 v}{Bq_2} \quad \text{... (ii)}$$

From Eq. (i) ÷ (ii), we get

$\therefore$ $$\frac{r_1}{r_2} = \frac{m_1 \cancel{v}}{\cancel{B} q_1} \times \frac{\cancel{B} q_2}{m_2 \cancel{v}}$$

$$= \frac{m_1/m_2}{q_1/q_2} = \frac{\cancel{4}}{\cancel{2}} = \mathbf{2}.$$

S39. Magnetic field produced due to the straight conductor,

$$B = \frac{\mu_0}{4\pi} \cdot \frac{2I}{a} = \frac{10^{-7} \times 2 \times 5}{10 \times 10^{-2}} = 10^{-5}\,\text{T}$$

Here, $F = Bqv \sin\theta = 10^{-5} \times 1.6 \times 10^{-19} \times 10^{6} \sin 90°$

$= \mathbf{1.6 \times 10^{-18}\ N}$.

S40. Now, energy of electron,

$$\frac{1}{2}mv^2 = 100\ \text{eV}$$

Here, $$\frac{1}{2}mv^2 = 100 \times 1.6 \times 10^{-19} = 1.6 \times 10^{-17}\ \text{J}.$$

$$v = \sqrt{\frac{2 \times 1.6 \times 10^{-17}}{m}} = \sqrt{\frac{2 \times 1.6 \times 10^{-17}}{9.1 \times 10^{-31}}} = 5.93 \times 10^{5}\ \text{ms}^{-1}$$

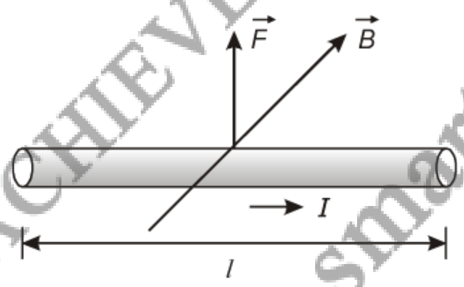
Now, $$\frac{mv^2}{r} = Bev$$

or $$r = \frac{mv}{eB}$$

or $$r = \frac{9.1 \times 10^{-31} \times 5.93 \times 10^{5}}{1.6 \times 10^{-19} \times 0.004} = \mathbf{8.4\ mm}.$$

S41. The currents in arm *PQ* and wire *AB* are in same direction and therefore hence wire will be attract the arm *PQ* with a force, say F_1. On the other hand, the arm *RS* of the loop will experience a force of repulsion, say F_2. Since the arm *PQ* is closer to the *AB*, $F_1 > F_2$. Hence, the loop will move towards the wire.

S42. Given: $\lambda = \frac{m}{l} \Rightarrow m = \lambda l$



According to question

$$IlB = mg$$

$$IlB = \lambda l g$$

or $$B = \frac{\lambda g}{I}$$

Magnetic field will act in a direction perpendicular to the direction of flow of current.

S43. The oscillator frequency should be same as proton's cyclotron frequency.

$$B = 2\pi m\nu/q = 6.3 \times 1.67 \times 10^{-27} \times 10^{7}/(1.6 \times 10^{-19}) = 0.66\,\text{T}$$

Final velocity of protons is

$$v = r \times 2\pi\nu = 0.6\,\text{m} \times 6.3 \times 10^{7} = 3.78 \times 10^{7}\,\text{m/s}.$$

$$E = ½\, mv^2 = 1.67 \times 10^{-27} \times 14.3 \times 10^{14}/(2 \times 1.6 \times 10^{-13}) = 7\,\text{MeV}.$$

S44. Given: $N = 200$; $r = 10\,\text{cm} = 0.1\,\text{m}$; $B = 0.5\,\text{T}$; $I = 3.0\,\text{A}$

(a) As $\vec{B}$ is parallel to the dipole moment ($\vec{M}$), *i.e.*, $\theta = 0$.

$$\tau = MB \sin\theta$$

$$\tau = MB \sin 0° = 0$$

(b) As the forces on different parts of the coil appear in pairs. Equal in magnitude and opposite in direction. Net force on the coil is zero. *i.e.*, $F = 0$

(c) Given; $A = 10^{-5}\,\text{m}^2$ and $n = 10^{29}\,\text{m}^{-3}$

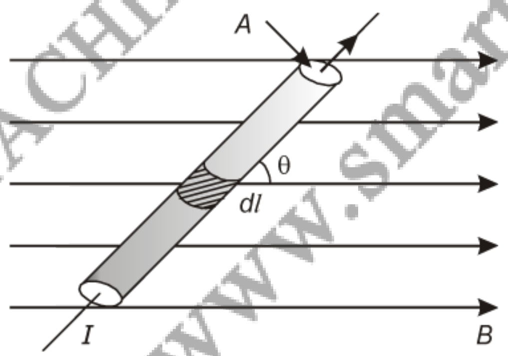
$$F = Bev_d$$

$$= B\cancel{e}\left(\frac{I}{\cancel{e}nA}\right) \qquad \left(I = v_d neA \quad \text{or} \quad v_d = \frac{I}{neA}\right)$$

$$F = \frac{BI}{nA} = \frac{0.5 \times 3}{10^{29} \times 10^{-5}}$$

$$= 1.5 \times 10^{-24}\,\text{N}.$$

S45. Let us consider a conductor placed in a uniform magnetic field $\vec{B}$, which makes an angle θ with the direction of the magnetic field. Let a current I flows through the conductor. Let v_d be the drift velocity of electrons in the conductor in a direction opposite to the direction of current, as shown in figure below.



Let n be the number of electrons per unit volume, then the total number of electrons in small current element dl is

$$= nAdl$$

$\therefore$ total charge in element dl = $neAdl$

Let $\vec{F}$ be the force experienced by each free electron due to the magnetic field $\vec{B}$ then,

$$\vec{F} = e(\vec{v_d} \times \vec{B})$$

The force experienced by small current element is given by

$$d\vec{F} = neAdl(\vec{v_d} \times \vec{B})$$

or $$dF = neAv_d\, dl\, B \sin\theta$$

But, $$neAv_d = I$$

$\therefore$ $$dF = BIdl \sin\theta$$

Hence, total force experienced by whole current carrying conductor is given by

$$F = \int_0^l dF = \int_0^l BIdl \sin\theta$$

where, l = total length of the conductor

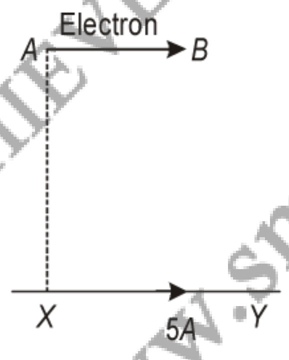
$\therefore$ $$F = BIl \sin\theta$$

In vector $$\vec{F} = I(\vec{l} \times \vec{B}).$$

Case (a): If $\theta = 90°$, then $F = BIl$, which is maximum *i.e.*, when current-carrying conductor is held perpendicular to the direction of magnetic field then the force experienced by the conductor is maximum.

(b): If $\theta = 0°$, then $F = 0$ which is minimum. Hence if a conductor is placed parallel to the direction of magnetic field then force experienced by the conductor is zero.

S46. Magnetic field at a distance of 20 cm from current carrying conductor XY is



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

$$B = \frac{2 \times 10^{-7} \times 5}{20 \times 10^{-2}}$$

$$B = 5 \times 10^{-6}\,\text{T}$$

Force experienced by the electron is

$$F = evB \qquad (\because \theta = 90°)$$

$$= 1.6 \times 10^{-19} \times 10^5 \times 5 \times 10^{-6} \text{ N}$$

$$= 8 \times 10^{-20} \text{ N.}$$

According to Right hand screw rule direction of force will be upwards.

S47. As electric current associated with the revolving electron

$$I = \frac{e}{T} = \frac{ev}{2\pi r}$$

where, time period, $T = \frac{2\pi r}{v}$

r = radius of orbit

v = velocity of electron

The magnetic moment due to the current,

$$M = IA = \frac{ev}{2\pi r} \times \pi r^2$$

$$\Rightarrow \qquad M = \frac{evr}{2}$$

If electron revolves in anti-clockwise sense, the current will be in clockwise sense. Hence, according to right hand rule, the direction of magnetic moment must will be perpendicular to the plane of orbit and directed inward to the plane.

So, $$M = \frac{evrm}{2m} = \frac{e \cdot l}{2m}$$

where, $vrm = l$ = angular momentum orbital of electron and in vector form,

$$M = -e\frac{l}{2m}$$

(–)ve sign indicates M and l are in mutually opposite directions. From Bohr's postulates,

$$l = mvr = \frac{nh}{2\pi}, \qquad \text{where} \quad n = 1, 2, 3, \ldots$$

$$\therefore \qquad M = \frac{e}{2m} \cdot \frac{nh}{2\pi} = nM_{\min}$$

where, $$M_{\min} = \frac{eh}{4\pi m}$$

is called **Bohr magneton**.

S48. Given: $r = 0.51$ Å $= 0.51 \times 10^{-10}$ m; $v = 2 \times 10^5$ m/s

Time period, $$T = \frac{2\pi r}{v}$$

(a) Electric current

$$I = \frac{e}{T} = \frac{e}{\left(\frac{2\pi r}{v}\right)} = \frac{eV}{2\pi r}$$

$$I = \frac{1.6 \times 10^{-19} \times 2 \times 10^5}{2 \times 3.14 \times 0.51 \times 10^{-10}} = \mathbf{9.99 \times 10^{-5}\ A}$$

(b) $$B = \frac{\mu_0 I}{2r} = \frac{\mu_0}{2r}\left(\frac{eV}{2\pi r}\right)$$

$$= \frac{4\pi \times 10^{-7}}{2 \times 0.51 \times 10^{-10}} \times 9.99 \times 10^{-5}$$

$$B = \mathbf{1.23\ T}$$

(c) Magnetic moment, $M = IA$

$$= 9.99 \times 10^{-5} \times (\pi \times r^2)$$

$$= 9.99 \times 10^{-5} \times 3.14 \times 0.51 \times 0.51 \times 10^{-20}$$

$$= \mathbf{8.16 \times 10^{-25}\ A\text{-}m^2}.$$

S49. (a) A galvanometer of range I_B and resistance G_1 can be converted into

(i) a vlotmeter of range V, by connecting a high resistance R in series with it where value is given by

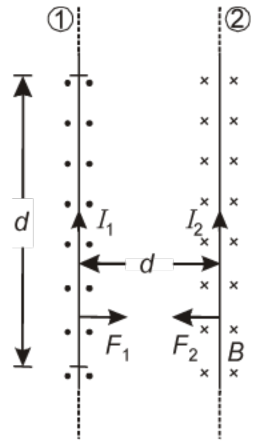
$$R = \frac{V}{I_s} - G$$

(ii) an ammeter of range, I by connecting a very low resistance (Shunt) in parallel with galvanometer whose value is given by

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

(b) Let two straight wires of infinite length are carrying currents, I_1 and I_2 in the same direction and separated, by distance d apart from each other.

The magnetic field due to wire 1 at any point on wire 2,



$$B_1 = \frac{\mu_0}{4\pi}\frac{2I_1}{d} \quad \text{... (i)}$$

The distance of B_1 is perpendicular to plane of paper and directed inward.

Magnetic force on wire 2, in L length of it

$$F_2 = I_2 B_1 L \sin 90°$$

$$= I_2\left(\frac{\mu_0}{4\pi}\cdot\frac{2I_1}{d}\right)L \times 1$$

$\therefore$ $$F_2 = \frac{\mu_0}{4\pi}\frac{2I_1 I_2}{d} \quad \text{[Towards wire] ... (ii)}$$

By Fleming left hand rule.

Similarly, force on wire 1 due to wire 2 can be proved

$$F_1 = \frac{\mu_0}{4\pi}\frac{2I_1 I_2}{d} \quad \text{... (iii)}$$

Thus, the nature of force is attractive.

When direction of flow of current gets in opposite direction, the nature of force becomes repulsive.

S50. (a) The required expression for the force is

$$F = q(v \times B) = qvB\sin\theta$$

Now, $$\mathbf{F} = q(v \times \mathbf{B})$$

$\Rightarrow$ $$F = qvB\sin\theta$$

where, θ is the angle between v and B

$\Rightarrow$ $$B = \frac{F}{qv\sin\theta}$$

i.e., if $q = 1$ C, $v = 1$ m/s, $\theta = 90°$, then $B = F$. The magnetic field at any point is given by

$$B = \frac{F}{qv\sin\theta}$$

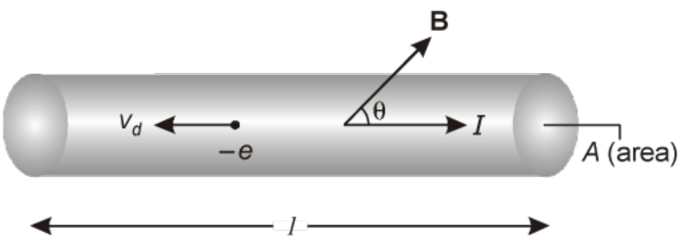
$$= \frac{1N}{(1C)(1m/s)\sin 90°}$$

$$= \mathbf{1\ N/A\text{-}m = 1\ T}$$

$\therefore$ SI unit of magnetic field 1 T.

Thus, the magnetic field induction at a point is said to be one tesla if a charge of one coulomb while moving at right angle to a magnetic field, with a velocity of 1 m/s experiences a force of 1 N at that point.

(b) Consider the segment of a conductor given in the figure below:



Let the number of electron per unit volume of the conductor is n, the drift speed of electron inside the conductor is v_d and the magnetic field is **B**. Then Lorentz magnetic force, $F_l = -e\,(v_d \times \mathbf{B})$.

$\therefore$ Force on all the mobile electrons of the conductor

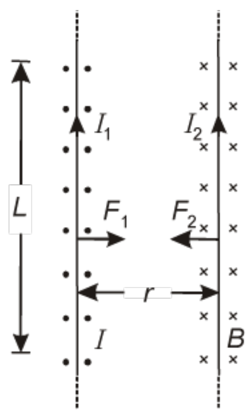
$$\mathbf{F} = F_l \cdot nAl = -\,nAle\,(v_d \times \mathbf{B})$$

or $$\mathbf{F} = l(\mathbf{I} \times \mathbf{B}) = IlB \sin\theta$$

This is the expression for the force experienced by current carrying wire.

S51. (a) Let two infinitely long straight current carrying conductor carries currents I_1 and I_2 in the same direction. Magnetic field B_1 due to first wire on second *i.e.*,

$$B_1 = \frac{\mu_0}{4\pi}\frac{2I_1}{r} \quad \text{... (i)}$$



The magnetic field is perpendicular to the plane of paper and directed inward *i.e.*, (X) type.

Now, magnetic force on L length of wire second is given by

$$F_2 = I_2 B_1 L \sin 90° = I_2\left(\frac{\mu_0}{4\pi}\cdot\frac{2I_1}{r}\right)L$$

$$\Rightarrow \quad \frac{F_2}{L} = \frac{\mu_0}{4\pi}\cdot\frac{2I_1I_2}{r} \quad \text{... (ii)}$$

By Fleming's left hand rule, the direction of force F_2 is perpendicular to the second wire in the plane of paper towards the first wire.

Similarly, magnetic force on 1st wire is given by

$$\frac{F_1}{L} = \frac{\mu_0}{4\pi} \cdot \frac{2I_1 I_2}{r} \quad \text{... (iii)}$$

The force F_1 is directed towards the second wire.

(b) As, $$\frac{F}{L} = \frac{\mu_0}{4\pi} \frac{2I_1 I_2}{r}$$

$$I_1 = I_2 = 1A \quad \text{or} \quad r = 1 \text{ m}$$

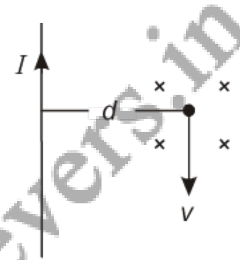
$$\frac{F}{L} = 2 \times 10^{-7} \text{ N/m}$$

One ampere is that current, which when flowing through each of the two parallel conductors of infinite length and placed in free space at a distance of one meter from each other, produces between them a force of 2×10^{-7} newton per meter of their lengths.

(c) Here, magnetic field due to the current carrying conductor at a distance d from it

$$B = \frac{\mu_0}{4\pi} \cdot \frac{2I}{d}$$

$\therefore$ Force on proton



Perpendicular to plane of paper and directed inward

$$F = (e)(v) B \sin 90°$$

$$F = evB$$

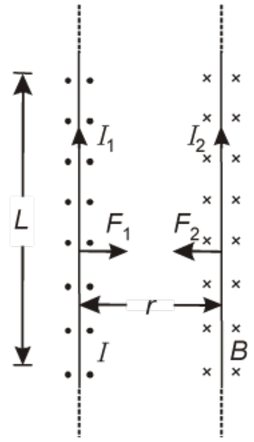
$$F = eV\left(\frac{\mu_0}{4\pi}\frac{2I}{d}\right)$$

$$F = \frac{\mu_0}{4\pi} \cdot \frac{2IeV}{d}$$

The proton is directed perpendicular to straight conductor and away from it.

S52. (a) Let two infinitely long straight current carrying conductor carries currents I_1 and I_2 in the same direction. Magnetic field B_1 due to first wire on second *i.e.*,

$$B_1 = \frac{\mu_0}{4\pi}\frac{2I_1}{r} \quad \text{... (i)}$$



The magnetic field is perpendicular to the plane of paper and directed inward *i.e.*, (*X*) type.

Now, magnetic force on L length of wire second is given by

$$F_2 = I_2 B_1 L \sin 90° = I_2\left(\frac{\mu_0}{4\pi}\cdot\frac{2I_1}{r}\right)L$$

$$\Rightarrow \quad \frac{F_2}{L} = \frac{\mu_0}{4\pi}\cdot\frac{2I_1 I_2}{r} \quad \text{... (ii)}$$

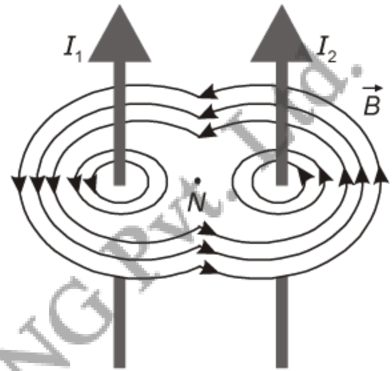
By Fleming's left hand rule, the direction of force F_2 is perpendicular to the second wire in the plane of paper towards the first wire.

Similarly, magnetic force on 1st wire is given by

$$\frac{F_1}{L} = \frac{\mu_0}{4\pi}\cdot\frac{2I_1 I_2}{r} \quad \text{... (iii)}$$

The force F_1 is directed towards the second wire.

Current carrying conductors having same direction of flow of current, so the force between them, will be attractive.



Magnetic field lines due to both conductors

(b) (i) Perpendicular to the plane of the paper and directed inward.

(ii)
- When angle between area vector of coil and magnetic field is 90° then maximum torque experienced by the coil
- When θ = 0° or 180° then torque will be minimum *i.e.*, zero.

Date: 20/10/2021

Q1. **A long straight wire in the horizontal plane carries a current of 50 A in North to South direction. Give the magnitude and direction of *B* at a point 2.5 m East of the wire.**

Q2. **A long straight wire carries a current of 35 A. What is the magnitude of the field *B* at a point 20 cm from the wire?**

Q3. **A horizontal overhead power line carries a current of 90 A in east to west direction. What is the magnitude and direction of the magnetic field due to the current 1.5 m below the line?**

Q4. **What will be the path of a charged particle moving along the direction of a uniform magnetic field?**

Q5. **A magnetic field that varies in magnitude from point to point but has a constant direction (east to west) is set up in a chamber. A charged particle enters the chamber and travels undeflected along a straight path with constant speed. What can you say about the initial velocity of the particle?**

Q6. **What kind of magnetic field is produced by an infinitely long current carrying conductor?**

Q7. **An electron travelling west to east enters a chamber having a uniform electrostatic field in north to south direction. Specify the direction in which a uniform magnetic field should be set up to prevent the electron from deflecting from its straight line path.**

Q8. **A charged particle enters an environment of a strong and non-uniform magnetic field varying from point to point both in magnitude and direction, and comes out of it following a complicated trajectory. Would its final speed equal the initial speed if it suffered no collisions with the environment?**

Q9. **A moving charge experience a force when placed in a magnetic field. Why?**

Q10. **What is the magnitude of transverse acceleration produced in the motion of the electron, when it passes through the electric field?**

Q11. **An electron enters in electric field at right angles to the direction of electric field. What is the nature of the path followed?**

Q12. **A beam of α-particles projected along + *X*-axis experiences a force due to a magnetic field along + *Y*-axis. What is the direction of the magnetic field?**

Q13. **State Fleming's left hand rule.**

Q14. **A narrow beam of protons and deuterons, each having the same momentum, enters a region of uniform magnetic field directed perpendicular to their direction of momentum. What would be the ratio of the radii of the circular paths described by them?**

Q15. **A stationary charge experiences no magnetic Lorentz force. Why?**

Q16. **Define one tesla.**

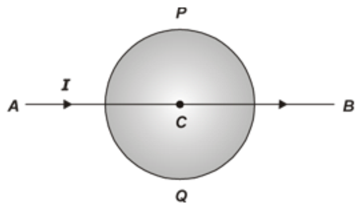
Q17. **What will be the path of a charged particle moving perpendicular to the direction of a uniform magnetic field?**

Q18. What is the work done by magnetic field on a moving an α-particle and why?

Q19. Using Biot-Savart law, deduce an expression for the magnetic field at the centre of a current carrying circular loop.

Q20. A circular coil of wire consisting of 100 turns, each of radius 8.0 cm carries a current of 0.40 A. What is the magnitude of the magnetic field *B* at the centre of the coil?

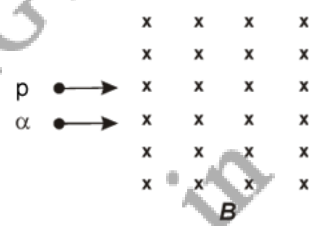
Q21. Consider the circuit as shown in figure below, where *APB* and *AQB* are semi-circles. What will be the magnetic field at the centre *C* of the circular loop?



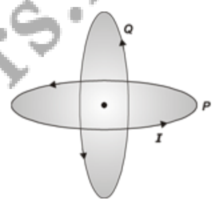
Q22. A straight wire carries a current of 3 A. Calculate the magnitude of the magnetic field at a point 15 cm away from the wire. Draw a diagram to show the direction of the magnetic field.

Q23. An electron of kinetic energy 25 keV moves perpendicular to the direction of a uniform magnetic field of 0.4 mT. Calculate the time period of rotation of the electron in the magnetic field.

Q24. An α-particle and a proton moving with the same speed enter the same magnetic field region at right angles to the direction of the field. Show the trajectories followed by the two particles in the region of the magnetic field. Find the ratio of the radii of the circular paths which the two particles may describe.

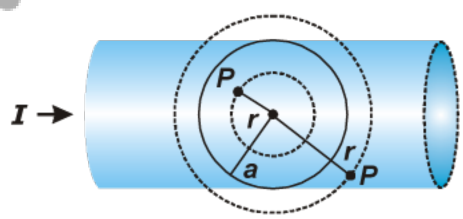


Q25. Two identical circular wires *P* and *Q*, each of radius r and current *I* are kept in perpendicular plane, such that they have a common centre as shown in figure below. Find the magnitude and direction of the net magnetic field at the common centre of the two coils.

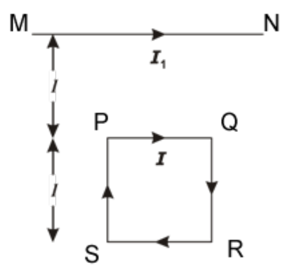


Q26. Using Biot-Savart law derive the expression for the magnetic field at a distance x along the axis from the centre of a current carrying circular loop.

Q27. Figure shows a long straight wire of a circular cross-section of radius a carrying steady current *I*. The current *I* is uniformly distributed across this cross-section. Derive the expressions for the magnetic field in the region $r < a$.



Q28. Write the expression for the magnetic moment (*m*) due to a planar square loop of side l carrying a steady current *I* in a vector form. In the given figure, this loop is placed in a horizontal plane near a long straight conductor carrying a steady current I_1 at a distance l as shown. Give reasons to explain that the loop will experience a net force but no torque. Write the expression for this force acting on the loop.



Q29. (a) In what respect, is a toroid different from a solenoid? Draw and compare the pattern of the magnetic field lines in the two cases.

(b) How is the magnetic field inside a given solenoid made strong?

Q30. A long straight wire of circular cross-section of radius a, carries a steady current I. The current is uniformly distributed across the cross-section of the wire. Use Ampere's circuital law to show that the magnetic field, due to this wire, in the region inside the wire, increases in direct proportion to the distance of the field point from the axis of the wire. Write the value of this magnetic field on the surface of the wire.

Q31. (a) State Ampere's circuital law.

(b) Use it to derive an expression for magnetic field inside, along the axis of an air cored solenoid.

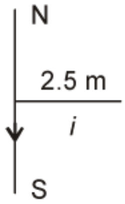
(c) Sketch the magnetic field lines for a finite solenoid. How are these field lines different from the electric field lines from an electric dipole?

Q32. (a) State Ampere's circuital law. Show through an example, how this law enables an easy evaluation of this magnetic field when there is a symmetry in the system?

(b) What does a toroid consist of? Show that for an ideal toroid of closely wound turns, the magnetic field is present only inside the toroid and find its expression.

Date: 20/10/2021

S1. Current in the wire, $I = 50$ A



A point is 2.5 m away from the East of the wire.

Magnitude of the distance of the point from the wire, $r = 2.5$ m.

Magnitude of the magnetic field at that point is given by the relation,

$$B = \frac{\mu_0 2I}{4\pi r}$$

Where,

$$\mu_0 = \text{Permeability of free space}$$
$$= 4\pi \times 10^{-7}\ \text{T m A}^{-1}$$

$$B = \frac{4\pi \times 10^{-7} \times 2 \times 50}{4\pi \times 2.5}$$
$$= 4 \times 10^{-6}\ \text{T}$$

The point is located normal to the wire length at a distance of 2.5 m. The direction of the current in the wire is vertically downward. Hence, according to the Maxwell's right hand thumb rule, the direction of the magnetic field at the given point is vertically upward.

S2. Current in the wire, $I = 35$ A

Distance of a point from the wire, $r = 20$ cm = 0.2 m

Magnitude of the magnetic field at this point is given as:

$$B = \frac{\mu_0}{4\pi}\frac{2I}{r}$$

Where,

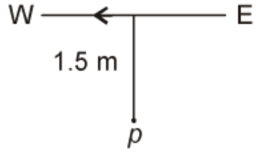
$$\mu_0 = \text{Permeability of free space}$$
$$= 4\pi \times 10^{-7}\ \text{T m A}^{-1}$$

$$B = \frac{4\pi \times 10^{-7} \times 2 \times 35}{4\pi \times 0.2}$$

$$= 3.5 \times 10^{-5}\ \text{T}$$

Hence, the magnitude of the magnetic field at a point 20 cm from the wire is 3.5×10^{-5} T.

S3. Current in the power line, $I = 90$ A



Point is located below the power line at distance, $r = 1.5$ m

Hence, magnetic field at that point is given by the relation,

$$B = \frac{\mu_0 2I}{4\pi r}$$

Where,

$$\mu_0 = \text{Permeability of free space}$$
$$= 4\pi \times 10^{-7}\ \text{T m A}^{-1}$$

$$B = \frac{4\pi \times 10^{-7} \times 2 \times 90}{4\pi \times 1.5}$$
$$= 1.2 \times 10^{-5}\ \text{T}$$

The current is flowing from East to West. The point is below the power line. Hence, according to Maxwell's right hand thumb rule, the direction of the magnetic field is towards the South.

S4. When the charged particle moves along the direction of a uniform magnetic field (*i.e.*, $\theta = 0°$), it experiences no force on charged particle and therefore it will move along its original straight line.

S5. The initial velocity of the particle is either parallel or anti-parallel to the magnetic field. Hence, it travels along a straight path without suffering any deflection in the field.

S6. Magnetic field lines are concentric circular loops in a plane perpendicular to the straight conductor. The centers of the circular magnetic field lines lie on the conductor.

S7. An electron travelling from West to East enters a chamber having a uniform electrostatic field in the North-South direction. This moving electron can remain undeflected if the electric force acting on it is equal and opposite of magnetic field. Magnetic force is directed towards the South. According to Fleming's left hand rule, magnetic field should be applied in a vertically downward direction.

S8. Yes, the final speed of the charged particle will be equal to its initial speed. This is because magnetic force can change the direction of velocity, but not its magnitude.

S9. A moving charge produces magnetic field. This magnetic field interacts with another magnetic field of a magnet and hence, it experiences force.

S10. If an electron charge e having mass m_e passes transversely through an electric field E, then

acceleration, $a = \dfrac{eE}{m_e}$

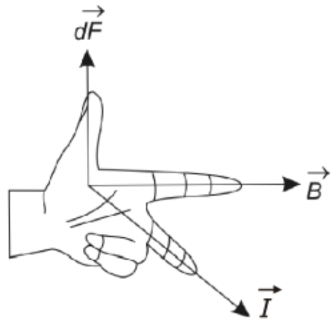
S11. The electron will move along a parabolic path.

S12. From Lorenz force

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

If the α-particle (a positively charged particle) moving along + X-axis experiences force along + Y-axis, then the magnetic field must be directed along – Z-axis.

S13. If the thumb and first two fingers of the left hand are held each at right angles to the each other, with the first finger pointing in the direction of the field and the second finger in the direction of the current, then the thumb predicts the direction of the thrust or force, as shown in figure.



S14. Magnetic force = Centrifugal force

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

$$r = \frac{mv}{qB} \qquad (\because \ mv \text{ and } B \text{ are constant for both particles})$$

$$\frac{r_P}{r_D} = \frac{q_D}{q_P} \qquad (\text{where charge } q_P = q_D)$$

$$\frac{r_P}{r_D} = \mathbf{1 : 1}$$

S15. For a stationary charge, $v = 0$.

$\therefore \qquad \vec{F} = Bq\,(0) \sin\theta = 0.$

S16. The strength of magnetic field at a point is called one tesla, if a charge of one coulomb, when moving with a velocity of 1 ms^{-1} along a direction perpendicular to the direction of the magnetic field, experiences a force of 1 N.

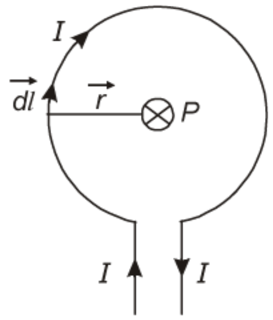
S17. When the charged particle moves perpendicular to the direction of a uniform magnetic field, it experiences a force perpendicular to its direction of motion. As such, it moves along a circular path.

S18. Work done by magnetic field on a moving an α-particle is zero. It is because, force on the α-particle due to magnetic field is always perpendicular to its path.

S19. Consider a circular loop of radius r carrying a current I. At all positions $\vec{dl} \perp \vec{r}$ so that $\theta = 90°$.

From Biot-Savart law magnetic field due to element dl is given by

$$dB = \frac{\mu_0}{4\pi} \cdot \frac{I dl \sin 90°}{r^2} = \frac{\mu_0}{4\pi} \cdot \frac{I dl}{r^2}$$



Field due to entire loop

$$B = \int dB$$

$$= \int_0^{2\pi} \frac{\mu_0}{4\pi} \cdot \frac{I dl}{r^2} = \frac{\mu_0 I}{4\pi r^2} [2\pi r - 0] = \frac{\mu_0 I}{2r}$$

or $$B = \frac{\mu_0 I}{2r}$$

Special case: If the number of turns in the coil is N, then

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

S20. Number of turns on the circular coil, $n = 100$

Radius of each turn, $r = 8.0\,\text{cm} = 0.08\,\text{m}$

Current flowing in the coil, $I = 0.4\,\text{A}$

Magnitude of the magnetic field at the centre of the coil is given by the relation,

$$|\boldsymbol{B}| = \frac{\mu_0}{4\pi} \frac{2\pi n I}{r}$$

Where,

$$\mu_0 = \text{Permeability of free space}$$
$$= 4\pi \times 10^{-7}\,\text{T m A}^{-1}$$

$$|\boldsymbol{B}| = \frac{4\pi \times 10^{-7}}{4\pi} \times \frac{2\pi \times 100 \times 0.4}{0.08}$$

$$= 3.14 \times 10^{-4}\,\text{T}$$

Hence, the magnitude of the magnetic field is 3.14×10^{-4} T.

S21. The magnitude of magnetic field due to current flowing through the semi-circular part *APB* or *AQB* is

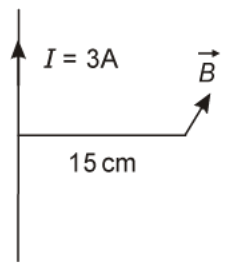
$$B = \frac{\mu_0}{4\pi} \cdot \frac{\pi I}{a}. \qquad \text{(Applying ampere circuital law)}$$

The direction of magnetic field due to the semi-circular part *APB* is perpendicular to the paper and in downward direction, while that due to the semi-circular part *AQB* is in upward direction. Thus, the two semi-circular parts *APB* and *AQB* produce equal and opposite magnetic fields at the centre *C*. Therefore, the magnetic field at the centre *C* is zero.

S22. Given: current in straight wire $I = 3\,A$;

Perpendicular distance $a = 15\,cm = 0.15\,m$

We know, $$B = \frac{\mu_0}{4\pi} \cdot \frac{2I}{a} = \frac{10^{-7} \times 2 \times 3}{0.15} = \mathbf{4 \times 10^{-6}}\, \boldsymbol{T}.$$



The direction of magnetic field will be perpendicular to the plane of paper and in inward direction, shown as above figure.

S23. Given: For an electron in magnetic field Kinetic energy of electron,

$$E = 25\,keV = 25 \times 1.6 \times 10^{-16}\,J$$

$$B = 0.4\,mT = 0.4 \times 10^{-3}\,\text{Tesla}$$

(perpendicular to electron's velocity)

$$T = ?$$

We know, $$T = \frac{2\pi m}{qB} = \frac{2 \times 3.14 \times 9.11 \times 10^{-31}}{1.6 \times 10^{-19} \times 0.4 \times 10^{-3}} = \mathbf{8.94 \times 10^{-8}\ sec}$$

S24. As, $\vec{F} = q(\vec{v} \times \vec{B})$, we find the α-particle and a proton moving anticlockwise.

Radius of circular path of a charged particle in the magnetic field is

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

Ratio of radii of circular paths for an α-particle and a proton is

$$\frac{r_\alpha}{r_P} = \frac{m_\alpha}{m_P} \times \frac{q_P}{q_\alpha}$$

We know $m_\alpha = 4m_P$

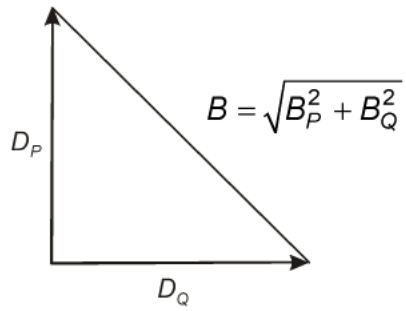
$q_\alpha = 2q_P$

$$\frac{r_\alpha}{r_P} = \frac{4}{2} \quad \text{or} \quad \mathbf{r_\alpha : r_P = 2 : 1}.$$

S25. Magnetic field due circular wire P, at center

$$B_P = \frac{\mu_0}{4\pi} \cdot \frac{2\pi I}{r}$$ (along vertically upwards)

Magnetic field due to circular wire Q, at center



$$B_Q = \frac{\mu_0}{4\pi} \cdot \frac{2\pi I}{r}$$ (along horizontal towards left)

Net magnetic field at the common centre of the two coils,

$$B = \sqrt{B_P^2 + B_Q^2} = \sqrt{2} \times \frac{\mu_0}{4\pi} \cdot \frac{2\pi I}{r} \qquad (\because \quad B_P = B_Q)$$

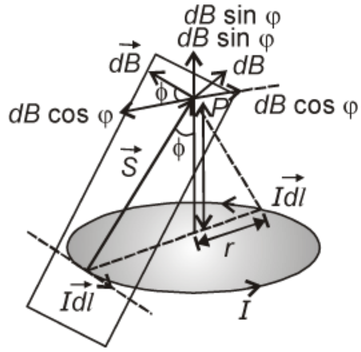
As the fields produced by the two coils is equal (in magnitude), the net magnetic field will be inclined equally to both the coils.

S26. Consider a circular current carrying conductor of radius r.

According to Biot Savart's law, the magnetic field at P due to current element $I\vec{dl}$ is

$$\vec{dB} = \frac{\mu_0}{4\pi} \frac{I dl \sin 90^\circ}{S^2}$$

Direction of $\vec{dB}$ is perpendicular to the plane containing $\vec{S}$ and $\vec{dl}$. We resolve $\vec{dB}$ into rectangular components. $dB \cos \varphi$ and $dB \sin \varphi$. $dB \cos \varphi$ gets cancelled by the corresponding component of magnetic field at P produced by current element diametrically opposite to the previous one. It is only $dB \sin \varphi$ that is added up for magnetic field of every current element on the loop.



Thus, total magnetic field is

$$B = \int dB \sin\varphi = \int \frac{\mu_0 I dl \sin\theta}{4\pi(r^2 + x^2)} \qquad \left[(\because \ \sin\varphi) = \frac{r}{\sqrt{x^2 + r^2}} \right]$$

$$= \frac{\mu_0 I \sin\theta}{4\pi(r^2 + x^2)} \int dl$$

$$B = \frac{\mu_0 I}{4\pi(r^2 + x^2)} \frac{r}{(x^2 + r^2)^{1/2}} \cdot 2\pi r$$

$$B = \frac{\mu_0 I r^2}{2(r^2 + x^2)^{3/2}}.$$

S27. Consider a loop of radius r whose centre lies at the axis of wire where, $r < a$ as shown in figure inside the wire.

Applying Ampere's circuital law,

$$\oint \mathbf{B}.dl = \mu_0 I' \qquad \text{... (i)}$$

$$\oint B\, dl \cos 0^\circ = \mu_0 \left(\frac{Ir^2}{a^2} \right) \qquad \text{[From Eq. (i)]}$$

$$B \oint dl = \mu_0 \frac{Ir^2}{a^2}$$

$$B \times 2\pi r = \frac{\mu_0 I r^2}{a^2}$$

$$B = \frac{\mu_0 I r}{2\pi a^2} \Rightarrow \quad B \propto r$$

S28. The magnetic moment of a current carrying loop

$$\mathbf{m} = I\mathbf{A}$$

where, **A** = area of the loop (Square)

$\therefore$ $$\mathbf{A} = l^2\hat{\mathbf{n}}$$

Here, $\hat{\mathbf{n}}$ is unit vector normal to the area 2 – *e* direction of area vector.

The forces acting on the arms *QR* and *SP* of given (in question-figure) loop are equal, mutually opposite and collinear. Hence they are balanced by one another.

Force on arm *PQ*, $F_1 = BIl = \frac{\mu_0 I_1}{2\pi} Il = \frac{\mu_0 I_1 I}{2\pi}$ obviously F_1 is of the attractive nature and directed towards *MN*.

Again, force on arm *RS*,

$$F_2 = B_2 Il = \frac{\mu_0 I_1 Il}{2\pi(2l)} = \frac{\mu_0 I_1 Il}{4\pi}$$

F_2 is perpendicular to wire *RS* and directed away from the conductor *MN*.

$\therefore$ Net force on loop *PQRS*,

$$\mathbf{F}_{net} = \mathbf{F}_1 + \mathbf{F}_2$$

$\Rightarrow$ $$\mathbf{F}_{net} = F_1 - F_2 = \frac{\mu_0 I_1 I}{2\pi} - \frac{\mu_0 I_1 I}{4\pi}$$

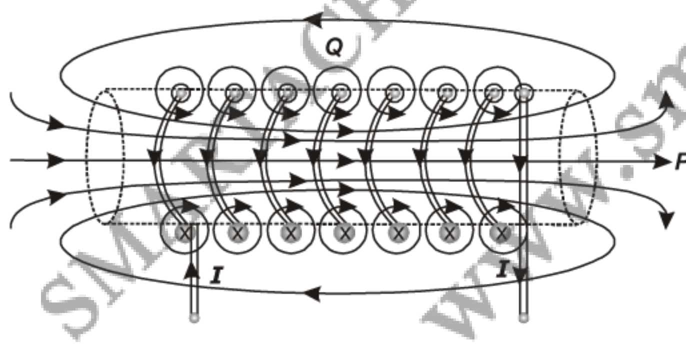
or $$F_{net} = \frac{\mu_0 I_1 I}{4\pi}.$$ [Attractive]

As F_1 and $\mathbf{F}_2$ are collinear, hence does not produce torque on the loop *PQRS*.

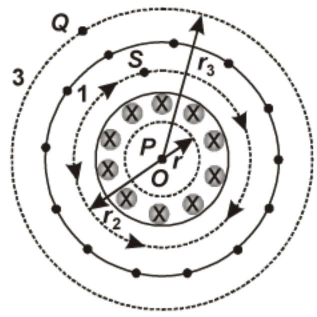
S29. Solenoid is a hollow circular ring having large number of turn of insulated copper wire, on it.

There we can assume that toroid is a bent solenoid to close on it self.

The magnetic fields due to solenoid and toroid is given in figures below.



Field due to solenoid



Field due to toroid

Magnetic field inside the solenoid is uniform, strong and along its axis also field lines are all most parallel while inside the toroid field line makes closed path.

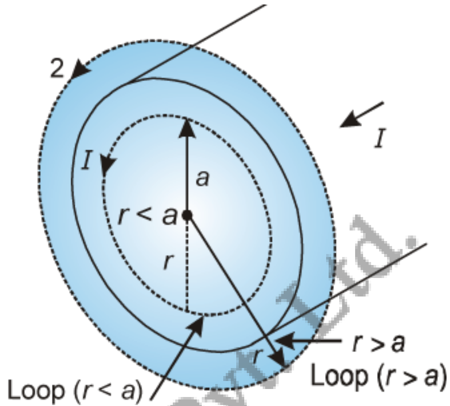
(c) The magnetic field in the solenoid can be increased by inserting a soft iron core inside it.

S30. Consider a loop of radius r whose centre lies at the axis of wire where, $r < a$ as shown in figure inside the wire.

Applying Ampere's circuital law,

$$\oint \mathbf{B}.d\mathit{l} = \mu_0 I'$$

$$\oint B\,d\mathit{l}\cos 0^\circ = \mu_0\left(\frac{Ir^2}{a^2}\right) \qquad \text{[From Eq. (i)]}$$



$$B\oint d\mathit{l} = \mu_0\frac{Ir^2}{a^2}$$

$$B\times 2\pi r = \frac{\mu_0 I r^2}{a^2}$$

$$B = \frac{\mu_0 I r}{2\pi a^2} \quad\Rightarrow\quad B \propto r$$

$\because$ $$B = \frac{\mu_0 I}{2\pi a^2}r$$

$\Rightarrow$ $$B \propto r$$

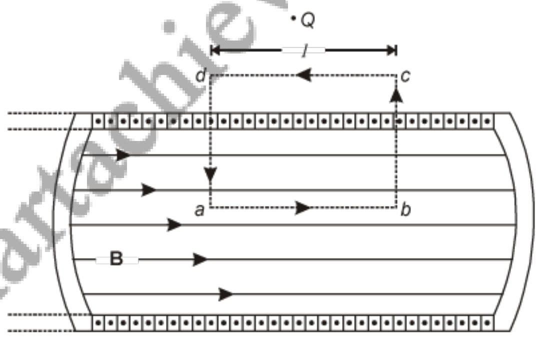
Now, the value of magnetic field on the surface of wire i.e.,

$$r = a$$

$$B = \frac{\mu_0 I}{2\pi a^2}\times a = \frac{\mu_0 I}{2\pi a}$$

S31. (a) ***Ampere's circuital law:*** The line integral of magnetic field over a closed loop is equal to μ_0 times total current I threading the loop *i.e.*,

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



(b) Figures shows the longitudinal sectional view of long current carrying solenoid. The current comes out of the plane of paper at points marked.

The **B** is the magnetic field at any point inside the solenoid. Considering the rectangular closed path *abcd*. Applying Ampere's circuital law over loop *abcd*.

$$\oint \mathbf{B}.d\mathit{l} = \mu_0 \times \text{(Total current passes through loop } abcd\text{)}$$

$$\int_a^b \mathbf{B}.d\mathit{l} + \int_b^c \mathbf{B}.d\mathit{l} + \int_c^d \mathbf{B}.d\mathit{l} + \int_d^a \mathbf{B}.d\mathit{l} = \mu_0\left(\left(\frac{N}{L}\right)\mathit{l}i\right)$$

where, $\frac{N}{L}$ = number of turns per unit length $ab = cd = \mathit{l}$ = length of rectangle.

$$\int_a^b Bdl\cos 0^\circ + \int_b^c Bdl\cos 90^\circ + 0 + \int_d^a Bdl\cos 90^\circ = \mu_0\left(\frac{N}{L}\right) l - i$$

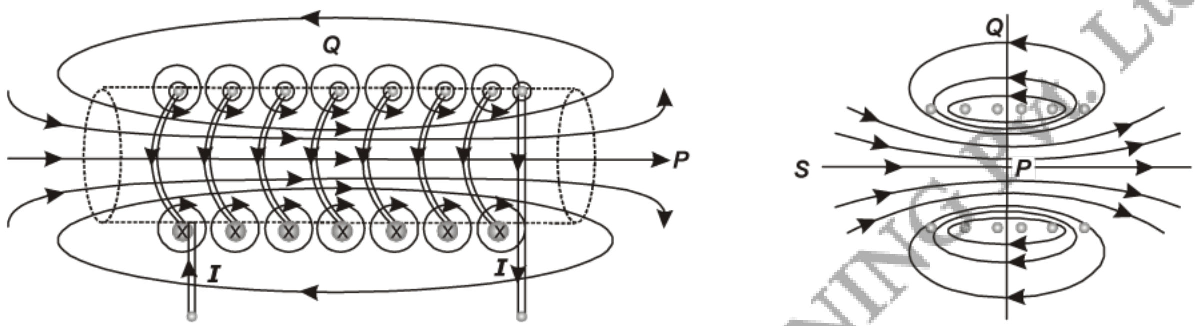
$$B\int_a^b dl = \mu_0\left(\frac{N}{L}\right) li$$

$$B = \mu_0\left(\frac{N}{L}\right) li$$

$$\Rightarrow \qquad B = \mu_0\left(\frac{N}{L}\right) i \quad \text{or} \quad B = \mu_0 ni$$

where, n = number of turns per unit length. This is required expression for magnetic field inside the long current carrying solenoid.

(c) Magnetic field lines due to a finite solenoid has been shown below:



All the magnetic field lines are necessarily closed loops whereas electric lines of force are not.

S32. (a) ***Ampere's circuital law:*** The line integral of magnetic field over a closed loop is equal to μ_0 times total current I threading the loop *i.e.*,

$$\oint \mathbf{B}.dl = \mu_0 I.$$

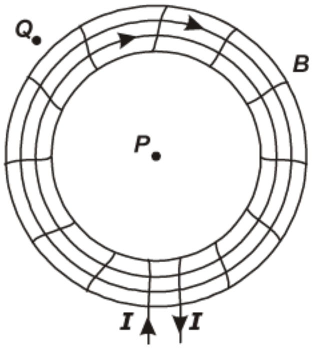
For the evaluation of magnetic field for a symmetrical system, we can consider the example of a current carrying solenoid.

(b) A solenoid bent into the form of closed-loop is called toroid. The magnetic field **B** has a constant magnitude everywhere inside the toroid.

(i) Let magnetic field inside the toroid is B along the considered loop 1 as shown in figure.
Applying Ampere's circuital law

$$\oint_{\text{loop 1}} \mathbf{B}.dl = \mu_0 (NI)$$

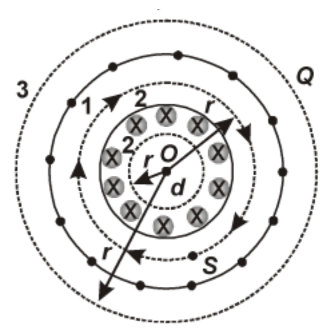
Note: Since, toroid of N turns, threads the loop 1, N times, each carrying current I inside the loop. Therefore, total current threading the loop 1 is NI.



$$\Rightarrow \qquad \oint_{loop\,1} \mathbf{B}.dl = \mu_0 NI$$

$$\mathbf{B} \oint_{loop} dl = \mu_0 NI$$

$$B \times 2\pi r = \mu_0 NI \quad \text{or} \quad B = \frac{\mu_0 NI}{2\pi r}$$



(ii) ***Magnetic field inside the open space interior the toroid:*** Let the loop 2 is shown in figure experience magnetic field B.

No current threads the loop 2 which lie in the open space inside the toroid.

∴ Ampere's circuital law

$$\oint_{loop\,2} \mathbf{B}.dl = \mu_0 (\theta) \quad \Rightarrow \quad B = 0$$

(iii) ***Magnetic field in the open space exterior of toroid:*** Let us consider a coplanar loop 3 in the open space of exterior of toroid. Here, each turn of totoid threads the loop two times in opposite directions.

Therefore, net current threading the loop

$$= NI - NI = 0$$

∴ By Ampere's circuital law,

$$\oint_{loop\,3} \mathbf{B}.dl = \mu_0 (NI - NI) \quad \Rightarrow \quad B = 0$$

Thus, there is no magnetic field in the open space interior and exterior of toroid.

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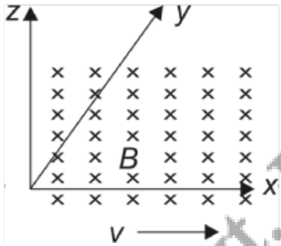
Q1. **Consider a tightly wound 100 turn coil of radius 10 cm, carrying a current of 1 A. What is the magnitude of the magnetic field at the centre of the coil?**

Q2. **A conductor carrying current is placed somewhere. What is the magnitude and direction of the field due to a small part of the conductor at a point near it?**

Q3. **If the magnetic field is parallel to the + ve *y*-axis and the charged particle is moving along the + ve *x*-axis, which way would the Lorentz force be for (a) an electron (negative charge) (b) a proton (positive charge), as shown in figure.**



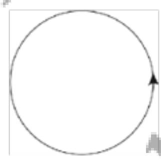
Q4. **Name the SI unit of magnetic permeability of free space.**

Q5. **What is the value of constant $\mu_0/4\pi$?**

Q6. **Write the dimensional formula of μ_0.**

Q7. **State the rule that is used to find the direction of field acting at a point near a current carrying straight conductor.**

Q8. **In the figure is shown a circular loop carrying current *I*. Show the direction of the magnetic field with the help of lines of force.**



Q9. **The force $\vec{F}$ experienced by a particle of charge q moving with velocity $\vec{v}$ in a magnetic field $\vec{B}$ is given by $\vec{F} = q(\vec{v} \times \vec{B})$. Of these, name the pairs of vectors which are always at right angles to each other.**

Q10. **Does a current carrying circular coil produce uniform magnetic field?**

Q11. **Looking at a circular coil, the current is found to be flowing in clockwise direction. Predict the direction of magnetic field produced at a point on the axis of the coil on the same side as the observer.**

Q12. **In which circumstances, will a current carrying loop not rotate the magnetic field?**

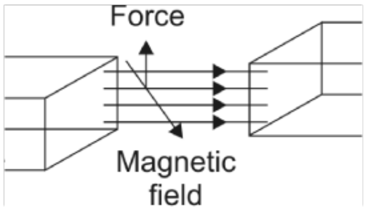
Q13. **In hydrogen atom, if the electron is replaced by a particle which is 200 times heavier but has the same charge, how would its radius change?**

Q14. **Write an expression for the magnetic field produced by an infinitely long straight wire carrying a current *I*, at a short perpendicular distance *a* from itself.**

Q15. **How will the magnetic field intensity at the centre of a circular coil carrying current change, if the current through the coil is doubled and the radius of the coil is 1/4?**

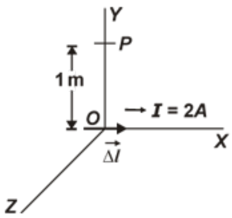
Q16. An electron and a proton, moving parallel to each other in the same direction with equal momenta, enter into a uniform magnetic field which is at right angles to their velocities. Trace their trajectories in the magnetic field.

Q17. A charged particle enters into a uniform magnetic field and experiences an upward force as indicated in the figure. What is the charge sign on the particle? as shown in figure.



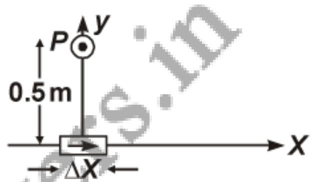
Q18. In a chamber, a uniform magnetic field of 6.5 G ($1\ G = 10^{-4}\ T$) is maintained. An electron is shot into the field with a speed of $4.8 \times 10^6\ m s^{-1}$ normal to the field. Explain why the path of the electron is a circle. Determine the radius of the circular orbit. ($e = 1.6 \times 10^{-19}$ C, $m_e = 9.1 \times 10^{-31}$ kg)

Q19. An element $\overline{\Delta l} = \Delta x \hat{i}$ placed at the origin and carries a current $I = 2A$, as shown in figure below:



Find out the magnetic field at a point P on Y-axis at a distance of 1 m due to the element Δx = 1 cm. Give also the direction of the field produced.

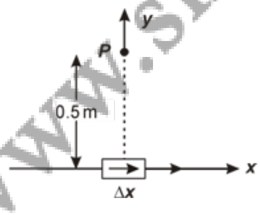
Q20. An element $\Delta l = \Delta x \hat{i}$ is placed at the origin and carries a large current I = 10 A (figure). What is the magnetic field on the y-axis at a distance of 0.5 m. Δx = 1 cm.



Q21. The frequency of revolution of the electron in its circular orbit. Does the answer depend on the speed of the electron? Explain.

Q22. An electron moving at $10^6\ ms^{-1}$ in a direction parallel to the current of 5 A, flowing through infinitely long straight wire, separated by perpendicular distance of 10 cm in air. Calculate the magnitude of the force experienced by the electron.

Q23. An element $\Delta l = \Delta x \hat{i}$ is placed at the origin and carries a large current I = 20 A. What is the magnetic field on the y-axis at a distance of 0.5 m? Δx = 1 cm.



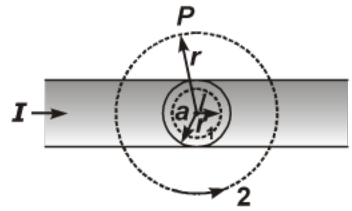
Q24. A straight wire carrying a current of 12A is bent into a semi-circular arc of radius 2.0 cm as shown. What is the magnetic field B at O due to

(i) straight segments, (ii) the semicircular arc?

Q25. An electron emitted by a heated cathode and accelerated through a potential difference of 2.0 kV, enters a region with uniform magnetic field of 0.15 T. Determine the trajectory of the electron if the field (a) is transverse to its initial velocity, (b) makes an angle of 30° with the initial velocity.

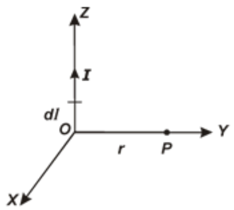
Q26. A straight wire of length *L* is bent into a semi-circular loop. Use Biot-Savart law to deduce an expression for the magnetic field at its centre due to the current, *I* passing through it.

Q27. Figure shows a long straight wire of a circular cross-section (radius *a*) carrying steady current *I*. The current *I* is uniformly distributed across this cross-section. Calculate the magnetic field in the region $r < a$ and $r > a$.



Q28. State Biot-Savart law.

A current *I* flows in a conductor placed perpendicular to the plane of the paper. Indicate the direction of the magnetic field due to a small element *dl* at a point *P* situated at a distance r from the element as shown in the figure.



Q29. For a circular coil of radius *R* and *N* turns carrying current *I*, the magnitude of the magnetic field at a point on its axis at a distance *x* from its centre is given by,

$$B = \frac{\mu_0 I R^2 N}{2(x^2 + R^2)^{\frac{3}{2}}}$$

(a) Show that this reduces to the familiar result for field at the centre of the coil.

(b) Consider two parallel co-axial circular coils of equal radius *R*, and number of turns *N*, carrying equal currents in the same direction, and separated by a distance *R*. Show that the field on the axis around the mid-point between the coils is uniform over a distance that is small as compared to *R*, and is given by,

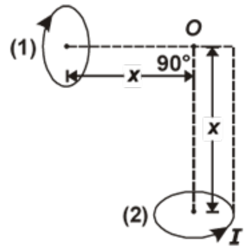
$$B = 0.72 \frac{\mu_0 BNI}{R}, \quad \text{(approximately).}$$

[Such an arrangement to produce a nearly uniform magnetic field over a small region is known as *Helmholtz coils*.]

Q30. State Biot-Savart law, using it, deduce an expression for the magnetic field on the axis of a circular current loop. Draw the magnetic field line due to a circular current carrying loop.

Q31. (a) State Ampere's circuital law, write an expression for the magnetic field at the centre of a circular coil of radius *R*, number of turn *N*, carrying current *I*.

(b) Two small identical circular coils marked 1, 2 carry equal currents and are placed with their geometric axes perpendicular to each other as shown in the figure. Derive expression for the resultant magnetic field at *O*.



Q32. State Biot-Savart law. Use it to derive an expression for the magnetic field at the centre of a circular loop of radius r carrying a steady current I.

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S1. Since the coil is tightly wound, we may take each circular element to have the same radius R = 10 cm = 0.1 m. The number of turns N = 100. The magnitude of the magnetic field is,

$$B = \frac{\mu_0 NI}{2R} = \frac{4\pi \times 10^{-7} \times 10^2 \times 1}{2 \times 10^{-1}}$$

$$= 2\pi \times 10^{-4} = \mathbf{6.28 \times 10^{-4}\,T}.$$

S2. It is state that

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

where I is a conductor carrying current, $d\vec{l}$ is length of small part, r is a distance from small length to that point.

S3. The velocity v of particle is along the x-axis, while B, the magnetic field is along the y-axis, so $v \times B$ is along the z-axis (screw rule or right-hand thumb). So, (a) for electron it will be along $-z$-axis. (b) for a positive charge (proton) the force is along $+z$-axis

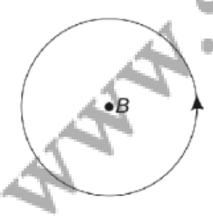
S4. The SI unit of permeability is **weber ampere^{-1} metre^{-1} (Wb A^{-1}m^{-1})** or **tesla ampere^{-1} metre (TA^{-1}m)**.

S5.
$$\frac{\mu_0}{4\pi} = \frac{4\pi \times 10^{-7}}{4\pi} = 10^{-7}\ TA^{-1}\,m$$

S6. The dimensional formula of μ_0 is $[MLT^{-2}A^{2}]$

S7. Right hand thumb rule can be used to find the direction of magnetic field at a point near a current carrying conductor.

S8. According to right hand thumb rule, when the current flows through the circular loop in the direction as perpendicular to the plane of the loop and in outward direction. It has been represented by a dot (.) as shown in figure.



S9. In Lornetz force equation

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

(a) Magnetic field (B) and velocity (v) of particle are perpendicular each other

(b) Magnetic force F and magnetic field B are perpendicular each other.

S10. No, magnetic field produced due to a current carrying circular coil is not uniform. Because, it may be considered as uniform at the centre of the circular coil.

S11. The direction of magnetic field is perpendicular to the plane of the coil and directed upwards the observer.

S12. If the current carrying loop is placed in a magnetic field, with its plane 90° to the field, then it will not rotate.

S13. Mass of electron is Me

Mass of particles 200 Me

We know, $r = \frac{mv}{qB}$

$\therefore$ q, B and v are constant

$$r \propto m$$

Hence, we conclude that radius of the particle become 2000 time then that of electron.

S14. It is given by

$$B = \frac{\mu_0}{4\pi} \cdot \frac{2I}{a}.$$

where μ_0 absolute permeability of free space, I carrying current in long straight wire and a perpendicular distance from the wire.

S15. Given, at initially the current of the coil is I and radius of the coil is r

Magnetic field $B = \frac{n\mu_0 I}{2r}$

$$I' = 2I$$

$$r' = r/4$$

$$B' = \frac{2n\mu_0 I}{r/4}$$

$$= \frac{8n\mu_0 I}{r} = 8\left(\frac{n\mu_0 I}{r}\right)$$

$$B' = \mathbf{8\,B}.$$

Hence magnetic field 8 times of initial magnetic field.

S16. We know,

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

The electron and proton follow circular path equal radii and but electron revolving clockwise and proton revolving anticlockwise

S17. We know,

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

If the charged particle enters the magnetic field (B) as shown in the figure and experiences force in upward direction, it must be + ve charged.

S18. Magnetic field strength, $B = 6.5\,\text{G} = 6.5 \times 10^{-4}\,\text{T}$

Speed of the electron, $v = 4.8 \times 10^{6}\,\text{m/s}$

Charge on the electron, $e = 1.6 \times 10^{-19}\,\text{C}$

Mass of the electron, $me = 9.1 \times 10^{-31}\,\text{kg}$

Angle between the shot electron and magnetic field, $\theta = 90°$

Magnetic force exerted on the electron in the magnetic field is given as:

$$F = evB \sin\theta$$

This force provides centripetal force to the moving electron. Hence, the electron starts moving in a circular path of radius

Hence, centripetal force exerted on the electron,

$$F_c = \frac{mv^2}{r}$$

In equilibrium, the centripetal force exerted on the electron is equal to the magnetic force *i.e.*,

$$F_c = F$$

$$\frac{mv^2}{r} = evB \sin\theta$$

$$r = \frac{mv}{Be \sin\theta}$$

$$= \frac{9.1 \times 10^{-31} \times 4.8 \times 10^{6}}{6.5 \times 10^{-4} \times 1.6 \times 10^{-19} \times \sin 90°}$$

$$= 4.2 \times 10^{-2}\,\text{m} = 4.2\,\text{cm}$$

Hence, the radius of the circular orbit of the electron is 4.2 cm.

S19. According to Biot-Savart's law, the magnetic field at point P due to a small current element is given by

$$\vec{dB} = \frac{\mu_0}{4\pi} \cdot \frac{I\,\vec{dl} \times \hat{r}}{r^2} \qquad \text{(According Biot-Savart's law)}$$

Given: Length of small element $\vec{dl} = \Delta x \hat{i}$ and perpendicular distance is $r = \hat{j}$.

$$\therefore \quad \vec{dB} = \frac{\mu_0}{4\pi} \cdot \frac{I \Delta x \hat{i} \times \hat{j}}{r^2} = \frac{\mu_0}{4\pi} \cdot \frac{I \Delta x \hat{k}}{r^2}$$

Therefore, magnetic field at point P is directed along positive direction of Y-axis.

The magnitude of the magnetic field is given by

$$dB = \frac{\mu_0}{4\pi} \cdot \frac{I \Delta x}{r^2} = \frac{10^{-7} \times 2 \times 0.01}{1^2} = \mathbf{2 \times 10^{-9}}\ \boldsymbol{T}.$$

S20. $$|d\mathbf{B}| = \frac{I\,dl \sin\theta}{r^2} \quad \text{[using Eq. (4.11)]}$$

$$dl = \Delta x = 10^{-2}\,\text{m}, \quad I = 10\,\text{A}, \quad r = 0.5\,\text{m} = y, \quad \mu_0/4\pi = 10^{-7}\,\frac{\text{Tm}}{\text{A}}$$

$$\theta = 90°; \quad \sin\theta = 1$$

$$|d\mathbf{B}| = \frac{10^{-7} \times 10 \times 10^{-2}}{25 \times 10^{-2}} = 4 \times 10^{-8}\,\text{T}$$

The direction of the field is in the $+z$-direction. This is so since,

$$dl \times \mathbf{r} = \Delta x \hat{\mathbf{i}} \times y \hat{\mathbf{j}} = y\,\Delta x\,(\hat{\mathbf{i}} \times \hat{\mathbf{j}}) = y\,\Delta x\,\hat{\mathbf{k}}$$

S21. Magnetic field strength, $B = 6.5 \times 10^{-4}\,\text{T}$

Charge of the electron, $e = 1.6 \times 10^{-19}\,\text{C}$

Mass of the electron, $me = 9.1 \times 10^{-31}\,\text{kg}$

Velocity of the electron, $v = 4.8 \times 10^{6}\,\text{m/s}$

Radius of the orbit, $r = 4.2\,\text{cm} = 0.042\,\text{m}$

Frequency of revolution of the electron = ν

Angular frequency of the electron = $\omega = 2\pi\nu$

Velocity of the electron is related to the angular frequency as:

$$v = r\omega$$

In the circular orbit, the magnetic force on the electron is balanced by the centripetal force. Hence, we can write:

$$evB = \frac{mv^2}{r}$$

$$eB = \frac{m}{r}(r\omega) = \frac{m}{r}(r 2\pi\nu)$$

$$\nu = \frac{Be}{2\pi m}$$

This expression for frequency is independent of the speed of the electron.

On substituting the known values in this expression, we get the frequency as:

$$\nu = \frac{6.5 \times 10^{-4} \times 1.6 \times 10^{-19}}{2 \times 3.14 \times 9.1 \times 10^{-31}}$$

$$= 1.82 \times 10^{6}\,\text{Hz} = 1.82\,\text{MHz}.$$

Hence, the frequency of the electron is around 1.82 MHz and is independent of the speed of the electron.

S22. Given: Current in straight wire $I = 5$ A

Distance from wire to point $r = 10$ cm $= 0.1$ m

Magnetic field produce due to the straight conductor

$$B = \frac{\mu_0}{4\pi} \cdot \frac{2I}{r} = \frac{10^{-7} \times 2 \times 5}{0.1} = 10^{-5}\,T$$

$$B = 10^{-5}\,T.$$

S23. Given: Length of element $dl = \Delta x = 10^{-2}$ m

Current in element $I = 20$ A

Perpendicular distance $r = 0.5$ m

Angle between them $\theta = 90°$

According to Biot-Savart law

$$dB = \frac{\mu_0}{4\pi} \frac{I\,dl \sin\theta}{r^2}$$

Putting the values, $$dB = \frac{10^{-7} \times 20 \times 1 \times 10^{-2}}{25 \times 10^{-2}}$$

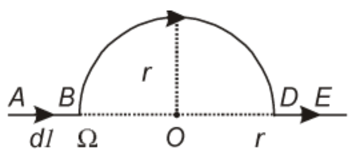
$$dB = 8 \times 10^{-8}\,\text{T}$$

As $$\vec{dl} \times \vec{r} = \Delta x\hat{i} \times y\hat{j} = y\Delta x\hat{k}$$

The direction of the field is in the Z-direction.

S24. Magnetic field due to straight part

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



For point O, dl and r for each element of the straight segments AB and DE are parallel Therefore, $d\mathbf{l} \times \mathbf{r} = 0$. Hence, magnetic field due to straight segments is zero.

Magnetic field at the centre due to circular point

$$= \frac{\text{Magnetic field at the centre of circular coil}}{2} = \frac{1}{2}\left(\frac{\mu_0 I}{2r}\right) = \frac{\mu_0 i}{4r} \quad [\because \text{ Here, coil is half}]$$

$$\Rightarrow \quad B = \frac{\mu_0 I}{4r} = \frac{(4\pi \times 10^{-7}) \times 12}{4 \times 2 \times 10^{-2}} = 6\pi \times 10^{-5}\,\text{T}.$$

S25. Magnetic field strength, $B = 0.15\,\text{T}$

Charge on the electron, $e = 1.6 \times 10^{-19}\,\text{C}$

Mass of the electron, $m = 9.1 \times 10^{-31}\,\text{kg}$

Potential difference, $V = 2.0\,\text{kV} = 2 \times 10^3\,\text{V}$

(a) Thus, kinetic energy of the electron = eV

$$\Rightarrow \quad \frac{1}{2}mv^2 = eV$$

$$\Rightarrow \quad v^2 = \frac{2eV}{m} \quad \text{... (i)}$$

$$\Rightarrow \quad v = \sqrt{\frac{2eV}{m}}$$

Where, v = velocity of the electron

Magnetic force on the electron provides the required centripetal force of the electron. Hence, the electron traces a circular path of radius r.

Magnetic force on the electron is given by the relation,

$$BeV = \frac{mv^2}{r}$$

Centripetal force

$$\therefore \quad BeV = \frac{mv^2}{r}$$

$$r = \frac{mv^2}{r} \quad \text{... (ii)}$$

From Eqns. (i) and (ii), we get

$$r = \frac{m}{Be}\left[\frac{2eV}{m}\right]^{\frac{1}{2}}$$

$$= \frac{9.1 \times 10^{-31}}{0.15 \times 1.6 \times 10^{-19}} \times \left(\frac{2 \times 1.6 \times 10^{-19} \times 2 \times 10^3}{9.1 \times 10^{-31}}\right)^{\frac{1}{2}}$$

$$= 100.55 \times 10^{-5}\,\text{m} = 1.01 \times 10^{-3}\,\text{m} = 1\,\text{mm}$$

Hence, the electron has a circular trajectory of radius 1.0 mm normal to the magnetic field.

(b) When the field makes an angle θ of 30° with initial velocity, the initial velocity will be,

$$v_1 = v \sin\theta$$

From Eqn. (ii), we can write the expression for new radius as:

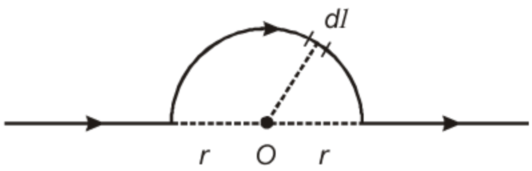
$$r_1 = \frac{mv_1}{Be} = \frac{mv\sin\theta}{Be}$$

$$= \frac{9.1\times10^{-31}}{0.15\times1.6\times10^{-19}}\times\left(\frac{2\times1.6\times10^{-19}\times2\times10^{3}}{9.1\times10^{-31}}\right)^{\frac{1}{2}}\times\sin 30^\circ$$

$$= 0.5\times10^{-5}\,\text{m} = 0.5\,\text{mm}$$

Hence, the electron has a helical trajectory of radius 0.5 mm along the magnetic field direction.

S26. When a straight wire is bent into semicircular loop, then there are two parts which produce the magnetic field at the centre; one is circular part and other is straight part.



∵ Length L is bent into semicircular loop.

Length of wire = Circumference of semi circular wire

⇒ $L = \pi r$

$$r = \frac{L}{\pi} \quad \text{... (i)}$$

Considering a small element dl on current loop. The magnetic field dB due to small current element Idl at centre C. Using Biot-Savart law, we have

$$dB = \frac{\mu_0}{4\pi}\cdot\frac{Idl\sin 90^\circ}{r^2} \qquad [\because\ Idl\perp \mathbf{r}\ \therefore\ \theta = 90^\circ]$$

$$dB = \frac{\mu_0}{4\pi}\cdot\frac{Idl}{r^2}$$

∴ Net magnetic field at C due to semicircular loop,

$$B = \int_{\text{semicircle}}\frac{\mu_0}{4\pi}\frac{Idl}{r^2}$$

$$B = \frac{\mu_0}{4\pi}\cdot\frac{I}{r^2}\int_{\text{semicircle}} dl$$

$$B = \frac{\mu_0}{4\pi}\cdot\frac{I}{r^2}(L)$$

But $$r = \frac{L}{\pi}$$

$$B = \frac{\mu_0}{4\pi} \cdot \frac{IL}{(L/\pi)^2}$$

$$= \frac{\mu_0}{4\pi} \times \frac{IL}{L^2} \times \pi^2$$

$$B = \frac{\mu_0 I \pi}{4L}.$$

This is required expression.

S27. (a) Consider the case $r > a$. The Amperian loop, labelled 2, is a circle concentric with the cross-section. For this loop,

$$L = 2\pi r$$

I_e = Current enclosed by the loop = I

The result is the familiar expression for a long straight wire

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

$$B = \frac{\mu_0 I}{2\pi r} \quad \text{... (i)}$$

$$B \propto \frac{1}{r} \qquad (r > a)$$

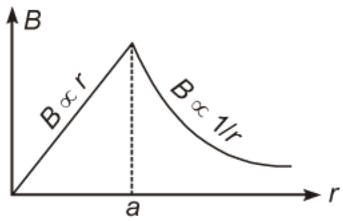
(b) Consider the case $r < a$. The Amperian loop is a circle labelled 1.

For this loop, taking the radius of the circle to be r,

$$L = 2\pi r$$

Now the current enclosed I_e is not I, but is less than this value. Since the current distribution is uniform, the current enclosed is,

$$I_e = I\left(\frac{\pi r^2}{\pi a^2}\right) = \frac{Ir^2}{a^2}$$



Using Ampere's law,

$$B(2\pi r) = \mu_0 \frac{Ir^2}{a^2}$$

$$B = \left(\frac{\mu_0 I}{2\pi a^2}\right) r \quad \text{... (ii)}$$

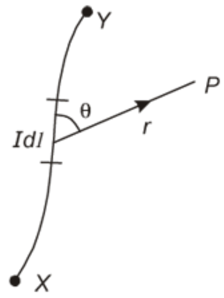
$$B \propto r \qquad (r < a)$$

The above figure shows a plot of the magnitude of ***B*** with distance r from the centre of the wire. The direction of the field is tangential to the respective circular loop (1 or 2) and given by the right-hand rule described earlier in this section.

This example possesses the required symmetry so that Ampere's law can be applied readily.

S28. Biot-Savart law.

This law states that the magnetic field (dB) at P, due to small current element Idl of current carrying conductor is



(a) directly proportional to the Idl (current) element of the conductor.

$$dB \propto Idl$$

(b) directly proportional sin θ

$$dB \propto \sin\theta$$

where, θ is the angle between dl and r.

(c) inversely proportional to the square of the distance of point P from the current element.

$$dB \propto \frac{1}{r^2}$$

Combining all the inequalities

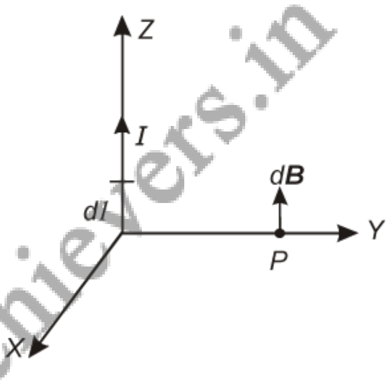
$$dB = \frac{Idl\sin\theta}{r^2}$$

$$dB = \frac{\mu_0}{4\pi}\cdot\frac{Idl\sin\theta}{r^2}$$

where, $\frac{\mu_0}{4\pi} = 10^{-7}$ T-m/A for free space.

The direction of magnetic field can be obtained using right hand thumb rule.

In vector form,



$$d\mathbf{B} = \frac{\mu_0}{4\pi}\cdot\frac{Id\mathbf{l}\times\hat{\mathbf{r}}}{|\mathbf{r}|^2}$$

The direction of magnetic field will be perpendicular to Y-axis along upward in the plane of paper.

S29. Radius of circular coil = R

Number of turns on the coil = N

Current in the coil = I

(a) Magnetic field at a point on its axis at distance x is given by the relation,

$$B = \frac{\mu_0 IR^2N}{2(x^2+R^2)^{\frac{3}{2}}}$$

Where, μ_0 = Permeability of free space

If the magnetic field at the centre of the coil is considered, then $x = 0$.

$$\therefore \qquad B = \frac{\mu_0 IR^2 N}{2R^3} = \frac{\mu_0 IN}{2R}$$

This is the familiar result for magnetic field at the centre of the coil.

Radii of two parallel co-axial circular coils = R

Number of turns on each coil = N

Current in both coils = I

Distance between both the coils = R

Let us consider point Q at distance d from the centre.

Then, one coil is at a distance of $\frac{R}{2} + d$ from point Q.

$\therefore$ Magnetic field at point Q is given as:

$$B_1 = \frac{\mu_0 NIR^2}{2\left[\left(\frac{R}{2}+d\right)^2 + R^2\right]^{\frac{3}{2}}}$$

Also, the other coil is at a distance of $\frac{R}{2} - d$ from point Q.

$\therefore$ Magnetic field due to this coil is given as:

$$B_2 = \frac{\mu_0 NIR^2}{2\left[\left(\frac{R}{2}-d\right)^2 + R^2\right]^{\frac{3}{2}}}$$

Total magnetic field,

$$B = B_1 + B_2$$

$$= \frac{\mu_0 IR^2}{2}\left[\left\{\left(\frac{R}{2}-d\right)^2 + R^2\right\}^{-\frac{3}{2}} + \left\{\left(\frac{R}{2}+d\right)^2 + R^2\right\}^{-\frac{3}{2}}\right]$$

$$= \frac{\mu_0 IR^2}{2}\left[\left(\frac{5R^2}{4} + d^2 - Rd\right)^{-\frac{3}{2}} + \left(\frac{5R^2}{4} + d^2 + Rd\right)^{-\frac{3}{2}}\right]$$

$$= \frac{\mu_0 IR^2}{2} \times \left(\frac{5R^2}{4}\right)^{-\frac{3}{2}}\left[\left(1 + \frac{4}{5}\frac{d^2}{R^2} - \frac{4}{5}\frac{d}{R}\right)^{-\frac{3}{2}} + \left(1 + \frac{4}{5}\frac{d^2}{R^2} + \frac{4}{5}\frac{d}{R}\right)^{-\frac{3}{2}}\right]$$

For d << R, neglecting the factor , we get

$$\approx \frac{\mu_0 I R^2}{2} \times \left(\frac{5R^2}{4}\right)^{-\frac{3}{2}} \times \left[\left(1-\frac{4d}{5R}\right)^{-\frac{3}{2}} + \left(1+\frac{4d}{5R}\right)^{-\frac{3}{2}}\right]$$

$$\approx \frac{\mu_0 I R^2 N}{2R^3} \times \left(\frac{4}{5}\right)^{\frac{3}{2}} \left[1-\frac{6d}{5R}+1+\frac{6d}{5R}\right]$$

$$B = \left(\frac{4}{5}\right)^{\frac{3}{2}} \frac{\mu_0 I N}{R} = 0.72\left(\frac{\mu_0 I N}{R}\right)$$

Hence, it is proved that the field on the axis around the mid-point between the coils is uniform.

S30. ***According Biot-Savart law:***

(a) Directly proportional to the current *i.e.*,

$$dB \propto I.$$

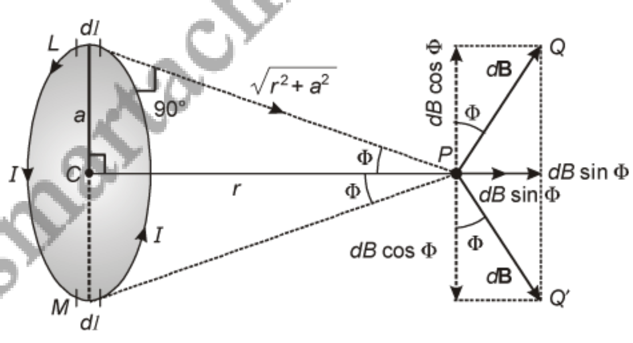
(b) Directly proportional to the length of the elementary portion *i.e.*,

$$dB \propto dl.$$

(c) Directly proportional to sine of the angle θ between the direction of the flow of current and the line joining the elementary portion to the observation point *i.e.*,

$$dB \propto \sin\theta.$$

For magnetic field at the centre of circular loop: Let us consider a circular loop of radius a with centre C. Let the plane of the coil be perpendicular to the plane of the paper and current I be flowing in the direction shown. Suppose P is any point on the axis at direction r from the centre.



Now consider a current element dl on top (L) where, current comes out of paper normally whereas at bottom (M) centres into the plane paper normally.

$\because$ **LP** $\perp dl$

Also **MP** $\perp dl$

$\because$ $LP = MP = \sqrt{r^2 + a^2}$

The magnetic field at P due to current element dl. According to Biot-savart law,

$$dB = \frac{\mu_0}{4\pi} \cdot \frac{I\,dl \sin 90^\circ}{(r^2 + a^2)}$$

Where, a = radius of circular loop, and r = distance of point P from centre along the axis.

The direction of dB is perpendicular to LP and along PQ. Similarly, the same magnitude of magnetic field is obtained due to current element dl at the bottom and direction is along PQ', where $PQ' \perp MP$. Now, resolving dB due to current element at L and M.$dB \cos\phi$ components balance each other and net magnetic field is given by

$$B = \oint dB \sin\phi = \oint \frac{\mu_0}{4\pi}\left(\frac{Idl}{r^2+a^2}\right)\cdot\frac{a}{\sqrt{r^2+a^2}} \qquad \left[\because \ \sin\phi = \frac{a}{\sqrt{r^2+a^2}} \text{ In } \Delta PCM\right]$$

$$= \frac{\mu_0}{4\pi}\frac{Ia}{(r^2+a^2)^{3/2}}\oint dl$$

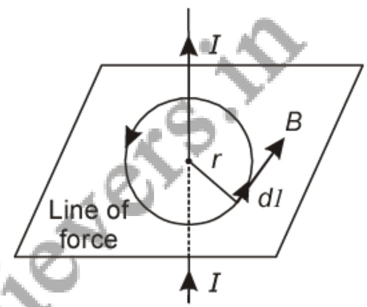
$$B = \frac{\mu_0}{4\pi}\frac{Ia}{(r^2+a^2)^{3/2}}(2\pi a) = \frac{\mu_0 Ia^2}{2(r^2+a^2)^{3/2}}$$

For n turns, $\quad B = \dfrac{\mu_0 nIa^2}{2(r^2+a^2)^{3/2}}$

Direction is along the axis and away from the loop.

S31. (a) ***Ampere's circuital law:*** The line integral of magnetic field over a closed loop is equal to μ_0 times total current I threading the loop *i.e.*,

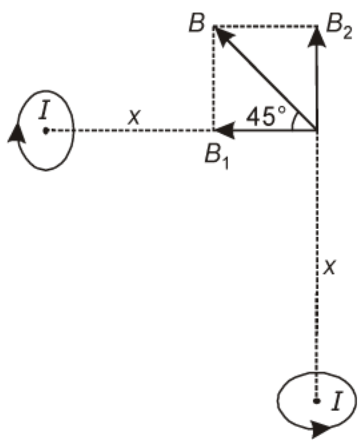
$$\oint \mathbf{B}.dl = \mu_0 I$$



Magnetic field at the centre of circular current carrying loop of radius R is given by

$$B = \frac{\mu_0 I}{2R}$$

(b) As both the coils are identical and carrying equal current, also the point of consideration O is at equal distance from the centre of coils. So the magnetic field produced at O due to both the coils will be equal in magnitude but they will be perpendicular to each other as shown in figure.



B_1 and B_2 are equal in magnetic field perpendicular to each other.

$$B_1 = B_2 = \frac{\mu_0 IR^2}{2(x^2+R^2)^{3/2}}$$

$$\therefore \quad B = \sqrt{B_1^2+B_2^2} = \sqrt{B_1^2+B_1^2} = \sqrt{2}B_1$$

$$\therefore \quad B = \frac{\mu_0 IR^2}{\sqrt{2}(x^2+R^2)^{3/2}}.$$

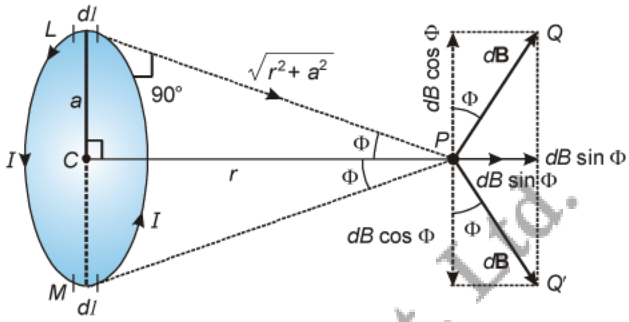
S32. ***According Biot-Savart law:*** (a) Directly proportional to the current *i.e.*, $dB \propto I$.

(b) Directly proportional to the length of the elementary portion *i.e.*, $dB \propto dl$.

(c) Directly proportional to sine of the angle θ between the direction of the flow of current and the line joining the elementary portion to the observation point *i.e.*, $dB \propto \sin\theta$.

For magnetic field at the centre of circular loop: Let us consider a circular loop of radius a with centre *C*. Let the plane of the coil be perpendicular to the plane of the paper and current I be flowing in the direction shown. Suppose *P* is any point on the axis at direction *r* from the centre.

Now consider a current element dl on top (*L*) where, current comes out of paper normally whereas at bottom (*M*) centres into the plane paper normally.



$\because$ $\qquad$ **LP** $\perp dl$

Also $\qquad$ **MP** $\perp dl$

$\because$ $\qquad LP = MP = \sqrt{r^2 + a^2}$

The magnetic field at *P* due to current element dl . According to Biot-savart law,

$$dB = \frac{\mu_0}{4\pi} \cdot \frac{I\,dl \sin 90^\circ}{(r^2 + a^2)}$$

Where, $\qquad a$ = radius of circular loop.

$\qquad r$ = distance of point *P* from centre along the axis.

The direction of *dB* is perpendicular to *LP* and along *PQ*. Similarly, the same magnitude of magnetic field is obtained due to current element dl at the bottom and direction is along *PQ′*, where $PQ' \perp MP$. Now, resolving *dB* due to current element at *L* and *M*.*dB* cos ϕ components balance each other and net magnetic field is given by

$$B = \oint dB \sin\phi = \oint \frac{\mu_0}{4\pi}\left(\frac{I\,dl}{r^2 + a^2}\right) \cdot \frac{a}{\sqrt{r^2 + a^2}} \left[\because \quad \sin\phi = \frac{a}{\sqrt{r^2 + a^2}} \text{ In } \Delta PCM\right]$$

$$= \frac{\mu_0}{4\pi} \frac{Ia}{(r^2 + a^2)^{3/2}} \oint dl$$

$$B = \frac{\mu_0}{4\pi} \frac{Ia}{(r^2 + a^2)^{3/2}} (2\pi a) = \frac{\mu_0 I a^2}{2(r^2 + a^2)^{3/2}}$$

For *n* turns, $\qquad B = \dfrac{\mu_0 n I a^2}{2(r^2 + a^2)^{3/2}}$

Direction is along the axis and away from the loop.

Magnetic field at centre *i.e.*, $r = 0$

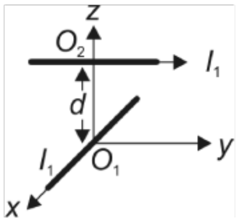
$$B = \mu_0 nI/2a$$

Date: 20/10/2021

Q1. What is an ampere in terms of the force between current carrying conductors.

Q2. What is the nature of force, when the two parallel conductors carry currents in the (a) same direction; (b) opposite direction?

Q3. Two long wires carrying current I_1 and I_2 are arranged as shown in the figure. The other carrying current I_2 is along a line parallel to the *y*-axis given by *x* = 0 and *z* = *d*. Find the force exerted at O_2 because of the write along the *x*-axis, as shown in figure.



Q4. State Ampere's circuital law.

Q5. What happen when we increase the number of turns in a current carrying circular coil?

Q6. What is the torque on a planar current loop in magnetic field change, when its shape is changed without changing its geometrical area?

Q7. Calculate the torque on a closed current loop placed in the magnetic field $\vec{B}$. What is the main function of soft iron core used in a moving coil galvanometer?

Q8. Two long and parallel straight wires *A* and *B* carrying currents of 8.0 A and 5.0 A in the same direction are separated by a distance of 4.0 cm. Estimate the force on a 10 cm section of wire *A*.

Q9. A straight horizontal conducting rod of length 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.

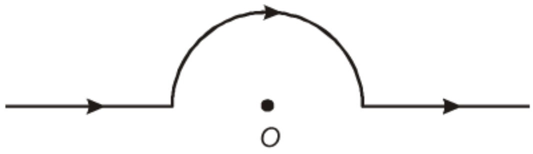
(a) What magnetic field should be set up normal to the conductor in order that the tension in the wires is zero?

(b) What will be the total tension in the wires if the direction of current is reversed keeping the magnetic field same as before? (Ignore the mass of the wires.) $g = 9.8 \text{ m s}^{-2}$.

Q10. Two concentric circular coils *X* and *Y* of radii 16 cm and 10 cm, respectively, lie in the same vertical plane containing the north to south direction. Coil *X* has 20 turns and carries a current of 16 A; coil *Y* has 25 turns and carries a current of 18 A. The sense of the current in *X* is anticlockwise, and clockwise in *Y*, for an observer looking at the coils facing west. Give the magnitude and direction of the net magnetic field due to the coils at their centre.

Q11. A straight wire carrying a current of 12 A is bent into a semicircular are of radius 2.0 cm as shown in figure below.

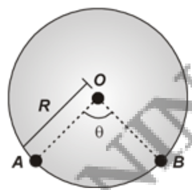
(a) What is the direction and magnitude of magnetic field at the centre of the are?



(b) Would your answer change, if the wire were bent into a semicircular arc of the same radius but in the opposite way as shown in figure below?

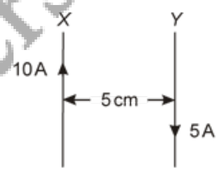
Q12. The wires which connect the battery of an automobile to its starting motor carry a current of 300 A (for a short time). What is the force per unit length between the wires if they are 70 cm long and 1.5 cm apart? Is the force attractive or repulsive?

Q13. A wire of uniform cross-section is bent into a circular loop of radius R. Consider two points A and B on the loop, such that $\angle AOB = \theta$ as shown in figure below. If now a battery is connected between A and B, show that the magnetic field at the centre of the loop will be zero irrespective of angle θ.

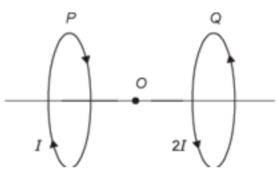


Q14. Why do two straight parallel metallic wires carrying current in the opposite directions repel each other.

Q15. Two parallel straight wires X and Y separated by a distance 5 cm in air carry current of 10 A and 5 A respectively in opposite direction as shown in figure below. Calculate the magnitude and direction of the force on a 20 cm length of the wire Y.



Q16. Two identical circular wire P and Q each of radius r and carrying current I and $2I$ respectively are lying in parallel plane, such that they have common axis as shown in figure below, find the net megnetic field at the common centre of the two coil.



Q17. (i) A coil of 70 turns and radius 22 cm has a current of 10 ampere flowing through it. Find the magnetic field at the centre of the coil.

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

Q18. A uniform magnetic field of 1.5 T exists in a cylindrical region of radius10.0 cm, its direction parallel to the axis along east to west. A wire carrying current of 7.0 A in the North to South direction passes through this region. What is the magnitude and direction of the force on the wire if,

(a) the wire intersects the axis.

(b) the wire is turned from N-S to Northeast-Northwest direction.

(c) the wire in the N-S direction is lowered from the axis by a distance of 6.0 cm?

Q19. State Ampere's circuital law. Write the expression for the magnetic field at the centre of a circular coil of radius R carrying a current I. Draw the magnetic field lines due to this coil.

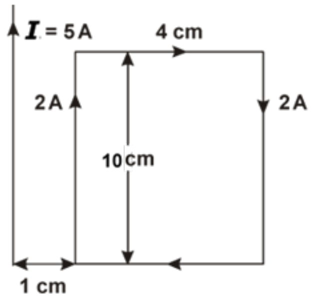
Q20. State and prove Ampere's circuital law.

Q21. A long straight wire of a circular cross-section of radius 'a' carries a steady current 'I'. The current is uniformly distributed across the cross-section. Apply Ampere's circuital law to calculate the magnetic field at a point 'r' in the region for (i) $r < a$ and (ii) $r > a$.

Q22. A rectangular loop of wire of size $4 cm \times 10 cm$ carries a steady current of 2 A. A straight long wire carrying 5 A current is kept near the loop as shown. If the loop and the wire are coplanar, find.

(a) the torque acting on the loop and

(b) the magnitude and direction of the force on the loop due to the current carrying wire.



Q23. Depict the magnetic field lines due to two straight, long parallel conductors carrying currents I_1 and I_2 in the same direction. Hence, deduce an expression for the force acting per unit length on one conductor due to the other. Is this force attractive or repulsive?

Q24. (a) Explain, giving reasons, the basic difference in converting a galvanometer into (*i*) a voltmeter and (*ii*) an ammeter.

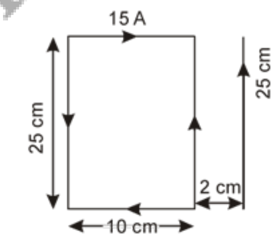
(b) Two long straight parallel conductors carrying steady current I_1 and I_2 in same direction and separated by a distance 'd'. Explain briefly, with the help of a suitable diagram, how the magnetic field due to one force acting between the two conductors. Mention the nature of this force.

Q25. What is ampere circutial law. A long straight wire of a circular cross-section of radius a carries a steady current I. The current is uniformly distributed across the cross-section. Apply Ampere's circuital law to calculate the magnetic field at a point in the region for (a) $r < a$ and (b) $r > a$.

Q26. Depict the magnetic field lines due to two straight, long, parallel conductors carrying currents I_1 and I_2 in the same direction. Hence, deduce an expression for the force acting per unit length on one conductor due to the other.

Is this force attractive or repulsive?

Figure shows a rectangular current-carrying loop placed 2 cm away from a long, straight, current-carrying conductor. What is the direction and magnitude of the net force acting on the loop?



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S1. One ampere is that current, which when flowing through each of the two parallel conductors of infinite length and placed in free space at a distance of one metre from each other, produces between them a force of 2×10^{-7} newton per metre of their length.

S2. (a) Force is attractive. (b) Force is repulsive.

S3. At O_2, the magnetic field due to I_1 is along the *y*-axis. The second wire is along the *y*-axis and hence the force is zero

S4. It states that the magnetic circulation (C) around are closed loop is μ_0 (absolute permeability of free space) times the net electric current (I) enclosed by the loop.

$$\oint_{\text{closed loop}} \vec{B} \cdot \vec{dl} = \mu_0 I_{\text{enclosed}}$$

S5. The magnetic field produced by a coil of *n* turns is *n* times the magnetic field produced by a coil of single turn.

$$B = \mu_0 nI.$$

S6. The torque on a planar current loop in a magnetic field does not change, when its shape is changed without changing the area of the loop.

S7. When a closed current loop is suspended in magnetic field, torque on the coil is given by

$$|\vec{\tau}| = |\vec{M} \times \vec{B}| = n\,IAB \sin\theta$$

where the letters have their usual meanings.

The use of the soft iron core strengthens the magnetic flux linked with the coil.

S8. Current flowing in wire *A*, I_A = 8.0 A

Current flowing in wire *B*, I_B = 5.0 A

Distance between the two wires, r = 4.0 cm = 0.04 m

Length of a section of wire *A*, l = 10 cm = 0.1 m

Force exerted on length l due to the magnetic field is given as:

$$F = \frac{\mu_0 2 I_A I_B l}{4\pi r}$$

Where,

$$\mu_0 = \text{Permeability of free space}$$
$$= 4\pi \times 10^{-7}\ \text{T m A}^{-1}$$

$$F = \frac{4\pi \times 10^{-7} \times 2 \times 8 \times 5 \times 0.1}{4\pi \times 0.04}$$

$$= 2 \times 10^{-5}\,\text{N}$$

The magnitude of force is 2×10^{-5} N. This is an attractive force normal to *A* towards *B* because the direction of the currents in the wires is the same.

S9. Length of the rod, $l = 0.45$ m

Mass suspended by the wires, $m = 60\,\text{g} = 60 \times 10^{-3}\,\text{kg}$

Acceleration due to gravity, $g = 9.8\,\text{m/s}^2$

Current in the rod flowing through the wire, $I = 5\,\text{A}$

Magnetic field (*B*) is equal and opposite to the weight of the wire *i.e.*,

$$BIl = mg$$

$$\therefore \quad B = \frac{mg}{Il} = \frac{60 \times 10^{-3} \times 9.8}{5 \times 0.45} = 0.26\,\text{T}$$

A horizontal magnetic field of 0.26 T normal to the length of the conductor should be set up in order to get zero tension in the wire. The magnetic field should be such that Fleming's left hand rule gives an upward magnetic force.

If the direction of the current is revered, then the force due to magnetic field and the weight of the wire acts in a vertically downward direction.

$\therefore$ Total tension in the wire $= BIl + mg$

$$= 0.26 \times 5 \times 0.45 + (60 \times 10^{-3}) \times 9.8$$

$$= 1.176\,\text{N}.$$

S10. Radius of coil *X*, $r_1 = 16\,\text{cm} = 0.16\,\text{m}$

Radius of coil *Y*, $r_2 = 10\,\text{cm} = 0.1\,\text{m}$

Number of turns of on coil *X*, $n_1 = 20$

Number of turns of on coil *Y*, $n_2 = 25$

Current in coil *X*, $I_1 = 16\,\text{A}$

Current in coil *Y*, $I_2 = 18\,\text{A}$

Magnetic field due to coil *X* at their centre is given by the relation,

$$B_1 = \frac{\mu_0 n_1 I_1}{2r_1}$$

Where, μ_0 = Permeability of free space

$$= 4\pi \times 10^{-7}\,\text{T m A}^{-1}$$

$$\therefore \quad B_1 = \frac{4\pi \times 10^{-7} \times 20 \times 16}{2 \times 0.16}$$

$$= 4\pi \times 10^{-4}\,\text{T (Towards East)}$$

Magnetic field due to coil Y at their centre is given by the relation,

$$B_2 = \frac{\mu_0 n_2 I_2}{2r_2}$$

$$= \frac{4\pi \times 10^{-7} \times 25 \times 18}{2 \times 0.10}$$

$$= 9\pi \times 10^{-4}\,\text{T (Towards West)}$$

Hence, net magnetic field can be obtained as:

$$B = B_2 - B_1$$

$$= 9\pi \times 10^{-4} - 4\pi \times 10^{-4}$$

$$= 5\pi \times 10^{-4}\,\text{T}$$

$$= 1.57 \;\; 10^{-3}\,\text{T (Towards West)}$$

S11. (a) **From the above Figure (a):** The magnetic field at the centre of a current carrying circular coil is given by

$$B = \frac{\mu_0}{4\pi} \cdot \frac{2\pi I}{a} \qquad \text{(By Biot-savart's law)}$$

For magnetic field at the centre O of the semicircular conductor, the above equation will modify to

$$B = \frac{1}{2} \times \frac{\mu_0}{4\pi} \cdot \frac{2\pi I}{a} = \frac{\mu_0}{4\pi} \cdot \frac{\pi I}{a}$$

Given: $I = 12$ A; $a = 2.0$ cm $= 2.0 \times 10^{-2}$ m

$$\therefore \qquad B = 10^{-7} \times \frac{\pi \times 12}{2.0 \times 10^{-2}} = \mathbf{1.885 \times 10^{-4}}\, \boldsymbol{T}.$$

The direction of the field will be **normal to the plane of the paper** in **downward direction**.

(b) **From the above Figure (b):** The field will be of the same magnitude *i.e.*, $\mathbf{1.885 \times 10^{-4}}\,\boldsymbol{T}$, but its direction will be **normal to the plane of paper** in **upwards direction**.

S12. Current in both wires, $I = 300$ A

Distance between the wires, $r = 1.5$ cm $= 0.015$ m

Length of the two wires, $l = 70$ cm $= 0.7$ m

Force per unit length between the two wires is given by the relation,

$$F = \frac{\mu_0 I^2}{2\pi r}$$

Where, μ_0 = Permeability of free space

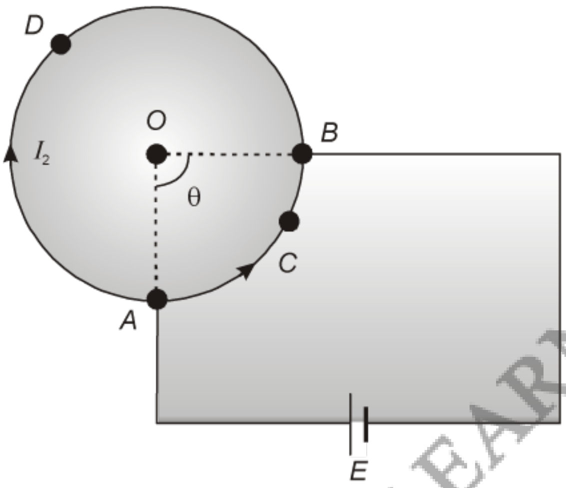
$= 4\pi \times 10^{-7}\,\text{T m A}^{-1}$

$$\therefore \quad F = \frac{4\pi \times 10^{-7} \times (300)^2}{2\pi \times 0.015} = 1.2\ \text{N/m}$$

Since the direction of the current in the wires is opposite, a repulsive force exists between them.

S13. Let $ADB = l_2, \quad ACB = l_1$

$R_{ADB} = R_2 \quad R_{ACB} = R_1$



then, $\frac{R_2}{R_1} = \frac{l_2}{l_1}$

Further $E_1 = E_2$ ... (i)

$\Rightarrow \quad I_1 R_1 = I_2 R_2$

$\Rightarrow \quad \frac{I_1}{I_2} = \frac{R_2}{R_1} = \frac{l_2}{l_1}$

$\Rightarrow \quad I_1 l_1 = I_2 l_2$ ... (ii)

S14. The current through one metallic wire produces magnetic field and the other parallel current carrying metallic wire experiences force due to this magnetic field. The application of Biot-Savart's law tells that when currents flow through the two conductors in opposite directions, the two wires repel each other.

S15. Given: $I_1 = 10\,\text{A}$, $I_2 = 5\,\text{A}$; $r = 5\ \text{cm} = 0.05\ \text{m}$

Force on a unit length of the wire Y due to the wire X,

$$F = \frac{\mu_0}{4\pi} \cdot \frac{2 I_1 I_2}{r}$$

Setting the values

$\therefore$
$$\frac{F}{L} = \frac{10^{-7} \times 2 \times 10 \times 5}{0.05} = 2 \times 10^{-4}\,\text{Nm}^{-1}$$

Force on 20 cm *i.e.*, 0.2 m length of the wire *Y*,

$$\frac{F'}{L} = F \times 0.2 = 2 \times 10^{-4} \times 0.2 = \mathbf{4 \times 10^{-5}\,N}.$$

S16. The direction of current in both the loop is clockwise as seen *O*, which is equidistant from *l* both the loops find the magnitude and net magnetic field at point *O*.

$$B_P = \frac{\mu_0}{4\pi} \cdot \frac{2\pi I}{r}$$ (Along vertically upwards)

Magnetic field due to circular wire *Q*

$$B_Q = \frac{\mu_0}{4\pi} \cdot \frac{4\pi I}{r}$$ (Along horizontal forwards left)

Net magnetic field is

$$B = B_P + B_Q \quad \Rightarrow \quad \frac{\mu_0}{4\pi} \cdot \frac{2\pi I}{r} + \frac{\mu_0}{4\pi} \cdot \frac{4\pi I}{r}$$

$$B = \frac{\mu_0}{4\pi} \cdot \frac{6\pi I}{r} = \frac{\mu_0}{2} \cdot \frac{3I}{r}$$

Direction of net magnetic field at the common center of the two coil will be towards left.

S17. (i) Here, $n = 70$, $I = 10$ amp, $r = 22$ cm $= 0.22$ m

Magnetic field at the centre of the coil

$$B = \frac{\mu_0}{4\pi} \frac{2\pi n I}{r} = \frac{10^{-7} \times 2\pi \times 70 \times 10}{0.22}$$

$$= 2 \times 10^{-3}\,\text{Wb/m}^2 \quad \text{or} \quad \text{tesla.}$$

(ii) Magnetic field at the centre of a semi-conductor coil

$$B = \frac{1}{2} \cdot \frac{\mu_0 I}{2r} = \frac{1}{2} \cdot \frac{4\pi \times 10^{-7}\ 10}{2 \times 0.20} = \mathbf{1.57 \times 10^{-5}\,T}.$$

S18. Magnetic field strength, $B = 1.5$ T

Radius of the cylindrical region, $r = 10$ cm $= 0.1$ m

Current in the wire passing through the cylindrical region, $I = 7$ A

(a) If the wire intersects the axis, then the length of the wire is the diameter of the cylindrical region.

Thus, $l = 2r = 0.2$ m

Angle between magnetic field and current,

$$\theta = 90°$$

Magnetic force acting on the wire is given by the relation,

$$F = BIl \sin\theta$$

$$= 1.5 \times 7 \times 0.2 \times \sin 90° = 2.1 \text{ N}$$

Hence, a force of 2.1 N acts on the wire in a vertically downward direction.

(b) New length of the wire after turning it to the Northeast-Northwest direction can be given as:

$$l_1 = \frac{l}{\sin\theta}$$

Angle between magnetic field and current, $\theta = 45°$

Force on the wire,

$$F = BIl_1 \sin\theta$$

$$= BIl = 1.5 \times 7 \times 0.2 = 2.1 \text{ N}$$

Hence, a force of 2.1 N acts vertically downward on the wire. This is independent of angle θ because $l \sin\theta$ is fixed.

(c) The wire is lowered from the axis by distance, $d = 6.0$ cm

Let l_2 be the new length of the wire.

$$\therefore \quad \left(\frac{l_2}{2}\right)^2 = 4(d + r)$$

$$= 4(10 + 6) = 4(16)$$

$$\therefore \quad l_2 = 8 \times 2 = 16 \text{ cm} = 0.16 \text{ m}$$

Magnetic force exerted on the wire,

$$F_2 = BIl_2$$

$$= 1.5 \times 7 \times 0.16 = 1.68 \text{ N}$$

Hence, a force of 1.68 N acts in a vertically downward direction on the wire.

S19. **Ampere's circuital law:** The magnetic circulation around a closed loop is μ_0 times the net electric current enclosed by the loop.

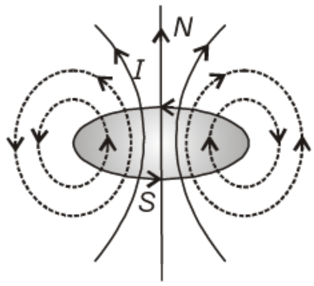
$$\oint_{\text{closed loop}} \vec{B} \cdot \vec{dl} = \mu_0 I_{\text{enclosed current}}$$

Magnetic field at the centre of a circular coil of radius R carrying a current I is

$$B = \frac{\mu_0 I}{2R}$$

If the circular coil has N turns, then the field at the centre would be

$$B = \frac{N\mu_0 I}{2R}.$$



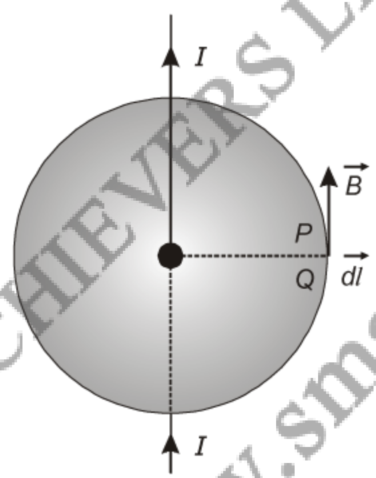
S20. Ampere's circuital law states that the line integral of the magnetic field around a closed path in vacuum is equal to μ_0 times the total current threading the closed path *i.e.*

$$\oint \vec{B}\cdot\vec{dl} = \mu_0 I$$

We know that the magnetic field due to a straight conductor at a point of distance r from it is given by

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

The direction of the magnetic field is along a tangent to a circle of radius r centered on the conductor as shown in the figure. At all points on the circumference of circle the magnetic field is constant in magnitude. The magnetic field is parallel to element dl.



Now, $$\oint \vec{B}\cdot\vec{dl} = \oint B\,dl\cos 0° = \oint B\,dl$$

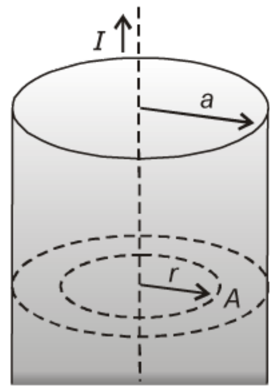
$$= B\oint dl = B.2\pi r$$

or $$\oint \vec{B}\cdot\vec{dl} = \frac{\mu_0 I}{2\pi r}(2\pi r) \qquad \left(Since,\quad B = \frac{\mu_0 I}{2\pi r}\right)$$

∴ $$\oint \vec{B}\cdot\vec{dl} = \mu_0 I,$$ which is Ampere's circuital law.

S21. (a) **Magnetic field at a point inside the current carrying wire, *i.e.*, $r < a$**

To calculate magnetic field at a point 'A' inside the wire we consider a circular loop of radius 'r' in such a way that point 'A' lies on it.



Current enclosed by this loop is magnetic moment remaining same

$$I' = I\left(\frac{\pi r^2}{\pi a^2}\right) = I\frac{r^2}{a^2}$$

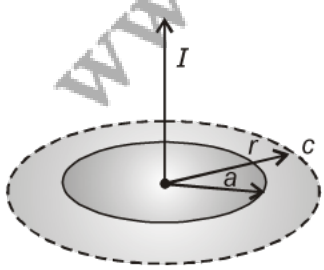
Using Ampere's circuital law,

$$\oint B.dl = \mu_0 I$$

$$B(2\pi r) = \mu_0\left(\frac{Ir^2}{a^2}\right)$$

or, $$B = \frac{\mu_0 I r}{2\pi a^2}$$

(b) **Magnetic field at a point outside the wire, *i.e.*, $r > a$**



Current enclosed by the loop of radius 'r' is

$$I' = I$$

Using Ampere's circuital law,

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

or, $$B = \frac{\mu_0 I}{2\pi r}.$$

S22. (a) Torque acting on the loop is

$$\tau = MB \sin\theta$$

As angle between magnetic field vector and dipole moment vector is zero.

$$\tau = MB \sin(0)$$

$$\tau = 0 \text{ Nm}$$

(b) Given: $l = 10 \times 10^{-2}$ m; $I_1 = 2$ A; $I_2 = 5$ A; $r_1 = 0.01$ m; $r_2 = 0.05$ m

Magnitude of force is

$$F = \frac{2\mu_0 I_1 I_2 l}{4\pi}\left[\frac{1}{r_1} - \frac{1}{r_2}\right]$$

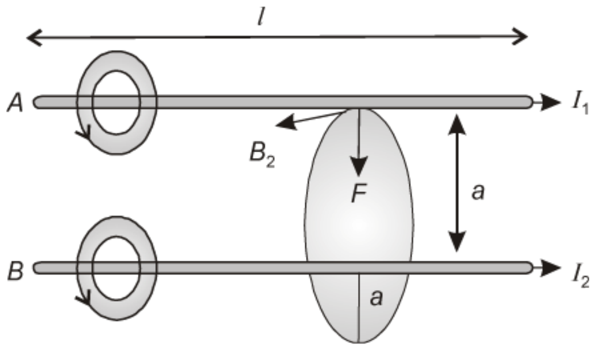
$$F = [2 \times 10^{-7} \times 2 \times 5 \times 10^{-1}]\left[\frac{1}{10^{-2}} - \frac{1}{5 \times 10^{-2}}\right]$$

$$= 20 \times 10^{-8}\left[1 - \frac{1}{5}\right] \times \frac{1}{10^{-2}}$$

$$= \frac{20 \times 10^{-6} \times 4}{5} = \mathbf{16 \times 10^{-6}\ N}.$$

Net force is attractive because the arm of the loop carrying current in the same direction as the direction of current in the wire is nearer.

S23. In the figure are shown two, long parallel conductor A and B carrying currents I_1 and I_2 in the same direction. Each conductor experiences a force because it is placed in the magnetic field of the other conductor. If a is the distance between the two conductors, then the magnetic field B_2 due to the current I_2 in B on the conductor A is given by



$$B_2 = \frac{\mu_0}{4\pi} \cdot \frac{2I_2}{a} \quad \text{perpendicular to } A. \qquad \text{... (i)}$$

If l is the length of the conductor, A carrying current I_1, then force acting on the conductor A is given by

$$\vec{F} = I(\vec{l} \times \vec{B}) = IlB \sin\theta$$

$$F = I_1 l B_2 \sin 90° \qquad (\because \theta = 90°)$$

$$F = I_1 l B_2 \qquad \text{... (ii)}$$

Putting the value of B_2 from (i) in (ii), we get

$$F = I_1 l \frac{\mu_0}{4\pi} \cdot \frac{2I_2}{a}$$

$$F = \frac{\mu_0}{2\pi} \cdot \frac{I_1 I_2}{a} l.$$

$\therefore$ Force per unit length acting on A is

$$\frac{F}{l} = \frac{\mu_0}{2\pi} \cdot \frac{I_1 I_2}{a} \text{ Nm}^{-1}.$$

The direction of this force is the direction of $\vec{l} \times \vec{B}$ which is towards the conductor B *i.e.*, the force is of attraction.

S24. (a) (i) While converting a galvanometer into voltmeter we join high resistance is series. Resistance of voltmeter is kept high so that it draws minimum amount of current at the time of measurement of potential difference between any two points in a electric current.

(ii) To converting a galvanometer into ammeter we join low resistance in parallel.

Ammeter is joined in series. So, the resistance of ammeter should be minimum *i.e.*, resistance if ammeter.

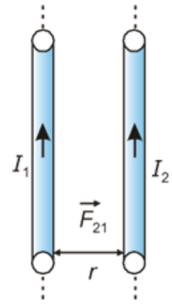
(b) There is magnetic field around the 1st current carrying wire.

$$B_1 = \frac{\mu_0 I_1}{2\pi d}$$

Here, B_1 is the magnitude of the field at a distance 'd' from the wire.

According to right hand palm rule the magnetic field B_1 is directed into the plane of the sheet.

As the second wire is also carrying current and is kept in the magnetic field B_1 it experience a force ($\vec{F}_{21}$).



$$F_{21} = I_2 (l_2) B_1$$

Force experienced per unit length of second wire is

$$f_{21} = \frac{F_{21}}{l_2} = I_2 B_1$$

$$f_{21} = \frac{\mu_0 I_1 I_2}{2\pi d}$$

According to Fleming's L.H.R., the force is directed towards the 1st wire.

Similarly, 1st wire is in the magnetic field of 2nd wire and experiences a force towards the 2nd wire.

$$f_{21} = \frac{\mu_0 I_1 I_2}{2\pi d} \qquad \text{... (ii)}$$

From the above discussion we conclude that wires will attract each other.

S25. Ampere's circuital law states that the line integral of the magnetic field around a closed path in vacuum is equal to μ_0 times the total current threading the closed path *i.e.*

$$\oint \vec{B} \cdot \vec{dl} = \mu_0 I$$

In these types of questions, first of all we have to calculate the current per unit area of cross section, so that we can calculate the current in each loop, then only we can find the magnetic fields.

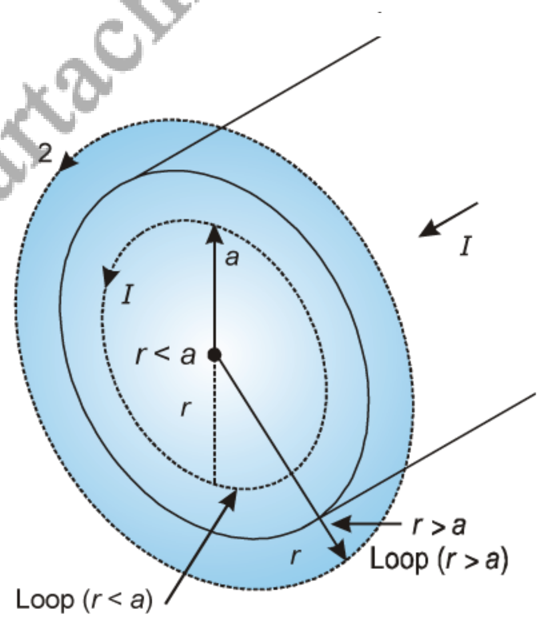
The current is distributed uniformly across the cross-section of radius a.

$\therefore$ Current passes per unit cross-section $= \dfrac{I}{\pi a^2}$

$\therefore$ Current passes through the cross-section of radius r is

$$I' = \left(\frac{I}{\pi a^2} \times \pi r^2\right) = \frac{I r^2}{a^2}$$

$$I' = \frac{I r^2}{a^2} \qquad \text{... (i)}$$



(a) Consider a loop of radius r whose centre lies at the axis of wire where, $r < a$ as shown in figure inside the wire.

Applying Ampere's circuital law,

$$\oint \mathbf{B}.dl = \mu_0 I'$$

$$\oint B\,dl\cos 0^\circ = \mu_0\left(\frac{Ir^2}{a^2}\right) \qquad \text{[From Eq. (i)]}$$

$$B\oint dl = \mu_0 \frac{Ir^2}{a^2}$$

$$B \times 2\pi r = \frac{\mu_0 I r^2}{a^2}$$

$$B = \frac{\mu_0 I r}{2\pi a^2} \quad \Rightarrow \quad B \propto r$$

(b) Applying Ampere's circuital law,

$$\oint \mathbf{B}.dl = \mu_0 I$$

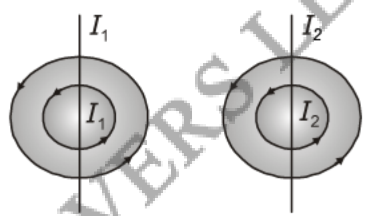
$$\oint B.dl\cos 0^\circ = \mu_0 I$$

$$B\oint dl = \mu_0 I$$

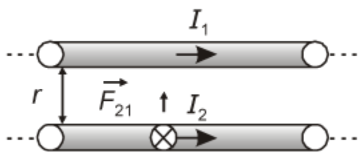
$$B \times 2\pi r = \mu_0 I$$

$$B = \frac{\mu_0 I}{2\pi r} \quad \Rightarrow \quad B \propto \frac{1}{r}.$$

S26. (a)



(b) Consider two infinitely long straight parallel wires carrying current I_1 and I_2 in the same direction. Let they be separated by a distance r.



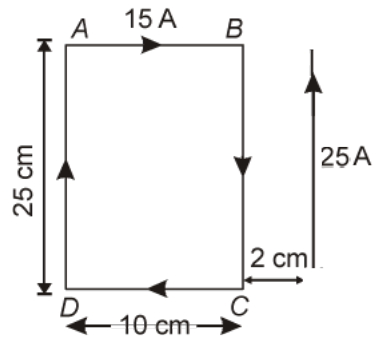
Magnetic field at the location of second wire due to current in first wire is

$$B_1 = \frac{\mu_0 I_1}{4\pi r} \quad \text{(directed inwards)}$$

According to Fleming's L.H.R., second wire will experience a force towards the first wire. Force experienced per unit length of the second wire will be

$$f_{21} = I_2 B_1 \quad \text{and} \quad f_{21} = \frac{\mu_0 I_1 I_2}{4\pi r}$$

(c) Force on the arm *BC*



$$F_1 = \frac{\mu_0}{4\pi}\frac{2I_1I_2}{r_1} \times l_{BC}$$

where, $I_1 = 25\,A$; $\frac{\mu_0}{4\pi} = 10^{-7}\,TA^{-1}m$; $I_2 = 15\,A$;

$r_1 = 2 \times 10^{-2}\,m$; and $l_{BC} = 25 \times 10^{-2}\,m$

$$F_1 = \frac{10^{-7} \times 2 \times 25 \times 15 \times 25 \times 10^{-2}}{2.0 \times 10^{-2}} = 9.375 \times 10^{-4}\,N$$ (towards left)

Force on arm *DA*

$$F_2 = \frac{\mu_0}{4\pi}\frac{2 \times I_1I_2}{12 \times 10^{-2}} \times l_{DA}$$

where, $r_2 = 10 + 2 = 12\,cm = 12 \times 10^{-2}\,m$

$$F_2 = \frac{10^{-7} \times 2 \times 25 \times 15 \times 25 \times 10^{-2}}{12 \times 10^{-2}} = 1.563 \times 10^{-4}\,N$$ (towards right)

Net force on the loop

$F = F_1 - F_2 = 7.812 \times 10^{-4}\,N$ (towards left, *i.e.*, away from the wire).

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Q1. A solenoid of length 0.5 m has a radius of 1 cm and is made up of 500 turns. It carries a current of 5 A. What is the magnitude of the magnetic field inside the solenoid?

Q2. A current-carrying circular loop lies on a smooth horizontal plane. Can a uniform magnetic field be set up in such a manner that the loop turns around itself (*i.e.*, turns about the vertical axis).

Q3. A current-carrying circular loop is located in a uniform external magnetic field. If the loop is free to turn, what is its orientation of stable equilibrium? Show that in this orientation, the flux of the total field (external field + field produced by the loop) is maximum.

Q4. A loop of irregular shape carrying current is located in an external magnetic field. If the wire is flexible, why does it change to a circular shape?

Q5. How much is the flux density B at the centre of a long solenoid?

Q6. Why the magnetic field lines can be entirely confined within the core of a toroid, but not within a straight solenoid.

Q7. What is a solenoid? Give the magnitude of magnetic field developed at a point well inside a solenoid carrying current.

Q8. What is a toroid?

Q9. Magnetic field lines can be entirely confined within the core of a toroid, but not within a straight solenoid, Why?

Q10. What kind of magnetic field is produced due to straight solenoid?

Q11. A closely wound solenoid 80 cm long has 5 layers of windings of 400 turns each. The diameter of the solenoid is 1.8 cm. If the current carried is 8.0 A, estimate the magnitude of B inside the solenoid near its centre.

Q12. Two moving coil meters, M_1 and M_2 have the following particulars:

$$R_1 = 10\,\Omega,\quad N_1 = 30,\quad A_1 = 3.6 \times 10^{-3}\,\text{m}^2,\quad B_1 = 0.25\,\text{T}$$
$$R_2 = 14\,\Omega,\quad N_2 = 42,\quad A_2 = 1.8 \times 10^{-3}\,\text{m}^2,\quad B_2 = 0.50\,\text{T}$$

(The spring constants are identical for the two meters).

Determine the ratio of (a) current sensitivity and (b) voltage sensitivity of M_2 and M_1.

Q13. A solenoid 60 cm long and of radius 4.0 cm has 3 layers of windings of 300 turns each. A 2.0 cm long wire of mass 2.5 g lies inside the solenoid (near its centre) normal to its axis; both the wire and the axis of the solenoid are in the horizontal plane. The wire is connected through two leads parallel to the axis of the solenoid to an external battery which supplies a current of 6.0 A in the wire. What value of current (with appropriate sense of circulation) in the windings of the solenoid can support the weight of the wire? $g = 9.8\ \text{m s}^{-2}$.

Q14. Using Ampere's circuit law, obtain an expression for the magnetic field along the axis of a current carrying solenoid of length l and having N number of turns.

Q15. Suppose a helical spring is suspended from the roof of a room and very small weight is attached to its lower end. What will happen to the spring when a current is passed through it? Give reason to support your answer

Q16. An air-core solenoid having N turns and length l is carrying a current I ampere: (a) Sketch the pattern of magnetic lines of force in the solenoid. (b) If an iron core is inserted in it, how is its field modified? (c) Write down the expression for the magnetic field at the centre of the solenoid along its axis.

Q17. Why the magnetic field at a point near the centre but outside a current carrying solenoid is zero.

Q18. The horizontal component of the Earth's magnetic field at a certain place is 3.0×10^{-5} T and the direction of the field is from the geographic South to the geographic North. A very long straight conductor is carrying a steady current of 1A. What is the force per unit length on it when it is placed on a horizontal table and the direction of the current is (a) East to West; (b) South to North?

Q19. A toroid has a core (non-ferromagnetic) of inner radius 25 cm and outer radius 26 cm, around which 3500 turns of a wire are wound. If the current in the wire is 11 A, what is the magnetic field (a) outside the toroid, (b) inside the core of the toroid, and (c) in the empty space surrounded by the toroid.

Q20. Using Ampere's circuital law, deduce an expression for the magnetic field due to a toroidal solenoid.

Q21. Obtain, with the help of necessary diagram, the expression for the magnetic field in the interior of a toroid carrying current.

Q22. A wire of length L is bent round in the form of a coil having N turns of same radius. If a steady current I flows through it in clockwise direction, find the magnitude and direction of the magnetic field produced at its centre.

Q23. What is solenoid? A solenoid, of length 1.0 m, has a radius of 1 cm and has a total of 1000 turns wound on it. It carries a current of 5 A. Calculate the magnitude of the axial magnetic field inside the solenoid. If an electron was to move with a speed of 10^4 m/s along the axis of this current carrying solenoid, what would be the force experienced by this electron?

Q24. Deduce the expression for the torque experienced by a rectangular loop carrying a steady current I and placed in a uniform magnetic field B. Indicate the direction of the torque acting on the loop.

Q25. A circular coil of 200 turns and radius 10 cm is placed in a uniform magnetic field of 0.5 T, normal to the plane of the coil. If the current in the coil is 3.0 A, calculate the

(a) total torque on the coil

(b) total force on the coil

(c) average force on each electron in the coil, due to the magnetic field. Assume the area of cross-section of the wire to be 10^{-5} m^2 and the free electron density is $10^{29}/m^3$.

Q26. What does a toroid consist of? Show that for an ideal toroid of closely wound turns, the magnetic fiedls (a) inside the toroid is constant, and (b) in the open space inside and exterior to the toroid is zero.

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S1. The number of turns per unit length is,

$$n = \frac{500}{0.5} = 1000 \text{ turns/m}$$

The length l = 0.5 m and radius r = 0.01 m. Thus, l/a = 50 *i.e.*, $l >> a$.

Hence, we can use the *long* solenoid formula,

$$B = \mu_0 n i$$
$$= 4\pi \times 10^{-7} \times 10^3 \times 5$$
$$= \mathbf{6.28 \times 10^{-3} T}.$$

S2. No, because that would require Ä to be in the vertical direction. But $\tau = \boldsymbol{IA} \times \boldsymbol{B}$, and since A of the horizontal loop is in the vertical direction, Ä would be in the plane of the loop for any $\boldsymbol{B}$.

S3. Orientation of stable equilibrium is one where the area vector $\boldsymbol{A}$ of the loop is in the direction of external magnetic field. In this orientation, the magnetic field produced by the loop is in the same direction as external field, both normal to the plane of the loop, thus giving rise to maximum flux of the total field.

S4. It assumes circular shape with its plane normal to the field to maximize flux, since for a given perimeter, a circle encloses greater area than any other shape.

S5. The magnetic field due to a long straight solenoid at a point well inside it, is given by

$$B = \mu_0 n I$$

Here, μ_0 is the permeability of free space, n is the number of turns per unit length of the solenoid and I is the current flowing through it.

S6. The magnetic field lines always form closed loops. As the turns of the wires in a toroidal solenoid are wound over its core in circular form, the field lines are confined within the core of the toroid.

In a straight solenoid, the magnetic field lines can not form closed loops within the solenoid.

S7. A solenoid as a circular coil of a large number of turns, such that the turns of the solenoid run parallel to its length.

The magnetic field at a point well inside the solenoid,

$$B = \mu_0 n I$$

where, n is number of turns per unit length of the solenoid, μ_0 absolute permeability of free space and I carrying current in solenoid.

S8. An anchor ring, around which a large number is turns of a metallic wire are wound, is called a toroid.

S9. At the edges of the solenoid, the field lines get diverged due to other fields and/or non-availability of dipole loops, while in toroids the dipoles orient continuously.

S10. The magnetic field produced by a straight solenoid is similar to that produced by a bar magnet.

S11. Length of the solenoid, l = 80 cm = 0.8 m

There are five layers of windings of 400 turns each on the solenoid.

Total number of turns on the solenoid, $N = 5 \times 400 = 2000$

Diameter of the solenoid, D = 1.8 cm = 0.018 m

Current carried by the solenoid, I = 8.0 A

Magnitude of the magnetic field inside the solenoid near its centre is given by the relation,

$$B = \mu nI$$

Where, μ_0 = Permeability of free space $= 4\pi \times 10^{-7}\ \text{T m A}^{-1}$

$$B = \frac{4\pi \times 10^{-7} \times 2000 \times 8}{0.8}$$

$$= 8\pi \times 10^{-3} = 2.512 \times 10^{-2}\ \text{T}$$

Hence, the magnitude of the magnetic field inside the solenoid near its centre is 2.512×10^{-2} T.

S12. For moving coil meter M_1:

Resistance,	$R_1 = 10\ \Omega$
Number of turns,	$N_1 = 30$
Area of cross-section,	$A_1 = 3.6 \times 10^{-3}\ \text{m}^2$
Magnetic field strength,	$B_1 = 0.25\ \text{T}$
Spring constant	$K_1 = K$

For moving coil meter M_2:

Resistance,	$R_2 = 14\ \Omega$
Number of turns,	$N_2 = 42$
Area of cross-section,	$A_2 = 1.8 \times 10^{-3}\ \text{m}^2$
Magnetic field strength,	$B_2 = 0.50\ \text{T}$
Spring constant,	$K_2 = K$

(a) Current sensitivity of M_1 is given as:

$$I_{s1} = \frac{N_1 B_1 A_1}{K_1}$$

And, current sensitivity of M_2 is given as:

$$I_{s2} = \frac{N_2 B_2 A_2}{K_2}$$

$\therefore$ Ratio $\quad \frac{I_{s2}}{I_{s1}} = \frac{N_2 B_2 A_2 K_1}{K_2 N_1 B_1 A_1}$

$$= \frac{42 \times 0.5 \times 1.8 \times 10^{-3} \times K}{K \times 30 \times 0.25 \times 3.6 \times 10^{-3}} = 1.4$$

Hence, the ratio of current sensitivity of M_2 to M_1 is 1.4.

(b) Voltage sensitivity for M_2 is given as:

$$V_{s2} = \frac{N_2 B_2 A_2}{K_2 R_2}$$

And, voltage sensitivity for M_1 is given as:

$$V_{s1} = \frac{N_1 B_1 A_1}{K_1}$$

$\therefore$ Ratio $\quad \frac{V_{s2}}{V_{s1}} = \frac{N_2 B_2 A_2 K_1 R_1}{K_2 R_2 N_1 B_1 A_1}$

$$= \frac{42 \times 0.5 \times 1.8 \times 10^{-3} \times 10 \times K}{K \times 14 \times 30 \times 0.25 \times 3.6 \times 10^{-3}} = 1$$

Hence, the ratio of voltage sensitivity of M_2 to M_1 is 1.

S13. Length of the solenoid, $L = 60$ cm $= 0.6$ m

Radius of the solenoid, $r = 4.0$ cm $= 0.04$ m

It is given that there are 3 layers of windings of 300 turns each.

$\therefore$ Total number of turns, $n = 3 \times 300 = 900$

Length of the wire, $l = 2$ cm $= 0.02$ m

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

Current flowing through the wire, $I = 6$ A

Acceleration due to gravity, $g = 9.8$ m/s^2

Magnetic field produced inside the solenoid,

$$B = \frac{\mu_0 n I}{L}$$

Where, μ_0 = Permeability of free space

$= 4\pi \times 10^{-7}$ T m A^{-1}

I = Current flowing through the windings of the solenoid

Magnetic force is given by the relation,

$$F = BIl = \frac{\mu_0 n I}{L} Il$$

Also, the force on the wire is equal to the weight of the wire.

$$\therefore \qquad mg = \frac{\mu_0 n I l}{L}$$

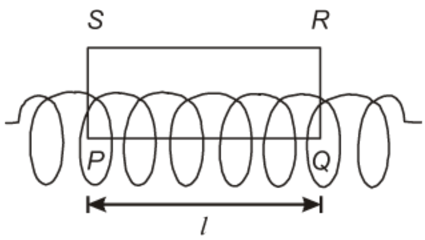
$$I = \frac{mgL}{\mu_0 n l I}$$

$$= \frac{2.5 \times 10^{-3} \times 9.8 \times 0.6}{4\pi \times 10^{-7} \times 900 \times 0.02 \times 6} = 108\text{ A}$$

Hence, the current flowing through the solenoid is 108 A.

S14. **Ampere's circuital law:** It state that the line integral of magnetic field around any closed loop is equal to μ_0 (in vacuum) times the total current threading the closed loop.

$$\oint \vec{B}.\vec{dl} = \mu_0 I$$



Consider 'l' length of a solenoid having n number of turns per unit of its length.

We imagine an amperian loop $PQRS$. Now

$$\oint \vec{B}.\vec{dl} = \int_P^Q \vec{B}.\vec{dl} + \int_Q^R \vec{B}.\vec{dl} + \int_R^S \vec{B}.\vec{dl} + \int_S^P \vec{B}.\vec{dl}$$

$$\int_P^Q \vec{B}.\vec{dl} = Bl$$

$$\int_Q^R \vec{B}.\vec{dl} = \int_S^P \vec{B}.\vec{dl} = 0 \qquad (\because\ \theta = 90°)$$

$$\int_R^S \vec{B}.\vec{dl} = 0 \qquad (\because\ \text{Outside the solenoid } B = 0)$$

Therefore, $$\oint \vec{B}.\vec{dl} = Bl \qquad \dots (i)$$

According to Ampere's circuital law.

$$\oint \vec{B}.\vec{dl} = \mu_0 I' = \mu n I l \qquad (\because\ I' = nlI) \qquad \dots (ii)$$

From Eqs. (i) and (ii), we get

$$Bl = \mu_0 n I l$$

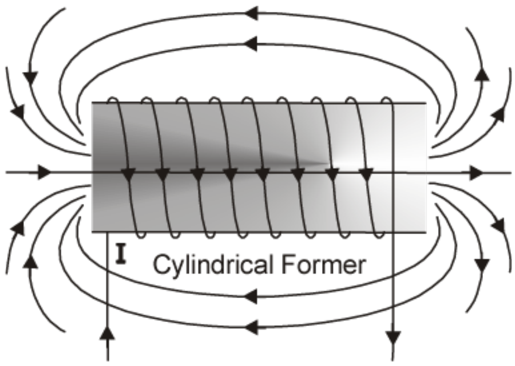
$$B = \mu_0 n I$$

$$B = \mu_0 \frac{N}{l} I \qquad \left(\therefore \quad n = \frac{N}{l}\right)$$

Where, N is total number of turns in the solenoid.

S15. When a current is passed through the spring, it will flow in the adjacent turns of the spring in the same direction. So there will be attraction between adjacent turns. The spring will contract and the weight will be lifted up.

S16. (a) For the pattern of magnetic field, shown as figure below:



(b) The magnetic field lines come closer to each other.

(c) The magnetic field as the centre of the solenoid.

$$B = \mu_0 \frac{N}{l} I$$

where N is the no of turns μ_0 is the magnetic permeability l is the length of solenoid, I is the current flowing in solenoid.

S17. Suppose a vertical plane through the centre of the solenoid and perpendicular to is length. The plane divides the solenoid into two equal parts. At a point outside the solenoid on this plane, corresponding turns of the two halves of the solenoid produce equal and opposite magnetic fields. Therefore, the magnetic field at such a point is **zero**.

S18.

$$F = Il \times B$$

$$F = IlB \sin \theta$$

The force per unit length is

$$f = F/l = IB \sin \theta$$

(a) When the current is flowing from east to west,

$$\theta = 90^\circ$$

Hence, $f = IB$

$$= 1 \times 3 \times 10^{-5} = 3 \times 10^{-5}\ \text{N m}^{-1}$$

This is larger than the value $2 \times 10^{-7}\,Nm^{-1}$ quoted in the definition of the ampere. Hence it is important to eliminate the effect of the Earth's magnetic field and other stray fields while standardising the ampere.

The direction of the force is downwards. This direction may be obtained by the directional property of cross product of vectors.

(b) When the current is flowing from South to North,

$$\theta = 0^o$$

$$f = 0$$

Hence there is no force on the conductor.

S19. Inner radius of the toroid, $r_1 = 25\text{ cm} = 0.25\text{ m}$

Outer radius of the toroid, $r_2 = 26\text{ cm} = 0.26\text{ m}$

Number of turns on the coil, $N = 3500$

Current in the coil, $I = 11\text{ A}$

(a) Magnetic field outside a toroid is zero.

(b) Magnetic field inside the core of a toroid is given by the relation,

$$B = \frac{\mu_0 NI}{l}$$

Where, μ_0 = Permeability of free space

$= 4\pi \times 10^{-7}\,\text{T m A}^{-1}$

l = length of toroid

$$= 2\pi\left[\frac{r_1 + r_2}{2}\right]$$

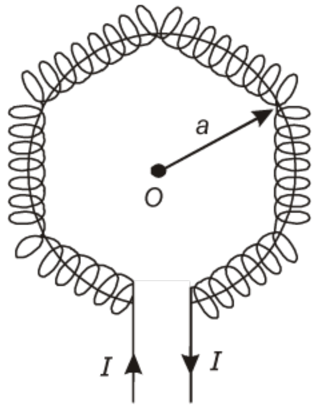
$$= \pi(0.25 + 0.26) = 0.51\pi$$

$$\therefore \qquad B = \frac{4\pi \times 10^{-7} \times 3500 \times 11}{0.51\pi}$$

$$\approx 3.0 \times 10^{-2}\,\text{T}$$

(c) Magnetic field in the empty space surrounded by the toroid is zero.

S20. Consider a toroidal solenoid having n turns per unit length. Let O be the centre and r be the radius of the circular ring. As shown in the figure.



Suppose current I is passed through the solenoid. The magnetic field produced will be same at all points on the circumference of the toroidal solenoid and at any point the field will act along tangent to the ring.

By Ampere's circuital law

$$\oint \vec{B}\cdot\vec{dl} = \mu_0 \text{ times the total current threaded by the ring of radius } r.$$

Since $\vec{B}$ and $\vec{dl}$ are along same direction

$$\therefore \qquad \oint \vec{B}\cdot\vec{dl} = \oint Bdl = B\oint dl = B(2\pi r)$$

Total current threaded by the ring of radius r

$= I \times$ no. of times current threads the ring

$= I \times$ total number of turns in the solenoid

$= I(2\pi rn)$ ... (ii)

Form Eqs. (i) and (ii), we get

$$B \,.\, 2\pi r = \mu_0 I \,.\, 2\pi rn$$

or $\qquad B = \mu_0 nI$

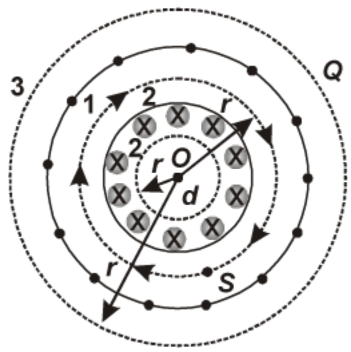
Hence the magnetic field due to toroidal solenoid depends upon the number of turns per unit length and not on the radius of the ring, over which the solenoid is wound.

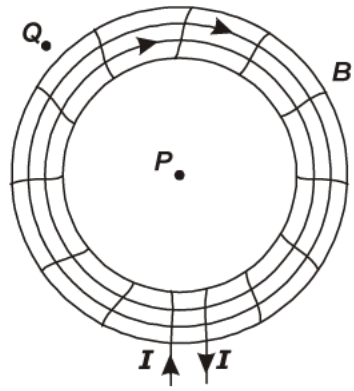
S21. *Toroid is an endless solenoid to calculate the magnetic field in the interior of toroid. Ampere's circuital law can be obtained.*

Toroid is a hollow circular ring on which a large number of insulated turns of a metallic wire are closely wound. The direction of the magnetic field at point P is given by tangent to the magnetic field line at that point.

Let B is the magnetic field in the open space interior to the toroid.

Considering a loop coplanar with toroid of radius x such that $x < R$ (radius of toroid) as shown in the figure.





Applying Ampere's circuital law over loop, we have

$$\oint \mathbf{B} . dl = \mu_0 \times \text{Current passes through the loop}$$

But no current passes through the loop.

$\therefore$ $$\oint \mathbf{B} . dl = \mu_0 \times 0 = 0$$

$\Rightarrow$ $$B = 0$$

This is the magnetic field exist in the interior of toroid.

S22. *When a straight wire is bent in the form of a circular coil of N turns, then the length of the wire is equal to circumference of the coil multiplied by the number of turns.*

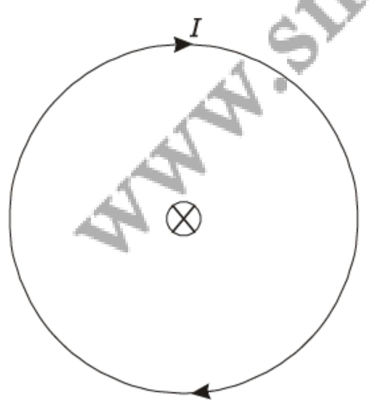
Let the radius of coil be r.

As the wire is bent round in the form of a coil having N turns.

$\therefore$ $N \times$ Circumference of the coil = Length of the wire

$\therefore$ $$(2\pi r) \times N = L$$

$$r = \frac{L}{2\pi N} \quad \text{... (i)}$$



Magnetic field at the centre due to n turn of a coil is given by

$$B = \frac{\mu_0 (NI)}{2r}$$

$$B = \frac{\mu_0 (NI)}{2\left(\frac{L}{2\pi N}\right)} \qquad \text{[From Eq. (i)]}$$

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

The direction of magnetic field is perpendicular to the plane of loop and entarining into it.

S23. A solenoid is a tightly wound helical loop from an insulated wire, such that its length is very large as compared to its diameter.

We have to calculate the axial magnetic field inside the solenoid. In a solenoid, the magnetic field is along its axis, so it is called axial magnetic field. So, to find the axial magnetic field inside the solenoid, its regular formula will be used.

Given: $L = 1$ m; $r = 1$ cm = 0.01 m; $N = 1000$; $I = 5$ A

$\therefore$ Magnetic field P inside the solenoid

$$B = \mu_0 nI = \mu_0 \left(\frac{N}{L}\right) I = \mu_0 \left(\frac{1000}{1}\right) \times 5$$

$$= 4\pi \times 10^{-7} \times 1000 \times 5$$

$$B = 2\pi \times 10^{-3} \text{ T.}$$

The direction of B is along the axis of solenoid.

Now, $q = -e$

$v = 10^4$ m/s

and the angle between B and v is 0° ($\because$ electron moves along the direction of the magnetic field)

$\therefore$ Magnetic Lorentz force

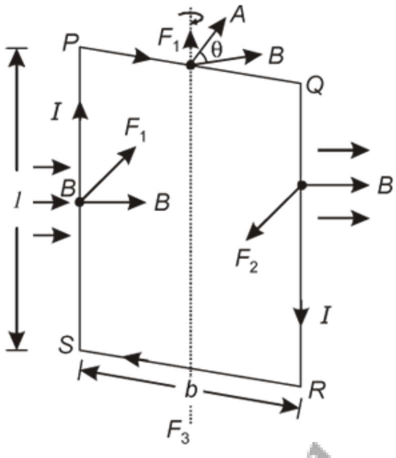
$$F_B = qvB \sin 0°$$

$$= qvB \times 0 = 0$$

$$F_B = 0$$

$\Rightarrow$ No magnetic force experienced by the electron.

S24. Let a current carrying rectangular loop $PQRS$ carrying a steady current I placed in uniform magnetic field B keeping axis of the coil perpendicular to field as shown in figure. Let at any instant the area vector **A** makes an angle θ with the direction of magnetic field B.



(a)

Let, length and breadth of coil are l and b respectively.

Now, magnetic force on PS arm of the coil is given by

$$F_1 = IBl \sin 90°$$

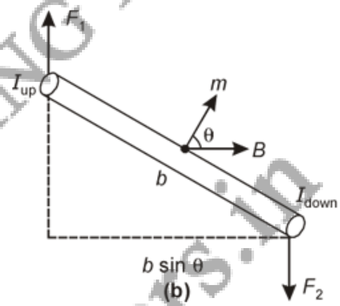
$$(\because\ PS \parallel \text{axis of coil}, \quad \therefore\ \theta = 90°)$$

$$F_1 = IBl \qquad \text{... (i)}$$

By Fleming's left hand rule, the direction of force is perpendicular to SP and B is along upward direction. Similarly, force of QR arm of the coil.

$$F_2 = IBl \sin 90° \qquad \text{... (ii)}$$

$\because$ F_1 and F_2 are equal in magnitude, opposite in direction, parallel to each other acting on the loop forms a couple which try to rotate the coil.



(b)

Now, force on RS part of the coil

$$F_3 = IBb \sin (90° + \theta)$$

$$= IBb \cos \theta$$

and force on PQ part of the coil

$$F_4 = IBb \sin (90 - \theta)$$

$$= IBb \cos \theta$$

But Fleming's left hand rule F_3 and F_4 are equal in magnitude and opposite in direction along the same line of action. Therefore, they balance each other. (Cancel out)

Now, torque due to F_1 and F_2 is even by

τ = Force perpendicular distance between line of action of F_1 and F_2

$$\tau = F \times b \sin \theta$$

But $\qquad F_1 = F_2 = F = IBl$

$$\tau = (IBl) \times (b \sin \theta)$$

$$\tau = IB\,(lb) \sin \theta$$

$$\tau = IBA \sin \theta$$

where, $\qquad A = lb$ = area of coil for N turns of coil

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

S25. Given: $N = 200$; $r = 10$ cm = 0.1; $B = 0.5$ T

Note: Magnetic field is normal to the plane of coil. Therefore, area vector of coil (which is normal to plane of coil) is along the direction of magnetic field.

$\therefore$ $\theta = 0$. Also $I = 3$A

(a) As, $\tau = NIAB = 200 \times 3 \times [\pi (0.1)^2] \times 0.5$ $(\because A = \pi r^2)$

$\Rightarrow$ $\tau = \mathbf{9.42\ N\text{-}m}$

(b) The net magnetic force on circular loop is **zero**.

(c) $\because$ Average force on electron

$$F = (-e)(v_d) B \sin 90°$$

But $I = -neAv_d$

or $$v_d = \frac{I}{-neA}$$

$\therefore$ $$F = (-e)\left(\frac{I}{neA}\right)B$$

$$F = \frac{IB}{nA} = \frac{3 \times 0.5}{10^{29} \times 10^{-5}}$$

$$F = \frac{1.5}{10^{24}}$$

$\Rightarrow$ $F = \mathbf{1.5 \times 10^{-24}\ N}$.

S26. A toroid consists of an anchor ring with some average radius (R) can which there number of turn (N) of insulator metallic wine is wound.

(a) When an amount of steady current passed through the toroid, the magnetic field at each and every point on its central axis is same and directed along the tangent on the ring.

Thus,

$$\oint \mathbf{B}.d\mathbf{l} = \oint B dl = \mathbf{B} \oint dl = \mathbf{B} 2\pi R$$

Now, from Ampere's Circuital law,

$$\mathbf{B} \oint \mathbf{d}\mathbf{l} = \mu_0 NI$$

$\Rightarrow \qquad B \times 2\pi R = \mu_0 NI$

$\Rightarrow \qquad B = \frac{\mu_0 NI}{2\pi R} = \mu_0 nI$

where, n = number of turn per unit length of solenoid *i.e.*, $\frac{N}{2\pi R}$

(b) At the condition, when we apply Amperes law to find magnetic field in the open space inside or outside the toroid, then for any closed loop having radius r

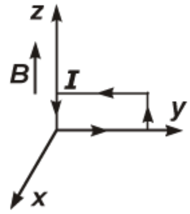
$$\mathbf{B} \oint \mathbf{d}\boldsymbol{l} = B(2\pi r) = \mu_0 I = \mu_0 (0) = 0$$

$\because$ current enclosed by loop is zero.

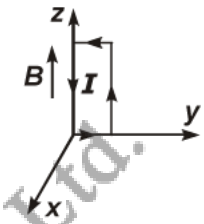
Hence, magnetic field B is zero.

Date: 20/10/2021

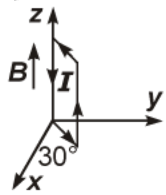
Q1. A uniform magnetic field of 3000 G is established along the positive *z*-direction. A rectangular loop of sides 10 cm and 5 cm carries a current of 12 A. What is the torque on the loop in the different cases shown in figure? What is the force on each case? Which case corresponds to stable equilibrium?



Q2. A uniform magnetic field of 3000 G is established along the positive *z*-direction. A rectangular loop of sides 10 cm and 5 cm carries a current of 12 A. What is the torque on the loop in the different cases shown in figure? What is the force on each case? Which case corresponds to stable equilibrium?



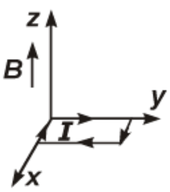
Q3. A uniform magnetic field of 3000 G is established along the positive *z*-direction. A rectangular loop of sides 10 cm and 5 cm carries a current of 12 A. What is the torque on the loop in the different cases shown in figure? What is the force on each case? Which case corresponds to stable equilibrium?



Q4. What is the torque on a planar current loop in magnetic field change, when its shape is changed without changing its geometrical area?

Q5. Two wires of equal lengths are bent in the form of two loops. One of the loops is square shaped whereas the other loop is circular. These are suspended in a uniform magnetic field and the same current is passed through them. Which loop will experience greater torque? Give reasons.

Q6. A uniform magnetic field of 3000 G is established along the positive *z*-direction. A rectangular loop of sides 10 cm and 5 cm carries a current of 12 A. What is the torque on the loop in the different cases shown in figure? What is the force on each case? Which case corresponds to stable equilibrium?



Q7. A current carrying loop is free to turn in a uniform magnetic field *B*. Under what conditions, will the torque acting on it be (a) minimum and (b) maximum?

Q8. Show that a force that does no work must be a velocity dependent force.

Q9. Calculate the torque on a closed current loop placed in the magnetic field $\vec{B}$. What is the main function of soft iron core used in a moving coil galvanometer?

Q10. How does the magnetic moment of an electron in a circular orbit of radius '*r*' and moving with a speed '*v*' change, when the frequency of revolution is doubled?

Q11. A Current carrying loop free to turn is placed in a uniform magnetic field *B*. What will be its orientation relative to *B* in the equilibrium state?

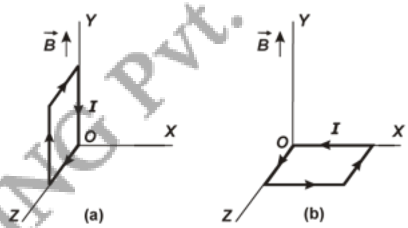
Q12. (a) A circular coil of 30 turns and radius 8.0 cm carrying a current of 6.0 A is suspended vertically in a uniform horizontal magnetic field of magnitude 1.0 T. The field lines make an angle of 60° with the normal of the coil. Calculate the magnitude of the counter torque that must be applied to prevent the coil from turning.

(b) Would your answer change, if the circular coil in (i) were replaced by a planar coil of some irregular shape that encloses the same area? (All other particulars are also unaltered.)

Q13. A magnetic field set up using Helmholtz coils (described in Exercise 4.16) is uniform in a small region and has a magnitude of 0.75 T. In the same region, a uniform electrostatic field is maintained in a direction normal to the common axis of the coils. A narrow beam of (single species) charged particles all accelerated through 15 kV enters this region in a direction perpendicular to both the axis of the coils and the electrostatic field. If the beam remains undeflected when the electrostatic field is $9.0 \times 10^{-5}\,V\,m^{-1}$, make a simple guess as to what the beam contains. Why is the answer not unique?

Q14. A circular coil of 'N' turns and diameter 'd' carries a current 'I'. It is unwound and wound to make another coil of diameter '$2d$', current 'I' remaining the same. Calculate the ratio of the magnetic moments of the new coil and the original coil.

Q15. A uniform magnetic field of 3,000 G is established along the positive Z-direction. A rectangular loop of sides 10 cm and 5 cm carries a current of 12 A. What is the torque on the loop in the two cases shown in the figure below.



Q16. A circular coil of 100 turns, radius 10 cm carries a current of 5 A. It is suspended vertically in a uniform horizontal magnetic field of 0.5 T, the field lines making an angle of 60° with the plane of the coil. Calculate the magnitude of the torque that must be applied on it to prevent if from rotating.

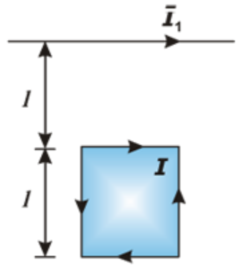
Q17. A circular coil of 100 turns, radius 15 cm carries a current of 2.5 A. It is suspended vertically in a uniform horizontal magnetic field of 0.5 T, the field lines making an angle of 30° with the plane of the coil. Calculate the magnitude of the torque that must be applied on it to prevent it from turning.

Q18. A small coil carrying a current is placed in a uniform magnetic field. How does the coil tend to orient itself relative to the magnetic field?

Q19. A square coil of side 10 cm consists of 20 turns and carries a current of 12 A. The coil is suspended vertically and the normal to the plane of the coil makes an angle of 30° with the direction of a uniform horizontal magnetic field of magnitude 0.80 T. What is the magnitude of torque experienced by the coil?

Q20. A 100 turn closely wound circular coil of radius 10 cm carries a current of 3.2 A. (a) What is the field at the centre of the coil? (b) What is the magnetic moment of this coil? The coil is placed in a vertical plane and is free to rotate about a horizontal axis which coincides with its diameter. A uniform magnetic field of 2T in the horizontal direction exists such that initially the axis of the coil is in the direction of the field. The coil rotates through an angle of 90° under the influence of the magnetic field. (c) What are the magnitudes of the torques on the coil in the initial and final position? (d) What is the angular speed acquired by the coil when it has rotated by 90°? The moment of inertia of the coil is 0.1 kg m^2.

Q21. Write the expression for the magnetic moment (m) due to a planar square loop of side 'l' carrying a steady current I in a vector form. In the given figure this loop is placed in a horizontal plane near a long straight conductor carrying a steady current I_1 at a distance l as shown. Give reasons to explain that the loop will experience a net force but no torque. Write the expression for this force acting on the loop.



Q22. (a) Show that a planer loop carrying a current I, having N closely wound turns and area of cross-section A, possesses a magnetic moment m = NIA.

(b) When this loop is placed in a magnetic field B, find out the expression for the torque acting on it.

(c) A galvanometer coil of 50 Ω resistance shows full scale deflection for a current of 5 mA. How will you convert this galvanometer into a voltmeter of range 0 to 15 V?

Q23. (a) Write the expression for the force, F, acting on a charged particle of charge q, moving with a velocity v in the presence of both electric field E and magnetic field, B. Obtain the condition under which the particle moves undeflected through the fields.

(b) A rectangular loop of size $l \times b$ carrying a steady current I is placed in a uniform magnetic field B. Prove that the torque τ acting on the loop is given by $\tau = m \times B$ where, m is the magnetic moment of the loop.

Date: 20/10/2021

S1. Torque $\tau = I\vec{A} \times \vec{B}$

From the given figure, it can be observed that *A* is normal to the *x*-*z* plane and *B* is directed along the *z*-axis.

$$\therefore \quad \tau = -12 \times (50 \times 10^{-4})\,\hat{j} \times 0.3\,\hat{k}$$

$$= -1.8 \times 10^{-2}\,\hat{i}\ \text{N m}$$

The torque is 1.8×10^{-2} N m along the negative *x* direction and the force is zero.

S2. Magnetic field strength, $B = 3000\ \text{G} = 3000 \times 10^{-4}\ \text{T} = 0.3\ \text{T}$

Length of the rectangular loop, $l = 10$ cm

Width of the rectangular loop, $b = 5$ cm

Area of the loop,

$$A = l \times b = 10 \times 5 = 50\ \text{cm}^2 = 50 \times 10^{-4}\ \text{m}^2$$

Current in the loop, $I = 12$ A

Now, taking the anti-clockwise direction of the current as positive and vise-versa:

Torque, $\vec{\tau} = I\vec{A} \times \vec{B}$

From the given figure, it can be observed that *A* is normal to the *y*-*z* plane and *B* is directed along the *z*-axis.

The torque is 1.8×10^{-2} N m along the negative *y*-direction. The force on the loop is zero because the angle between *A* and *B* is zero.

This case is similar to case (a). Hence, the answer is the same as (a).

S3. Torque $\tau = I\vec{A} \times \vec{B}$

$$= (50 \times 10^{-4} \times 12)\,\hat{k} \times 0.3\,\hat{k}$$

$$= 0$$

Hence, the torque is zero. The force is also zero.

S4. The torque on a planar current loop in a magnetic field does not change, when its shape is changed without changing the area of the loop.

S5. We know,

$$\vec{\tau} = I(\vec{A} \times \vec{B})$$

Both have same length but different area of circle is greater than the area of square *i.e.*, torque of circle is more than the square.

S6. Whereas, in case (*f*), the direction of $I\vec{A}$ and $\vec{B}$ is opposite. The angle between them is 180°. If disturbed, it does not come back to its original position. Hence, its equilibrium is unstable.

S7. (a) Torque is minimum when angle between area vector of the loop and magnetic field vector is zero *i.e.*, both are parallel because we know that

$$\vec{\tau} = IAB \sin \phi$$

(b) Torque is maximum when the angle between area vector and magnetic field will be 90° *i.e.*, $\vec{A} \perp \vec{B}$.

S8.

$$dW = F \,.\, d = 0$$

$$\Rightarrow \quad F \,.\, vdt = 0$$

$$\Rightarrow \quad F \,.\, v = 0$$

F must be velocity dependent which implies that angle between *F* and *v* is 90. If *v* changes (direction) then directions) *F* should also change so that above condition is satisfied.

S9. When a closed current loop is suspended in magnetic field, torque on the coil is given by

$$|\vec{\tau}| = |\vec{M} \times \vec{B}| = nIAB \sin \theta$$

where the letters have their usual meanings.

The use of the soft iron core strengthens the magnetic flux linked with the coil.

S10. Magnetic moment also doubled, when frequency revolution is doubled

Explanation:

We know, $M = IA$

$= (qf)(A)$

where *A* and *q* are constant for electron

$m \propto f$

Hence magnetic moment also doubled, when frequency revolution is doubled.

S11. In equilibrium state, the current carrying loop will orient itself, such that $\vec{B}$ is perpendicular to the plane of the coil. It is because of the fact that in this orientation, the torque on the current loop becomes zero.

S12. Number of turns on the circular coil, $n = 30$

Radius of the coil, $r = 8.0$ cm = 0.08 m

Area of the coil = $\pi r^2 = \pi(0.08)^2 = 0.0201 \text{ m}^2$

Current flowing in the coil, $I = 6.0$ A

Magnetic field strength, $B = 1$ T

Angle between the field lines and normal with the coil surface,

$$\theta = 60°$$

(a) The coil experiences a torque in the magnetic field. Hence, it turns. The counter torque applied to prevent the coil from turning is given by the relation,

$$\tau = n\, IBA \sin\theta \quad \text{... (i)}$$

$$= 30 \times 6 \times 1 \times 0.0201 \times \sin 60°$$

$$= 3.133 \text{ N m}$$

(b) It can be inferred from relation (i) that the magnitude of the applied torque is not dependent on the shape of the coil. It depends on the area of the coil. Hence, the answer would not change if the circular coil in the above case is replaced by a planar coil of some irregular shape that encloses the same area.

S13. Magnetic field, $B = 0.75$ T

Accelerating voltage, $V = 15 \text{ kV} = 15 \times 10^3$ V

Electrostatic field, $E = 9 \times 10^5 \text{ V m}^{-1}$

Mass of the electron $= m$

Charge of the electron $= e$

Velocity of the electron $= v$

Kinetic energy of the electron $= eV$

$$\Rightarrow \quad \frac{1}{2}mv^2 = eV$$

$$\therefore \quad \frac{e}{m} = \frac{v^2}{2V} \quad \text{... (i)}$$

Since the particle remains undeflected by electric and magnetic fields, we can infer that the electric field is balancing the magnetic field.

$$\therefore \quad eE = evB$$

$$v = \frac{E}{B} \quad \text{... (ii)}$$

Putting Eqn. (ii) in Eqn. (i), we get

$$\frac{e}{m} = \frac{1}{2}\frac{\left(\frac{E}{B}\right)^2}{V} = \frac{E^2}{2VB^2}$$

$$= \frac{(9.0 \times 10^5)^2}{2 \times 15000 \times (0.75)^2} = 4.8 \times 10^7 \text{ C/kg}$$

This value of specific charge e/m is equal to the value of deuteron or deuterium ions. This is not a unique answer. Other possible answers are He^{++}, Li^{++}, etc.

S14. Given: Circular coil has N turns diameter, of the coil is d and current is I

Now, Magnetic moment $M = NIA$

Let Magnetic moment $M_o = NI\pi \frac{d^2}{4}$ ... (i)

Let Magnetic moment of new coil M_n

Given: $N = N/2;\ d = 2d\ \&\ I = I$

$$M_n = \frac{N}{2} I\pi d^2 \quad \text{... (ii)}$$

Form Eq. (ii) ÷ (i), we get

$$= \frac{\frac{1}{4}(NI\pi d^2)}{\frac{1}{2}(NI\pi d^2)}$$

or $$\frac{M_n}{M_o} = \frac{2}{1}.$$

S15. Given: $B = 3{,}000$; $G = 3{,}000 \times 10^{-4} = 0.3\,T$; $A = 10 \times 5 = 50\,\text{cm}^2 = 50 \times 10^{-4}\,\text{m}^2$; $I = 12\,\text{A}$

$\therefore \quad IA = 50 \times 10^{-4} \times 12 = 0.06\,\text{A m}^2$

(a) Given: $I\vec{A} = -0.06\,\hat{j}\ \text{Am}^2$ and $\vec{B} = 0.3\,\hat{k}\,T$

We know, $\vec{\tau} = (I\vec{A}) \times \vec{B} = -0.06\,\hat{j} \times 0.3\,\hat{k} = -1.8 \times 10^{-2}\,\hat{i}\ \text{Nm}$

1.8×10^{-2} Nm acts along the negative Z-axis.

(b) Given: $I\vec{A} = 0.06\,\hat{k}\ \text{Am}^2$ and $\vec{B} = 0.3\,\hat{k}T$

We know, $\vec{\tau} = (I\vec{A}) \times \vec{B} = 0.06\,\hat{k} \times 0.3\,\hat{k} = 0$ or $\tau = 0(\hat{k} \times \hat{k} = 0)$.

S16. Given:

$N = 100 \quad r = 10\,\text{cm} = 0.1\,\text{m} \quad I = 5\,\text{A}$

$B = 0.5\,\text{T} \quad \theta = 60°$

Now, torque acting on the current carrying coil due to magnetic field.

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

$$= 100 \times 5 \times 0.01\pi \times 0.5 \times \sin 60°$$

$$\tau = \mathbf{6.80\ Nm}.$$

S17. Given: $N = 100, \quad r = 15 \text{ cm} = 0.15\text{m}$

$I = 2.5\text{ A}, \quad B = 0.5\text{ T}$

$\theta = 30°, \quad i.e., \ \varphi = 60°; \quad \tau = ?$

$\tau = NIBA \sin\varphi$

$\tau = 100 \times 2.5 \times 0.5 \times \pi \times (0.15)^2 \times \sin 60°$

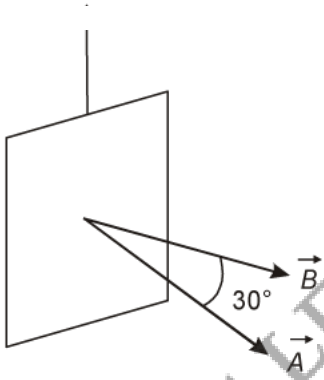
$\tau = 7.6520 \text{ Nm}.$

S18. A torque acting on a coil a given by

$$\tau = NIBA \cos\theta$$

where θ is the angle between the plane of the coil and direction of magnetic field. When $\theta = 90°$, $\tau = 0$. The coil tries to orient itself in this position. Thus, in equilibrium the coil will acquire a position such that its plane makes an angle of 90° with the direction of the magnetic field.

S19. Given: $a = 10 \text{ cm} = 0.1$; $N = 20$, $I = 12$ A; $B = 0.80$ T, $\theta = 30°$, $A = 0.01 \text{ m}^2$; $\tau = ?$



$\tau = NBAI \sin\theta$

$= 20 \times 0.80 \times 0.01 \times 12 \times \sin 30°$

$\tau = 0.96 \text{ Nm}.$

S20. (a) From Eq. (4.16)

$$B = \frac{\mu_0 NI}{2R}$$

Here, $N = 100$; $I = 3.2$ A, and $R = 0.1$ m. Hence,

$$B = \frac{4\pi \times 10^{-7} \times 10^2 \times 3.2}{2 \times 10^{-1}}$$

$$= \frac{4 \times 10^{-5} \times 10}{2 \times 10^{-1}} \qquad \text{(using } \pi \times 3.2 = 10\text{)}$$

$$= 2 \times 10^{-3} \text{ T}$$

The direction is given by the right-hand thumb rule.

(b) The magnetic moment is given by Eq. (4.30),

$$m = NIA = NI\pi r^2 = 100 \times 3.2 \times 3.14 \times 10^{-2} = 10 \text{ A m}^2$$

The direction is once again given by the right hand thumb rule.

(c) $$\tau = m \times B \qquad \text{[from Eq. (4.29)]}$$
$$= mB \sin \theta$$

Initially, $\theta = 0$. Thus, initial torque $\tau_i = 0$. Finally, $\theta = \pi/2$ (or 90º). Thus, final torque $\tau_f = mB = 10 \times 2 = 20$ N m.

(d) From Newton's second law,

$$\mathcal{I} \frac{d\omega}{dt} = mB \sin \theta$$

where $\mathcal{I}$ is the moment of inertia of the coil. From chain rule,

$$\frac{d\omega}{dt} = \frac{d\omega}{d\theta}\frac{d\theta}{dt} = \frac{d\omega}{d\theta}\omega$$

Using this, $\mathcal{I}\omega d\omega = mB \sin \theta d\theta$

Integrating from $\theta = 0$ to $\theta = \pi/2$,

$$\mathcal{I}\int_0^{\omega_f} \omega\, d\omega = mB \int_0^{\pi/2} \sin\theta\, d\theta$$

$$\mathcal{I}\frac{\omega_f^2}{2} = -mB \cos\theta \Big|_0^{\pi/2} = mB$$

$$\omega_f = \left(\frac{2mB}{\mathcal{I}}\right)^{1/2} = \left(\frac{2 \times 10}{10^{-1}}\right)^{1/2} = 20 \text{ s}^{-1}.$$

S21. (a) Expression for the magnetic moment ($\vec{m}$)

$$\vec{m} = I\vec{A} \qquad (\because\ n = 1)$$

where, I is the current through a square loop of side 'l' and $\vec{A}$ is area vector for the loop.

(b) Current in the loop is clockwise.

Torque: $\vec{\tau} = \vec{m} \times \vec{B}$

Magnetic moment vector and magnetic field due to straight wire both are perpendicular to the plane of paper and directed inwards, *i.e.*, both are same direction $\theta = 0°$.

$$\tau = mB \sin(\theta)$$

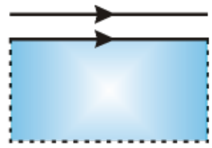
So, $$\vec{\tau} = \vec{0} \qquad (\because\ \theta = 0°)$$

Force: Force on upper horizontal side $F_1 = \frac{\mu_0 I I_1}{4\pi}$ (It's attractive)

Force on upper horizontal side $F_2 = \frac{\mu_0 I I_1}{4\pi}$ (It's repulsive)

As $\vec{F}_1 = -\vec{F}_2$

Net force is $F = F_1 - F_2$



$$F = \frac{\mu_0 I I_1}{4\pi}$$ (It's attractive)

Net force on the sides oriented normally to the current carrying wire is zero.

S22. (a) Torque on rectangular loop

$$\tau = NIAB \sin\theta \quad \text{... (i)}$$

where, symbols are as usual.

Also, torque experienced by magnetic dipole of moment m are placed in uniform magnetic field.

$$\tau = mB \sin\theta \quad \text{... (ii)}$$

Comparing Eqs. (i) and (ii), we get

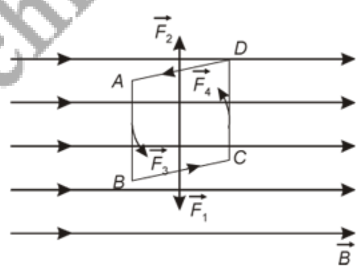
The magnetic dipole moment

$$m = NIA$$

Also, **m** is a along **A**

$$\mathbf{m} = NI\mathbf{A}$$

(b) Let us consider a rectangular loop $ABCD$, placed in a uniform magnetic field, having length l and breadth b. The axis of coil is perpendicular to the direction of magnetic field as shown in the figure.



Let θ be the angle between the plane of the coil and the direction of the magnetic field and I be the current through the coil.

Force on BC, $\vec{F}_1 = I(\vec{BC} \times \vec{B}) = BIb \sin\theta$

Force on AD, $\vec{F}_2 = I(\vec{AD} \times \vec{B}) = BIb \sin\theta$.

So, F_1 and F_2 are equal in magnitude but opposite in direction, hence they cancel out each other.

Force on AB, $\vec{F}_3 = I(\vec{AB} \times \vec{B}) = BIl \sin 90° = BIl$

Similarly, $F_4 = BIl$

Force $\vec{F}_3$ and $\vec{F}_4$ are equal in magnitude but opposite in direction with different line of action, so they constitute couple. Thus torque acting on the coil is given by

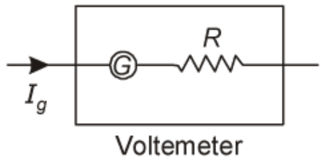
$$\tau = \text{Either force} \times \perp \text{distance between the line of action of force}$$

$$\tau = BIA \cos\theta$$

If the coil consists of N turns, then

$$\tau = NBIA\cos\theta$$

(c) $G = 50\,\Omega$, $I_g = 5\times10^{-3}$ A, $V = 15$ V



$\because$ $$V = I_g(G+R)$$

$\Rightarrow$ $$R = \frac{V}{I_g} - G = \frac{15}{5\times10^{-3}} - 50$$

$$R = 2950\,\Omega$$

A resistance $R = 2950\,\Omega$ is to be connected in series with galvanometer to convert it into a desired voltmeter.

S23. (a) Force on the charged particle due to electric and magnetic field,

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

For undeflected motion,

$$\mathbf{F} = 0$$

$$q\mathbf{E} + q(\mathbf{v}\times\mathbf{B}) = 0$$

$\Rightarrow$ $$\mathbf{E} + (\mathbf{v}\times\mathbf{B}) = 0$$

$$\mathbf{E} = -(\mathbf{v}\times\mathbf{B})$$

$\Rightarrow$ $$|\mathbf{E}| = |-\mathbf{v}\times\mathbf{B}|$$

$$\mathbf{E} = vB\sin\theta, \qquad \text{where } \theta = 90^\circ$$

$$v = E/B$$

(b) Magnetic force on AB and CD parts of wire

$$F_1 = F_2 = IBl \quad \text{as} \quad \theta = 90^\circ$$

The magnetic force on BC and DA part of wire are equal in magnitude, opposite in direction along the same line. Therefore, they balance each other.

Let at any instant area vector of coil made an angle θ with the direction of magnetic field.

$\therefore$ F_1 and F_2 forms couple which try to rotate the coil.

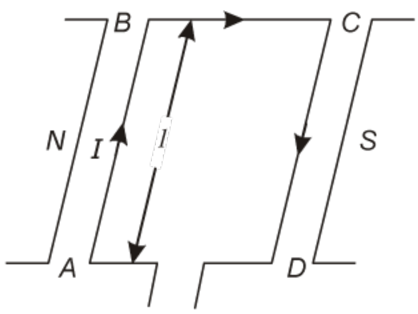
From figure,

$\therefore$ Torque (τ) = Force arm of the couple

$= (IBl)\times MD$

$= IBl\times b\sin\theta = IB(lb)\sin\theta$

$= IBA\sin\theta$



where, $A = lb$ = area of coil

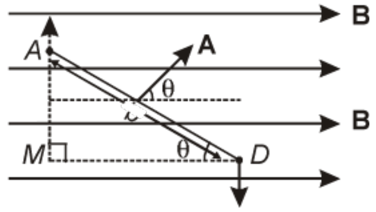
$\therefore$ $$\tau = IAB\sin\theta$$

But $m = IA$

$\therefore$ $\tau = mB \sin \theta$

In vector form

$$\tau = \mathbf{m} \times \mathbf{B}.$$



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Q1. What are the primary functions of electric field and the magnetic field in a cyclotron?

Q2. Write two factors by which voltage sensitivity of a galvanometer can be increased.

Q3. Does time spent by a proton inside the dee of the cyclotron depend upon (a) the radius of the circular path (b) the velocity of the proton?

Q4. What is the principle of a d.c. motor?

Q5. State the principle of cyclotron.

Q6. In a field, the force experienced by a charge depends upon its velocity and becomes zero, when it is at rest. What is the nature of the field?

Q7. An ammeter and a milliammeter are converted from the same galvanometer. Out of the two, which current measuring instrument has higher resistance?

Q8. State two properties of the material of the wire used for suspension of the coil in a moving coil galvanometer.

Q9. In a field, the force experienced by a charge depends only upon the magnitude of the field and does not depend upon the velocity. Is field electric or magnetic in nature?

Q10. What is the nature of magnetic field in a moving coil galvanometer?

Q11. What is the advantage of using radial magnetic field in a moving coil galvanometer?

Q12. State the principle of moving coil galvanometer.

Q13. Why the frequency of a charge circulating inside the Dees of a cyclotron does not depend upon the speed of the charge?

Q14. Give two differences between a voltmeter and an ammeter.

Q15. Can neutrons be accelerated in a cyclotron? Explain.

Q16. Define current sensitivity of a galvanometer.

Q17. How the sensitivity of a moving coil galvanometer can be increased?

Q18. How does (a) an ammeter (b) a voltmeter differ from a galvanometer?

Q19. Why should the spring/suspension wire in a moving coil galvanometer have a low torsional constant?

Q20. What is the resistance of an ideal voltmeter and an ammeter?

Q21. Write two properties of a material used as a suspension wire in a moving coil galvanometer.

Q22. Define current sensitivity of a moving coil galvanometer and state its SI unit.

Q23. Give two factors by which the current sensitivity of a moving coil galvanometer can be increased.

Q24. Why should an ammeter have a low resistance?

Q25. Define voltage sensitivity of a galvanometer.

Q26. What is shunt? State its SI units.

Q27. Is the resistance of a voltmeter greater than or less than that of the galvanometer of which it is formed?

Q28. A magnetic field of 100 G (1 G = 10^{-4} T) is required which is uniform in a region of linear dimension about 10 cm and area of cross-section about 10^{-3} m^2. The maximum current-carrying capacity of a given coil of wire is 15 A and the number of turns per unit length that can be wound round a core is at most 1000 turns m^{-1}. Suggest some appropriate design particulars of a solenoid for the required purpose. Assume the core is not ferromagnetic.

Q29. A galvanometer coil has a resistance of 15 Ω and the metre shows full scale deflection for a current of 4 mA. How will you convert the metre into an ammeter of range 0 to 6 A?

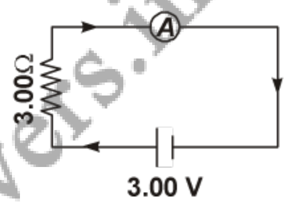
Q30. A galvanometer coil has a resistance of 12 Ω and the metre shows full scale deflection for a current of 3 mA. How will you convert the metre into a voltmeter of range 0 to 18 V?

Q31. Which one of the two, an ammeter or a milliammeter has a higher resistance and why?

Q32. What is the importance of radial magnetic field in a moving coil galvanometer?

Q33. You are given a low resistance R_1, a high resistance R_2 and a moving coil galvanometer. Suggest how you would use these to have an instrument that will be able to measure (a) currents, (b) potential differences.

Q34. In the circuit (see figure) the current is to be measured. What is the value of the current if the ammeter shown (a) is a galvanometer with a resistance R_G = 60.00 Ω; (b) is a galvanometer described in (a) but converted to an ammeter by a shunt resistance r_s = 0.02 Ω; (c) is an ideal ammeter with zero resistance?



Q35. How can a moving coil galvanometer be converted into a voltmeter?

Q36. A moving coil galvanometer of resistance G, gives full scale deflection, when a current I_g flows through its coil. It can be converted into an ammeter of range 0 to I ($I > I_g$), when a shunt of resistance S is connected across its coil. If this galvanometer is converted into an ammeter of range 0 to $2I$, find the expression for the shunt in terms of S and G.

Q37. In a galvanometer, there is a deflection of 10 divisions per a shunt of 2.5 Ω is connected to the galvanometer and there are 50 divisions in all on he scale of the galvanometer, calculate the maximum current which the galvanometer can read.

Q38. What is voltage sensitivity? How the voltage sensitivity of a galvanometer can be increased?

Q39. How do you convert a galvanometer into an ammeter? Why is an ammeter always connected in series?

Q40. Draw a circuit, showing how an ammeter and a voltmeter can be connected to a resistor to measure then current and voltage at a given instant.

Q41. Out of an ammeter and a voltmeter, which of the two has higher resistance and why?

Q42. A circular coil of 20 turns and radius 10 cm is placed in a uniform magnetic field of 0.10 T normal to the plane of the coil. If the current in the coil is 5.0 A, what is

(a) total torque on the coil,

(b) total force on the coil,

(c) average force on each electron in the coil due to the magnetic field?

(The coil is made of copper wire of cross-sectional area 10^{-5} m^2, and the free electron density in copper is given to be about 10^{29} m^{-3}.)

Q43. With due help of a labelled diagram, state the underlying principle of a cyclotron. Explain clearly how it works to accelerate the charged particles?

Show that cyclotron frequency is independent of energy of the particle. Is there an upper limit on the energy accquired by the particle? Given reason.

Q44. A galvanometer with a coil of resistance 120 Ω shows a full scale deflection for a current of 2.5 mA. Calculate the value of the resistance required to convert it into (a) an ammeter of range 0 to 7.5 A and (b) a voltmeter of range 0 to 10 V. Draw the diagrams to show how you will connect this resistance to the galvanometer in each case.

Q45. Explain the principle and working of a cyclotron with the help of schematic diagram. Write the expression for cyclotron frequency.

Q46. Draw a schematic sketch of the cyclotron. State its working principle. Show that the cyclotron frequency is independent of the velocity of the charged particles.

Q47. Explain how will you convert a galvanometer into an ammeter of given range.

Q48. Describe the principle and construction of a moving coil galvanometer. Prove that the current flowing in the coil is directly proportional to its deflection. What is the importance of the radial field?

Q49. (a) Draw a schematic sketch of a cyclotron. Explain clearly the role of crossed electric and magnetic field in accelerating the charge. Hence derive the expression for the kinetic energy acquired by the particles.

(b) An α-particle and a proton are released from the centre of the cyclotron and made to accelerate.

(i) Can both be accelerated at the same cyclotron frequency? Give reason to justify your answer.

(ii) When they are accelerated in turn, which of the two will have higher velocity at the exit slit of the does?

Q50. (a) With the help of a diagram, explain the principle and working of a 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 oil galvanometer as a voltmeter a high resistance in series is required whereas in an ammeter a shunt is used?

Q51. Draw a schematic sketch of a cyclotron. State its working principle. Describe briefly how it is used to accelerate charged particles. Show that the period of a revolution of an ion is independent of its speed or radius of the orbit. Write two important uses of a cyclotron.

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S1. The magnetic field makes the charged particle to cross the gap between the dees again and again by making it to move along circular path, while the oscillating electric field, applied across the dees, accelerates the charged particle again and again.

S2. Sensitivity of the galvanometer is:

$$V_s = \left(\frac{ANB}{k}\right)\frac{1}{R}$$

(a) Torsional constant should be less; (b) Resistance should be less.

S3. The time spent by a proton inside the dee of a cyclotron is independent of both the radius of circular path and the velocity of the proton.

S4. It is based on the principle that a current carrying coil placed inside a magnetic field experiences a torque.

S5. It states that the positive ions can acquire a large amount of energy with a comparatively smaller alternating potential difference by making them to cross the same electric field time and again by making use of a strong magnetic field.

S6. The field is magnetic in nature. It is because, force due to electric field is not affected, whether the charge is at rest or is in motion.

S7. Milliammeter will be having higher resistance because higher value of resistance small scale range of current.

S8. (a) Its tensile strength should be high, so that it does not break under the weight of the coil.

(b) Its restoring torque per unit twist should be low.

S9. The field is electric in nature.

S10. It is radial in nature.

S11. (a) Torque is uniform for all positions of the coil.

(b) Maximum torque is experienced.

(c) Plane of the coil is parallel to the direction of magnetic field.

S12. It is based on the principle that when a current carrying conductor is placed in magnetic field, it experiences a torque.

S13. The radius of the circular path inside the Dee increases in direct proportion to the velocity of the charge. As a result, the time period of the charge and hence its frequency remains independent of the speed of the charge.

S14.

Voltmeter	Ammeter
(a) A voltmeter is a high resistance instrument.	(a) An ammeter is low resistance instrument.
(b) It is used to measure potential difference in an electrical circuit.	(b) It is used to measure current in an electrical circuit.

S15. No, neutrons cannot be accelerated by using a cyclotron. This because, a cyclotron can accelerate charged particles and is particularly suitable for protons and positive ions.

S16. Sensitivity of a galvanometer may be defined as if it gives a large deflection, even when a small current is passed through it or a small voltage is applied across it coil.

S17. The current sensitivity may be increased by

(a) When we increasing *n*, ***B*** and **A**,

(b) When we decreasing *k*.

S18. (a) An ammeter is a galvanometer, in which a very small suitable resistance is connected in parallel to its coil.

(b) A voltmeter is a galvanometer, in which a very high suitable resistance is connected in series to its coil. However, the values of *n* and *A* cannot be increased beyond a limit.

S19. As such, the galvanometer gives a large deflection for a given value of current *i.e.*, it becomes highly sensitive.

S20. The resistance of an ideal voltmeter is **infinite** and that of an ammeter is **zero**.

S21. (a) Low value of '*k*'. (torsional constant)

(b) High conductivity.

S22. It may be defined as the deflection produced in the galvanometer on passing unit current through its coil.

Current sensitivity, $\frac{\alpha}{I} = \frac{nBA}{k}$.

The SI unit of current sensitivity is radian ampere^{-1}.

S23. Current sensitivity = $\frac{nBA}{k}$

where the letters have their usual meanings. Since *n* and *A* cannot be increased beyond a limit, the current sensitivity may be increased by (a) increasing *B* and (b) decreasing *k*.

S24. For measuring current in a circuit, an ammeter is connected in series. So that the current in the circuit remains practically unchanged on connecting the ammeter, the resistance of the ammeter should be low.

S25. It may be defined as the deflection produced in the galvanometer when a unit voltage is applied across the coil.

Voltage sensitivity, $\frac{\alpha}{V} = \frac{nBA}{kR}$.

S26. A small resistance connected in parallel to the coil of the galvanometer is called shunt. Its SI unit is **ohm**.

S27. The resistance of a voltmeter is always greater than that of the galvanometer, of which it is formed.

S28. Magnetic field strength, $B = 100\text{ G} = 100 \times 10^{-4}\text{ T}$

Number of turns per unit length, $n = 1000\text{ turns m}^{-1}$

Current flowing in the coil, $I = 15\text{ A}$

Permeability of free space, $\mu_0 = 4\pi \times 10^{-7}\text{ T m A}^{-1}$

Magnetic field is given by the relation,

$$B = \mu_0 nI$$

$$\therefore \quad nI = \frac{B}{\mu_0}$$

$$= \frac{100 \times 10^{-4}}{4\pi \times 10^{-7}} = 7957.74$$

$$\approx 8000\text{ A/m}$$

If the length of the coil is taken as 50 cm, radius 4 cm, number of turns 400, and current 10 A, then these values are not unique for the given purpose. There is always a possibility of some adjustments with limits.

S29. Resistance of the galvanometer coil, $G = 15\,\Omega$

Current for which the galvanometer shows full scale deflection,

$$I_g = 4\text{ mA} = 4 \times 10^{-3}\text{ A}$$

Range of the ammeter is 0, which needs to be converted to 6 A.

$\therefore$ Current, $I = 6\text{ A}$

A shunt resistor of resistance S is to be connected in parallel with the galvanometer to convert it into an ammeter. The value of S is given as:

$$S = \frac{I_g G}{I - I_g} = \frac{5 \times 10^{-3} \times 15}{6 - 4 \times 10^{-3}}$$

$$S = \frac{6 \times 10^{-2}}{6 - 0.004} = \frac{0.06}{5.996}$$

$$\approx 0.01\ \Omega = 10\ \text{m}\Omega$$

Hence, a 10 mΩ shunt resistor is to be connected in parallel with the galvanometer.

S30. Resistance of the galvanometer coil, $G = 12\,\Omega$

Current for which there is full scale deflection,

$$I_g = 3\ \text{mA} = 3 \times 10^{-3}\ \text{A}$$

Range of the voltmeter is 0, which needs to be converted to 18 V.

$\therefore \quad V = 18\ \text{V}$

Let a resistor of resistance R be connected in series with the galvanometer to convert it into a voltmeter. This resistance is given as:

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

$$= \frac{18}{3 \times 10^{-3}} - 12 = 6000 - 12 = 5988\,\Omega.$$

Hence, a resistor of resistance 5988 Ω is is to be connected in series with the galvanometer.

S31. From the relation: $S = \dfrac{I_g \times G}{I - I_g}$,

it follows that the value of S needed to convert a galvanometer into a milliammeter is larger than that required to convert it into an ammeter.

Since the resistance of current measuring instrument,

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

it follows that **milliameter** will possess higher resistance.

S32. The coil of the galvanometer experiences torque due to the action of magnetic field produced by the field magnet. In case the field magnet has flat poles, the torque on the coil decreases, as it rotates from its equilibrium position (when plane of the coil is parallel to the magnetic field). It is because, in the new position, the plane of the coil is not parallel to the magnetic field. Moreover, as such, the deflection in the coil is not directly proportional to the current passed through the coil.

When the magnetic field is made radial by using a field magnet with concave poles, the plane of the coil always remains parallel to the direction of the magnetic field. As a result, the magnitude of the torque on the coil remains the same throughout the rotation of the coil. As such, the current passing through the coil is directly proportional to the deflection *i.e.*, the galvanometer scale becomes linear.

S33. (a) To measure currents, the low resistance R_1 should be connected in paralled to the galvanometer.

(b) To measure potential differences, the high resistance R_2 should be connected in series to the galvanometer.

S34. (a) Total resistance in the circuit is,

$$R_G + 3 = 63\,\Omega$$

Hence, $$I = 3/63 = 0.048\text{ A}.$$

(b) Resistance of the galvanometer converted to an ammeter is,

$$\frac{R_G r_s}{R_G + r_s} = \frac{60\,\Omega \times 0.02\,\Omega}{(60 + 0.02)\,\Omega} = 0.02\,\Omega$$

Total resistance in the circuit is,

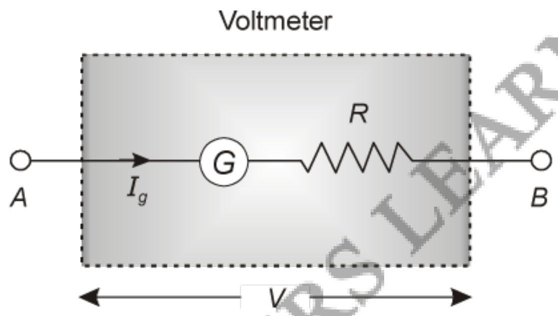
$$0.02\,\Omega + 3\,\Omega = 3.02\,\Omega$$

Hence, $$I = 3/3.02 = 0.99\text{ A}.$$

(c) For the ideal ammeter with zero resistance,

$$I = 3/3 = 1.00\text{ A}.$$

S35. A moving coil galvanometer can be converted into a voltmeter by connecting a suitable high resistance R in series with its coil. The value of R is given by



$$V = I_g(G + R)$$

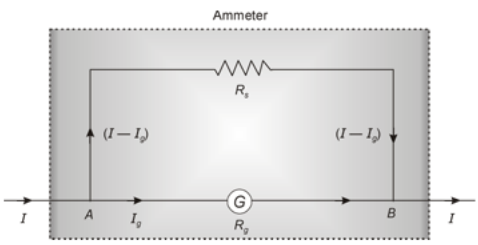
or $$\frac{V}{I_g} = G + R$$

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

where, I_g, G and V have their usual meanings.

S36. *When the galvanometer is converted into an ammeter of range 0 to I:*

For this purpose, the required value of shunt is given by



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

or $$I_g = \frac{I \times S}{G + S} \qquad \text{... (i)}$$

When the galvanometer is converted into an ammeter of range 0 to $2I$:

Suppose S' be the required shunt, then

$$S' = \frac{I_g \times G}{2I - I_g} \qquad \text{... (ii)}$$

From the equations (i) and (ii), we get

$$S = \frac{\boldsymbol{GS}}{\boldsymbol{2G + S}}.$$

S37. Given, $I_g = \frac{1}{10} \times 50 = 5\,\text{mA} = 5 \times 10^{-3}\,\text{A}$, $G = 60\,\Omega$ and $S = 2.5\,\Omega$

Now, $$S = \frac{I_g G}{I - I_g} \quad \text{or} \quad I = \frac{I_g G}{S} + I_g$$

putting values $$I = \frac{5 \times 10^{-3} \times 60}{2.5} + 5 \times 10^{-3} = 125 \times 10^{-3}\,A$$

$$= \mathbf{0.125\,A}.$$

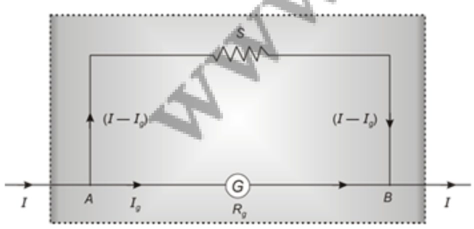
S38. Deflection of the galvanometer per unit voltage *i.e.*, $\frac{\alpha}{V}$.

Voltage sensitivity $\left(V_s = \frac{NBA}{KR}\right)$ of a moving coil galvnometer can be increased by increasing:

(a) the number of turns N of the coil, and

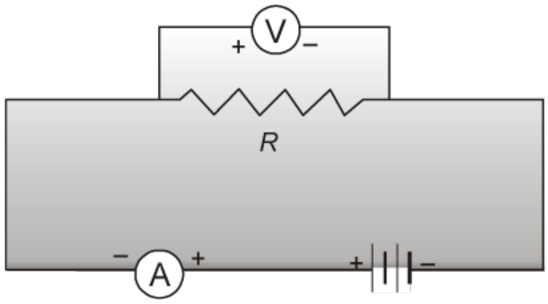
(b) area A of the coil.

S39. If we connect a shunt resistance (low resistance) S in parallel with a galvanometer we can convert it into an ammeter.



As ammeter is used to measure current so the actual amount of current to be measured should pass through it. This is possible only when ammeter having very less resistance is used in parallel.

S40. In order to measure current through the resistor R and to measure the voltage across it, an ammeter (A) and a voltmeter (V) are connected as shown in figure below.



S41. In an ammeter, a small resistance S is connected in parallel to the coil of the galvanometer.

Therefore, resistance of the ammeter,

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

Since is very very small as compared to G,

$$R_A \approx S \qquad \text{(very small)}$$

On the other hand, in a voltmeter, a suitable high resistance R in series with its coil.

Therefore, resistance of the voltmeter,

$$R_V = G + R \approx R \qquad \text{(very large)}$$

Therefore, a **voltmeter** has higher resistance than an ammeter.

S42. Number of turns on the circular coil, $n = 20$

Radius of the coil, $r = 10 \text{ cm} = 0.1 \text{ m}$

Magnetic field strength, $B = 0.10 \text{ T}$

Current in the coil, $I = 5.0 \text{ A}$

(a) The total torque on the coil is zero because the field is uniform.

(b) The total force on the coil is zero because the field is uniform.

(c) Cross-sectional area of copper coil, $A = 10^{-5} \text{ m}^2$

Number of free electrons per cubic meter in copper,

$$N = 10^{29} /\text{m}^3$$

Charge on the electron, $e = 1.6 \times 10^{-19} \text{ C}$

Magnetic force, $F = Bev_d$

Where, v_d = Drift velocity of electrons

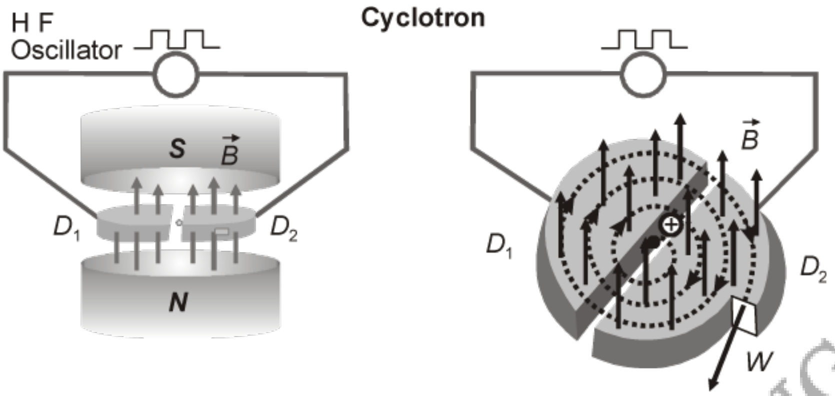
$$= \frac{I}{NeA}$$

$\therefore$ $$F = \frac{BeI}{NeA}$$

$$= \frac{0.10 \times 5.0}{10^{29} \times 10^{-5}} = 5 \times 10^{-25} \text{ N}$$

Hence, the average force on each electron is 5×10^{-25} N.

S43. The diagram cyclotron is shown below:



Principle of cyclotron: The cyclotron works on the principle that a positively charged ion can be accelerated to high kinetic energy by making it pass again and again smaller value of same oscillating electrical field by making use of strong perpendicular magnetic field. Also, the frequency of charge particle must be equal to the frequency of oscillating electrical field.

Working: Let initially positively charged in accelerated towards D_2 and enter into it.

Now, the charge particle experience magnetic Lorentz force due to strong normal magnetic field. It perform circular motion. The time taken by the charge particle to complete half revolution is equal to half of time period of AC oscillator between two dees. The charge *d* particle again accelerated towards D_1 as D_2 acquires positive and *d* negative polarity. Thus, the charge particle is brought again and again in the small region of oscillating electrical field by strong normal magnetic field. The charge particle repeatedly passes through oscillating electrical field. It traversed on spiral path and finally having radius of its circular path becomes equal to the radius of dees and finally comes out through window *W* and strikes to the target.

$\because$ Maximum K.E. of charge particle

$$= \frac{q^2B^2r_0^2}{2m}$$

where, r_0 = radius of dees

$\therefore$ Radius of dees is limited, there K.E.$_{max}$ also have limited value.

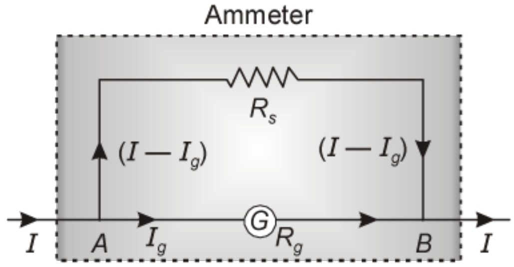
S44. Given:

$R_g = 120\,\Omega$

$I_g = 2.5 \times 10^{-3}$ A

$I = 7.5$ A.

By joining a shunt (a low resistance in parallel) with it, we can convert in into an ammeter.



$$R_g = \frac{I_g R_s}{I - I_g}$$

$$R_s = \frac{2.5 \times 10^{-3} \times 120}{7.5 - 2.5 \times 10^{-3}} = \mathbf{4 \times 10^{-2}\,\Omega}.$$

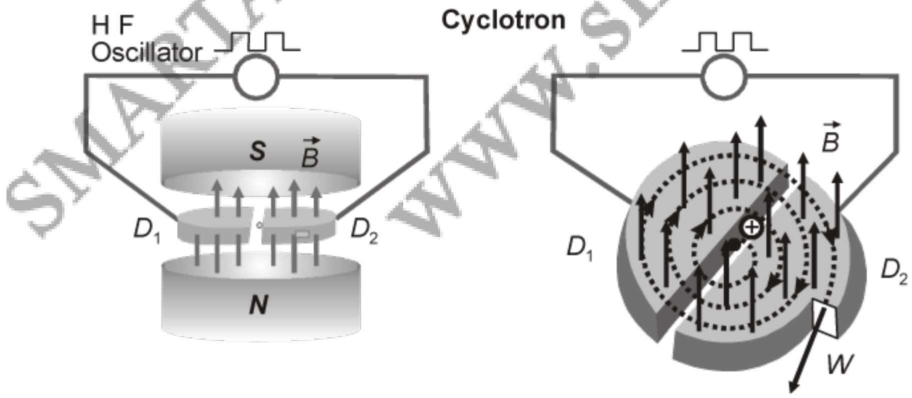
Net resistance of ammeter

$$R = \frac{R_s R_g}{R_s + R_g} = \mathbf{4 \times 10^{-2}\,\Omega}.$$

It reads slightly less than actual current, because net resistance of the circuit slightly increases. From the relation $V = IR$, we find that current decreases.

S45. ***Principle of cyclotron:*** The cyclotron works on the principle that a positively charged ion can be accelerated to high kinetic energy by making it pass again and again smaller value of same oscillating electrical field by making use of strong perpendicular magnetic field. Also, the frequency of charge particle must be equal to the frequency of oscillating electrical field.

The diagram cyclotron is shown below:



Essential details of construction of cyclotron: Cyclotron consists of

(i) Two semicircular, hollow metallic '*D*' shaped half cylinders known as dees.

(ii) High frequency oscillating electric field is produced by AC oscillator.

(iii) Strong normal magnetic field is produced in dees using field magnetic.

(iv) Whole system is enclosed in high vacuum chamber.

Working: Let initially positively charged in accelerated towards D_2 and enter into it.

Now, the charge particle experience magnetic Lorentz force due to strong normal magnetic field. It perform circular motion. The time taken by the charge particle to complete half revolution is equal to half of time period of AC oscillator between two dees. The charge *d* particle again accelerated towards D_1 as D_2 acquires positive and *d* negative polarity. Thus, the charge particle is brought again and again in the small region of oscillating electrical field by strong normal magnetic field. The charge particle repeatedly passes through oscillating electrical field. It traversed on spiral path and finally having radius of its circular path becomes equal to the radius of dees and finally comes out through window *W* and strikes to the target.

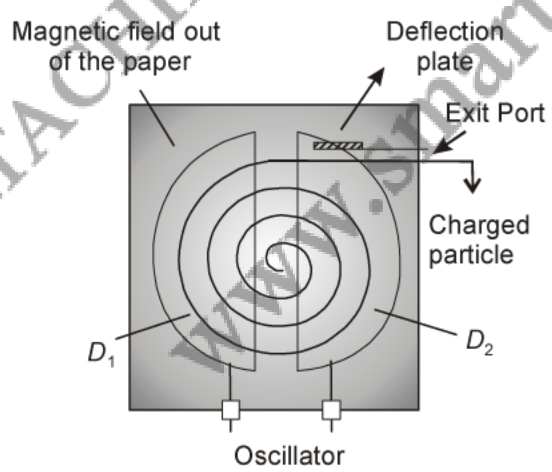
We know, time period of charge particle

$$T = \frac{2\pi r}{v} = \frac{2\pi m}{qB}$$

Now, Frequency $(f) = \dfrac{qB}{2\pi m}$

S46. **Principle:** It is based on the principle that the +ve ions can be accelerated to a high energy with a comparatively smaller potential difference by making them cross an electric field again and again by making use of a strong magnetic field. The electric field accelerates the charged ions and magnetic field makes it move in circular paths.

A schematic sketch of the cyclotron is given below:



It consists of two *D*-shaped hollow metal discs D_1 and D_2 having a very small gap between them. A high frequency alternating potential difference is applied across the 'Dees'. The dees are evacuated and the whole apparatus is placed between the poles of an electromagnet. The magnetic field is perpendicular to the dees.

Working: The heavy +ve ions to be accelerated are introduced in the space between the dees. The electric field between the dees accelerates the ions. The ions enters the dee and comes out of it with the same speed. Just when it comes out of a dee, the polarity of the dees is reversed and the ions are further accelerated. This goes on, till the ions acquire sufficient speed and are taken out with the help of the deflection plate. The time for which the ions remain inside the dee is constant and does not depend upon its speed and radius of the path. Let r_1 be radius of any circular orbit and v_1 the speed in that orbit, then time *t* for which the ions remain in the dee is

$$t = \frac{\pi r_1}{v_1} \quad \text{... (i)}$$

Also, force due to the magnetic field is given by

$$F = B\,Q\,v_1$$

magnetic force = centripetal force

$$\therefore \quad B\,Q\,v_1 = \frac{mv_1^2}{r_1}$$

$$\therefore \quad \frac{v_1}{r_1} = \frac{BQ}{m} \quad \text{or} \quad \frac{r_1}{v_1} = \frac{m}{BQ}$$

Value of $\frac{r_1}{v_1}$ put in Eq. (i), we get

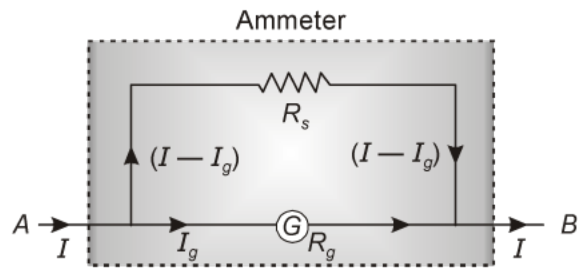
$$\therefore \quad t = \pi\frac{r_1}{v_1} = \frac{\pi m}{BQ}$$

If *T* is the time period of the ion, then

$$T = 2t = \frac{2m\pi}{BQ}$$

which is independent of velocity of the particle and radius of dee.

S47. To convert a galvanometer into an ammeter, a small resistance R_s, known as shunt, is connected in parallel with it. The value of the shunt is so chosen that only a small part of the total current, which produces full scale deflection in the galvanometer, passes through the galvanometer and the major portion of current pass through the shunt (as shown in the figure). Let I be the total current which produce full scale deflection and I_g the small portion of the current passing through the galvanometer of resistance R_s.



Potential difference across the galvanometer = $I_g R_g$.

Potential difference across the shunt = $(I - I_g) R_s$.

Since both are connected in parallel, therefore, the two potential difference are equal

$$(I - I_g) R_s = I_g R_g$$

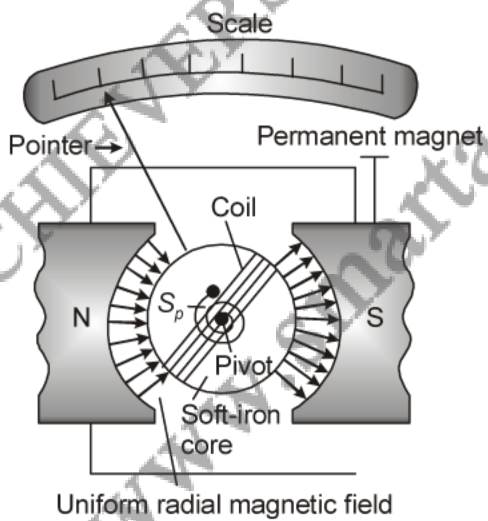
or
$$R_s = \frac{I_g \times R_g}{I - I_g}$$

Thus, by connecting a shunt of resistance R_s, a galvanometer is converted into an ammeter of range 0 to I ampere.

S48. Principle: A current carrying coil placed in a magnetic field experiences a torque.

Let N, l and b be the number of turns, length and breadth of coil respectively. When a current I is passed through the coil, the arms PS and OR experience a force equal to $NBIl$ in opposite directions. The two forces are equal and opposite and form a couple as their line of action are different. The couple exerts a torque on the coil.

Moving Coil Galvanometer



Torque, τ = Either force $\times \perp$ distance between the line of action of two forces

$\therefore$ $\tau = NlBI \;\; b \cos\theta$

$\tau = NABI \cos\theta$ (since $A = l \times b$)

Maximum torque, $\tau = NABI$ (when $\theta = 0°$)

As the coil rotates the suspension wire gets twisted and a restoring torque is developed on it. The restoring torque continue to increase and a stage is reached when restoring torque becomes equal to deflecting torque.

Let the coil is rotated by an angle α and k is the restoring torque per unit angle.

$\therefore$ Restoring torque = $k\alpha$.

In equilibrium,

Deflecting torque = Restoring torque

$\therefore$ $$NIBA = k\alpha$$

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

or $$I \propto \alpha,$$ Where $\frac{k}{NBA}$ = a constant of a galvanometer.

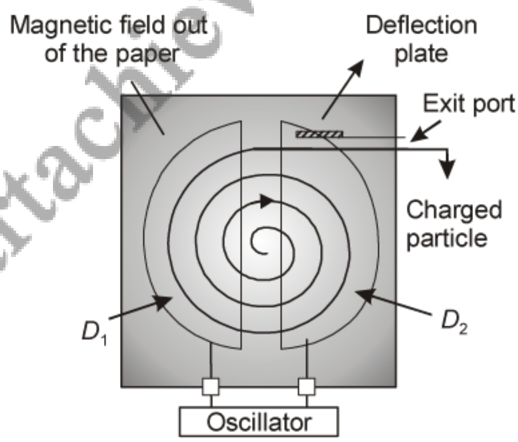
Thus, current flowing in the coil is directly proportional to its deflection.

S49. (a) The combination of crossed electric and magnetic fields is used to increase the energy of the charged particle. Cyclotron uses the fact that the frequency of revolution of the charged particle in a magnetic field is independent of its energy. Inside the dees the particle is shielded from the electric field and magnetic field acts on the particle and makes it to go round in a circular path inside a dee. Every time the particle moves from one dee to the other it comes under the influence of electric field which ensures to increase the energy of the particle as the sign of the electric field changed alternately. The increased energy increases the radius of the circular path so the accelerated particle moves in a spiral path.

Since radius of trajectory

$$r = \frac{vm}{qB}$$

$\therefore$ $$v = \frac{rqB}{m}$$



Hence, the kinetic energy of ions

$$= \frac{1}{2}mv^2 = \frac{1}{2}m\frac{r^2q^2B^2}{m^2} = \frac{1}{2}\frac{r^2q^2B^2}{m}$$

(b) (i) Let the mass of proton = m, charge of proton = q, mass of α-particle = 4 m; Charge of α-particle = $2q$.

Cyclotron Frequency, $$v = \frac{Bq}{2\pi m} \Rightarrow v \propto \frac{q}{m}$$

For proton Frequency, $$v_p \propto \frac{q}{m}$$

For α-particle: Frequency, $\nu_\alpha \propto \frac{2q}{4m}$ or $\nu_\alpha \propto \frac{q}{2m}$

Thus, particles will not accelerate with same cyclotron frequency. The frequency of proton is twivce than the frequency of α-particle.

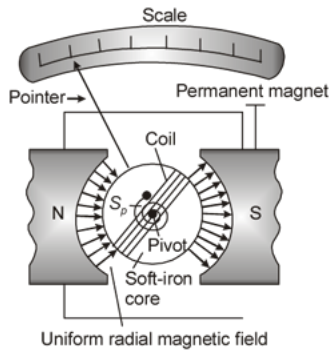
(ii) Velocity, $v = \frac{Bqr}{m} \Rightarrow v \propto \frac{q}{m}$

For proton: Velocity, $v_p \propto \frac{q}{m}$

For α-particle: Velocity, $v_\alpha \propto \frac{2q}{4m}$ or $v_\alpha \propto \frac{q}{2m}$

Thus particles will not exit the does with same velocity. The velocity of proton is twice than the velocity of α-particle.

S50.



(a) **Principle:** A current carrying loop placed is a uniform magnetic field experience a torque.

Working: A coil free to rotate in a uniform magnetic field about a fixed axis experience a torque when current is passed through it

$$\tau = NIAB$$

A spring S_p provides a counter torque $K\phi$ that balances the magnetic torque. For a steady angular deflection ϕ. In equilibrium

$$k\phi = NIBA$$

where, k is torsional constant of the spring. The deflection ϕ is taken a scale by a pointer attached to the spring.

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

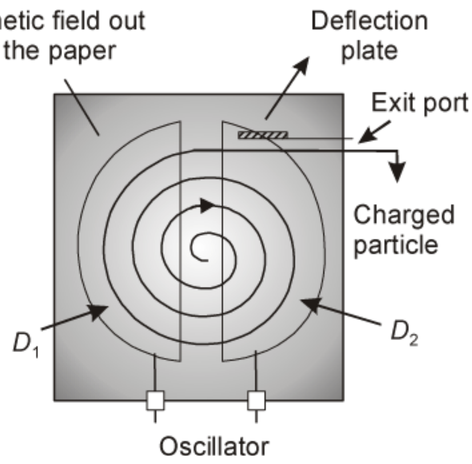
(b) With a radial magnetic field sin θ = 1 in the expression for the torque. Hence we can calibrate a scale.

(c) A high resistance is joined in series with a galvanometer so that when the arrangement (voltmeter) is used in parallel with the selected section of the circuit it should draw least amount of current.

In case voltmeter draws appreciable amount of current, it will disturb the original value of potential difference by a good amount.

To convert a galvanometer into ammeter a shunt is used in parallel with it. Do that when the arrangement is joined in series the value of current in the circuit does not get changed by a considerable amount.

S51. A schematic sketch of a cyclotron is as shown in the figure



Principle: It is based on the principle that the charged particles or ions can be accelerated to high energy with a comparatively smaller alternating potential difference by making them cross the electric field again and again by making use of a suitable strong magnetic field. Every time the charged particles or ions cross the electric field, they again energy.

Working: Let a particle of mass m and carrying a charge q move inside an evacuated chamber in a uniform magnetic field $\vec{B}$ that is perpendicular to the plane of their paths. The dees D_1 and D_2 produces an electric field which changes precisely twice in each revolution so that the particles get a push each time they cross the gap. As a result their speed and hence its kinetic energy goes on increasing. The direction of the electric field changes just when the particle comes out of the dee and thus the charged particle is continuously accelerated and moves in circles of increasing radius and is finally taken out from the exit port. The maximum energy acquired by the ions is limited by the radius of the dees.

Time period of revolution: Let r_1 to the radius of any orbit. Then the time for which the charged particle or ions remains in the dee

$$t = \frac{\pi r_1}{v_1} \quad \text{... (i)}$$

Also, $$B q v_1 = \frac{m v_1^2}{r_1}$$

$\therefore$ $$\frac{v_1}{r_1} = \frac{Bq}{m}$$

Putting this value of $\frac{v_1}{r_1}$ in (1)

$$\therefore \qquad t = \frac{m}{Bq}$$

Time period $\quad T = 2t = \frac{2m\pi}{Bq}$.

Clearly, T is independent of the velocity of the ion and radius of the orbit.

Uses:

(a) It is used for accelerating heavy charged particles required for starting nuclear reactions or disintegrations.

(b) It is also used in hospitals to produce radioactive material.