Moving Charges and Magnetism

Multiple Choice Questions

Choose and write the correct option(s) in the following questions.

1. **If a conducting wire carries a direct current through it, the magnetic field associated with the current will be ________ .**

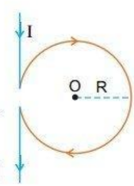
   (*a*) both inside and outside the conductor (*b*) neither inside nor outside the conductor
   (*c*) only outside the conductor (*d*) only inside the conductor

2. **A region has a uniform magnetic field in it. A proton enters into the region with velocity making an angle of 45° with the direction of the magnetic field. In this region the proton will move on a path having the shape of a** [*CBSE 2020 (55/3/1)*]

   (*a*) straight line (*b*) circle (*c*) spiral (*d*) helix

3. **Two charged particles traverse identical helical paths in a completely opposite sense in a uniform magnetic field $B = B_0\hat{k}$.** [*NCERT Exemplar*]

   (*a*) They have equal z-components of momenta
   (*b*) They must have equal charges
   (*c*) They necessarily represent a particle, anti-particle pair
   (*d*) The charge to mass ratio satisfy: $\left(\frac{e}{m}\right)_1 + \left(\frac{e}{m}\right)_2 = 0$



4. **A current I flows through a long straight conductor which is bent into circular loop of radius R in the middle as shown in the figure. The magnitude of the net magnetic field at point O will be** [*CBSE 2020 (55/4/1)*]

   (*a*) zero (*b*) $\frac{\mu_0 I}{2R}(1+\pi)$ (*c*) $\frac{\mu_0 I}{4\pi R}$ (*d*) $\frac{\mu_0 I}{2R}\left(1-\frac{1}{\pi}\right)$

5. Biot-Savart law indicates that the moving electrons (velocity v) produce a magnetic field B such that [*NCERT Exemplar*]

(*a*) B is perpendicular to v

(*b*) B is parallel to v

(*c*) it obeys inverse cube law

(*d*) it is along the line joining the electron and point of observation

6. An electron is projected with uniform velocity along the axis of a current carrying long solenoid. Which of the following is true? [*NCERT Exemplar*]

(*a*) The electron will be accelerated along the axis

(*b*) The electron path will be circular about the axis

(*c*) The electron will experience a force at 45° to the axis and hence execute a helical path

(*d*) The electron will continue to move with uniform velocity along the axis of the solenoid

7. A micro-ammeter has a resistance of 100 Ω and a full scale range of 50 m μA. It can be used as a higher range ammeter or voltmeter provided resistance is added to it. Pick the correct range and resistance combinations.

(*a*) 50 V range and 10 kΩ resistance in series

(*b*) 10 V range and 200 kΩ resistance in series

(*c*) 5 mA range with 1 Ω resistance in parallel

(*d*) 10 mA range with 1 Ω resistance in parallel.

8. A current carrying circular loop of radius R is placed in the x-y plane with centre at the origin. Half of the loop with $x > 0$ is now bent so that it now lies in the y-z plane. [*NCERT Exemplar*]

(*a*) The magnitude of magnetic moment now diminishes.

(*b*) The magnetic moment does not change.

(*c*) The magnitude of B at $(0,0, z)$, $z >> R$ increases.

(*d*) The magnitude of B at $(0,0, z)$, $z >> R$ is unchanged.

9. The sensitivity of a moving coil galvanometer increases with the decrease in

(*a*) number of turns (*b*) area of coil

(*c*) magnetic field (*d*) torsional rigidity

10. A voltmeter of range 2V and resistance 300 Ω cannot be converted to an ammeter of range

(*a*) 5 mA (*b*) 8 mA (*c*) 1 A (*d*) 10 A

11. In an ammeter 4% of the mains current is passing through galvanometer. If the galvanometer is shunted with a 5 Ω resistance, then resistance of galvanometer will be

(*a*) 116 Ω (*b*) 117 Ω (*c*) 118 Ω (*d*) 120 Ω

12. A rectangular coil of length 0.12 m and width 0.1 m having 50 turns of wire is suspended vertically in a uniform magnetic field of strength 0.2 Weber/m^2. The coil carries a current of 2 A. If the plane of the coil is inclined at an angle of 30° with the direction of the field, the torque required to keep the coil in stable equilibrium will be

(*a*) 0.24 Nm (*b*) 0.12 Nm (*c*) 0.15 Nm (*d*) 0.20 Nm

13. An electron is released from rest in a region of uniform electric and magnetic fields acting parallel to each other. The electron will [*CBSE 2020 (55/2/1)*]

(*a*) move in a straight line. (*b*) move in a circle.

(*c*) remain stationary. (*d*) move in a helical path.

14. A straight current carrying conductor is placed inside a uniform magnetic field. The force per unit length acting on the conductor is [*CBSE 2020 (55/2/3)*]

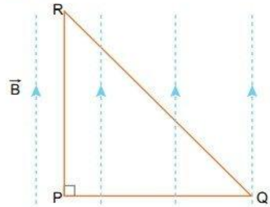
(*a*) maximum when the conductor is perpendicular to the direction of magnetic field.

(*b*) maximum when the conductor is along the direction of magnetic field.

(*c*) minimum when the conductor is perpendicular to the direction of magnetic field.

(*d*) minimum when the conductor makes an angle of 45° with the direction of magnetic field.

15. An isosceles right angled current carrying loop PQR is placed in a uniform magnetic field $\vec{B}$ pointing along PR. If the magnetic force acting on the arm PQ is F, then the magnetic force which acts on the arm QR will be *[CBSE 2020 (55/3/1)]*



(*a*) F (*b*) $\frac{F}{\sqrt{2}}$ (*c*) $\sqrt{2}F$ (*d*) $-F$

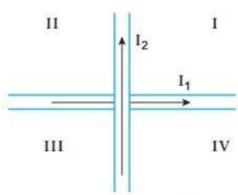
16. A current of 10 A is flowing from east to west in a long straight wire kept on a horizontal table. The magnetic field developed at a distance of 10 cm due north on the table is:
[CBSE 2020 (55/4/1)]

(*a*) 2×10^{-5} T, acting downwards (*b*) 2×10^{-5} T, acting upwards
(*c*) 4×10^{-5} T, acting downwards (*d*) 4×10^{-5} T, acting upwards

17. An electron and a proton are moving along the same direction with the same kinetic energy. They enter a uniform magnetic field acting perpendicular to their velocities. The dependence of radius of their paths on their masses is: *[CBSE 2020 (55/4/2)]*

(*a*) $r \propto m$ (*b*) $r \propto \sqrt{m}$ (*c*) $r \propto \frac{1}{m}$ (*d*) $r \propto \frac{1}{\sqrt{m}}$

18. Two wires carrying currents I_1 and I_2 lie, one slightly above the other, in a horizontal plane as shown in figure. The region of vertically upward strongest magnetic field is
[CBSE 2022 (55/2/4), Term-1]



(*a*) I (*b*) II (*c*) III (*d*) IV

19. The magnetic field at the centre of a current carrying circular loop of radius R, is B_1. The magnetic field at a point on its axis at a distance R from the centre of the loop is B_2. Then the ratio (B_1/B_2) is *[CBSE 2022 (55/2/4), Term-1]*

(*a*) $2\sqrt{2}$ (*b*) $\frac{1}{\sqrt{2}}$ (*c*) $\sqrt{2}$ (*d*) 2

20. A current carrying wire kept in a uniform magnetic field, will experience a maximum force when it is *[CBSE 2022 (55/2/4), Term-1]*

(*a*) perpendicular to the magnetic field (*b*) parallel to the magnetic field
(*c*) at an angle of 45° to the magnetic field (*d*) at an angle of 60° to the magnetic field

21. If an ammeter is to be used in place of a voltmeter, then we must connect with the ammeter a
[CBSE 2022 (55/2/4), Term-1]

(*a*) low resistance in parallel (*b*) low resistance in series
(*c*) high resistance in parallel (*d*) high resistance in series

22. A straight conducting rod of length l and mass m is suspended in a horizontal plane by a pair of flexible strings in a magnetic field of magnitude B. To remove the tension in the supporting strings, the magnitude of the current in the wire is *[CBSE 2022 (55/2/4), Term-1]*

(*a*) $\frac{mgB}{l}$ (*b*) $\frac{mgl}{B}$ (*c*) $\frac{mg}{lB}$ (*d*) $\frac{lB}{mg}$

23. Which of the following statements is correct? *[CBSE 2022 (55/2/4), Term-1]*

(*a*) Magnetic field lines do not form closed loops.
(*b*) Magnetic field lines start from north pole and end at south pole of a magnet.
(*c*) The tangent at a point on a magnetic field line represents the direction of the magnetic field at that point.
(*d*) Two magnetic field lines may intersect each other.

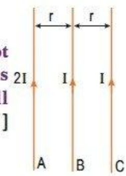
24. A proton and an alpha particle move in circular orbits in a uniform magnetic field. Their speeds are in the ratio of 9 : 4. The ratio of radii of their circular orbits $\left(\frac{r_p}{r_{\text{alpha}}}\right)$ is *[CBSE Sample paper-2022, Term-1]*

(*a*) $\frac{3}{4}$ (*b*) $\frac{4}{3}$ (*c*) $\frac{8}{9}$ (*d*) $\frac{9}{8}$

25. The current sensitivity of a galvanometer increases by 20%. If its resistance also increases by 25%, the voltage sensitivity will *[CBSE Sample Paper-2022, Term-1]*

(*a*) decrease by 1% (*b*) increase by 5%
(*c*) increase by 10% (*d*) decrease by 4%

26. Three infinitely long parallel straight current carrying wires A, B and C are kept at equal distance from each other as shown in the figure . The wire C experiences net force F .The net force on wire C, when the current in wire A is reversed will be *[CBSE Sample Paper-2022, Term-1]*



(*a*) zero (*b*) $F/2$
(*c*) F (*d*) $2F$

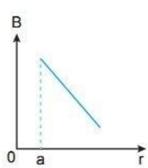
27. Beams of electrons and protons move parallel to each other in the same direction. They *[CBSE 2023 (55/2/1)]*

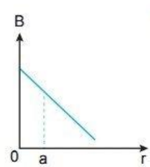
(*a*) attract each other.
(*b*) repel each other.
(*c*) neither attract nor repel.
(*d*) force of attraction or repulsion depends upon speed of beams.

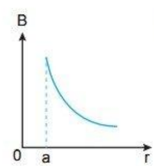
28. A long stratight wire of radius 'a' carries a steady current 'I'. The current is uniformly distributed across its area of cross-section. The ratio of magnitude of magnetic field $\overrightarrow{B_1}$ at $\frac{a}{2}$ and $\overrightarrow{B_2}$ at distance $2a$ is *[CBSE 2023 (55/2/1)]*

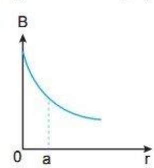
(*a*) $\frac{1}{2}$ (*b*) 1 (*c*) 2 (*d*) 4

29. Which of the following graphs correctly represents the variation of the magnitude of the magnetic field outside a straight infinite current carrying wire of radius 'a', as a function of distance 'r' from the centre of the wire? *[CBSE 2023 (55/3/1)]*

(*a*)


(*b*)


(*c*)


(*d*)


30. An electron enters a uniform magnetic field with speed v. It describes a semicircular path and comes out of the field. The final speed of the electron is [*CBSE 2023 (55/4/1)*]

(*a*) zero (*b*) v (*c*) $\frac{v}{2}$ (*d*) $2v$

Answers

1. (*c*)	2. (*d*)	3. (*d*)	4. (*d*)	5. (*a*)	6. (*d*)	7. (*b,c*)
8. (*a*)	9. (*d*)	10. (*a*)	11. (*d*)	12. (*d*)	13. (*a*)	14. (*a*)
15. (*d*)	16. (*a*)	17. (*b*)	18. (*b*)	19. (*a*)	20. (*a*)	21. (*d*)
22. (*c*)	23. (*c*)	24. (*d*)	25. (*d*)	26. (*a*)	27. (*b*)	28. (*b*)
29. (*c*)	30. (*b*)					

Assertion-Reason Questions

In the following questions, a statement of Assertion (A) is followed by a statement of Reason (R). Choose the correct answer out of the following choices.

(*a*) *Both A and R are true and R is the correct explanation of A.*

(*b*) *Both A and R are true but R is not the correct explanation of A.*

(*c*) *A is true but R is false.*

(*d*) *A is false and R is also false.*

1. Assertion(*A*) : On increasing the current sensitivity of a galvanometer by increasing the number of turns, may not necessarily increase its voltage sensitivity.

Reason (*R*) : The resistance of the coil of the galvanometer increases on increasing the number of turns. [*CBSE Sample Paper-2022, Term-1*]

2. Assertion(*A*) : When a magnetic dipole is placed in a non uniform magnetic field, only a torque acts on the dipole.

Reason (*R*) : Force would not act on dipole if magnetic field were non uniform.

3. Assertion(*A*) : To increase the range of an ammeter, we must connect a suitable high resistance in series to it.

Reason (*R*) : The ammeter with increased range should have high resistance.

[*CBSE Sample Paper-2022, Term-1*]

4. Assertion(*A*) : Galvanometer cannot as such be used as an ammeter to measure the value of the current in a given circuit.

Reason (*R*) : It gives a full-scale deflection for a current of the order of micro ampere.

5. Assertion(*A*) : Higher the range, lower is the resistance of an ammeter.

Reason (*R*) : To increase the range of an ammeter additional shunt is added in series to it.

[*CBSE 2022 (55/2/4), Term-1*]

6. Assertion(*A*) : A proton and an electron, with same momenta, enter in a magnetic field in a direction at right angles to the lines of the force. The radius of the paths followed by them will be same.

Reason (*R*) : Electron has less mass than the proton. [*CBSE Sample Paper-2022, Term-1*]

7. Assertion(*A*) : Magnetic field is caused by current element.

Reason (*R*) : Magnetic field due to a current element $I\,\overrightarrow{dl}$ is $\overrightarrow{dB} = \frac{\mu_0}{4\pi}\frac{I\overrightarrow{dl}\times\overrightarrow{r}}{r^3}$

8. **Assertion** (A) : If a proton and an α-particle enter a uniform magnetic field perpendicularly with the same speed, the time period of revolution of α-particle is double that of proton.

Reason (R) : In a magnetic field, the period of revolution of a charged particle is directly proportional to the mass of the particle and is inversely proportional to charge of particle. *[AIIMS 2010]*

9. **Assertion** (A) : When radius of a circular loop carrying a steady current is doubled, its magnetic moment becomes four times.

Reason (R) : The magnetic moment of a circular loop carrying a steady current is proportional to the area of the loop. *[CBSE 2023 (55/3/1)]*

10. **Assertion** (A) : A current carrying square loop made of a wire of length L is placed in a magnetic field. It experiences a torque which is greater than the torque on a circular loop made of the same wire carrying the same current in the same magnetic field.

Reason (R) : A square loop occupies more area than a circular loop, both made of wire of the same length. *[CBSE 2023 (55/4/1)]*

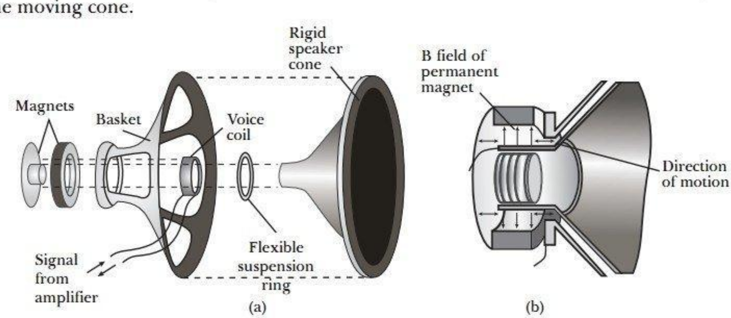
Answers

1. (*a*)	**2.** (*d*)	**3.** (*d*)	**4.** (*a*)	**5.** (*c*)	**6.** (*b*)	**7.** (*b*)
8. (*a*)	**9.** (*a*)	**10.** (*b*)				

Case-based/Passage-based Questions

Read the paragraph given below and answer the questions that follow:

Loudspeakers: A common application of the magnetic force on a current carrying wire is found in loudspeakers. The magnetic field created by the permanent magnet exerts a force on the voice coil that is proportional to the current in the coil; the direction of the force is either to the left or to the right, depending on the direction of the current. The signal coming from the amplifier causes the current to oscillate in direction and magnitude. The coil and the speaker cone to which it is attached respond by oscillating with an amplitude proportional to the amplitude of the current in the coil. Turning up the volume knob on the amplifier increases the current amplitude and hence the amplitudes of the cone's oscillation and of the sound wave produced by the moving cone.



The force is always perpendicular to both the conductor and the field, with the direction determined by the same right-hand rule we used for a moving positive charge. Hence, this force can be expressed as a vector product, just like the force on a single moving charge. We represent the segment of wire with a vector $\vec{l}$ along the wire in the direction of the current, then force $\vec{F}$ on this segment is

$$\vec{F} = I\vec{l} \times \vec{B} \text{ (i.e., magnetic force on a straight wire segment)}$$

(i) Loudspeaker works on the principle of

(a) detector (b) generator (c) amplifier (d) motor

(ii) Electrodynamic speaker can handle which type of audio power relative to permanent magnet type speaker?

(a) Lower (b) Equal
(c) Higher (d) Both (a) and (b)

(iii) To increase the power handling capacity in loudspeakers which type of magnet is used?

(a) Temporary magnet (b) Permanent magnet
(c) Electromagnet (d) None of these

OR

A horizontal wire 0.1 m long carries a current of 5 A. Find the magnitude and direction of the magnetic field, which can balance the weight of wire. Given the mass of the wire is 3×10^{-3} kg/m and $g = 10$ m/s^2.

(a) 6×10^{-3} T, acting horizontally perpendicular to wire
(b) 6×10^{-3} T, acting vertically upwards
(c) 6×10^{-2} T, acting vertically downwards
(d) 6×10^{-2} T, acting horizontally perpendicular to wire

(iv) A square current carrying loop is suspended in a uniform magnetic field acting in the plane of the loop. If the force on one arm of the loop is $\vec{F}$, the net force on the remaining three arms of the loop is

(a) $\vec{F}$ (b) $-\vec{F}$ (c) $3\vec{F}$ (d) $-3\vec{F}$

Explanations

(i) (d) A common application of the magnetic force on a current carrying wire is found in loudspeakers as similar case in motor in which current carrying coil experience force in presence of magnetic field.

(ii) (c) It is a type of higher audio power relative to permanent magnet type speaker.

(iii) (c) The electromagnet is used to increase the power handling capacity in loudspeakers.

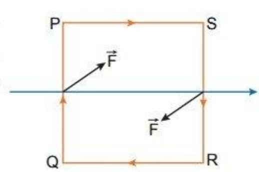
OR

(a) In equilibrium position, $F = IlB = mg$

$$\Rightarrow \quad B = \frac{mg}{Il} = \frac{(0.1 \times 3 \times 10^{-3}) \times 10}{5 \times 0.1} = 6 \times 10^{-3}\,\text{T}$$

The weight is wire be supported by force F if it acts vertically upwards. It will be so if the direction of $\vec{B}$ is horizontal and perpendicular to wire carrying current.

(iv) (b) As clear from figure, force on arm PS and arm RQ is zero. If $\vec{F}$ is force on arm RS, the force on arm PQ is $-\vec{F}$. Therefore, net force on the remaining three arms of the loop $= -\vec{F}$.



CONCEPTUAL QUESTIONS

Q. 1. Write the expression, in a vector form, for the Lorentz magnetic force $\vec{F}$ due to a charge moving with velocity $\vec{v}$ in a magnetic field $\vec{B}$. What is the direction of the magnetic force? [*CBSE Delhi 2014*]

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

Obviously, the force on charged particle is perpendicular to both velocity $\vec{v}$ and magnetic field $\vec{B}$.

Q. 2. When a charged particle moving with velocity $\vec{v}$ is subjected to magnetic field $\vec{B}$, the force acting on it is non-zero. Would the particle gain any energy? [*CBSE (F) 2013*]

Ans. No. (*i*) This is because the charge particle moves on a circular path.

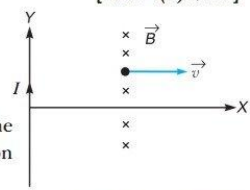
(*ii*) $\vec{F} = q(\vec{v} \times \vec{B})$

and power dissipated $P = \vec{F} \cdot \vec{v} \quad [\because \vec{v} \times \vec{B} \perp \vec{v}]$

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

The particle does not gain any energy.

Q. 3. A long straight wire carries a steady current I along the positive Y-axis in a coordinate system. A particle of charge $+Q$ is moving with a velocity $\vec{v}$ along the X-axis. In which direction will the particle experience a force? [*CBSE (F) 2013*]



Ans. From relation $\vec{F} = qvB[\hat{i} \times (-\hat{k})] = +qvB(\hat{j})$

Magnetic force $\vec{F}$ along $+Y$ axis.

OR

From Fleming's left hand rule, thumb points along $+Y$ direction, so the direction of magnetic force will be along $+Y$ axis (or in the direction of flow of current).

Q. 4. What can be the cause of helical motion of a charged particle? [*CBSE North 2016*]

Ans. Charge particle moves inclined to the magnetic field. When there is an angle between velocity of charged particle and magnetic field, then the vertical component of velocity ($v \sin \theta$) will rotate the charge particle on circular path, but horizontal component ($v \cos \theta$) will move the charged particle in straight line. Hence path of the charge particle becomes helical.

Q. 5. In a certain region of space, electric field $\vec{E}$ and magnetic field $\vec{B}$ are perpendicular to each other. An electron enters in the region perpendicular to the directions of both $\vec{B}$ and $\vec{E}$ and moves undeflected. Find the velocity of the electron. [*HOTS*] [*CBSE (F) 2013*]

Ans. Net force on electron moving in the combined electric field $\vec{E}$ and magnetic field $\vec{B}$ is

$$\vec{F} = -e[\vec{E} + \vec{v} \times \vec{B}]$$

Since electron moves undeflected then $\vec{F} = 0$.

$$\vec{E} + \vec{v} \times \vec{B} = 0$$

$$\Rightarrow \quad |\vec{E}| = |\vec{v} \times \vec{B}| \quad \Rightarrow \quad |\vec{v}| = \frac{|\vec{E}|}{|\vec{B}|}$$

Q. 6. 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 circular paths described by them? [*CBSE (F) 2011*]

OR

A proton and a deuteron having equal momenta enter in a region of uniform magnetic field at right angle to the direction of the field. Find the ratio of the radii of curvature of the path of the particle. [*CBSE Delhi 2013*]

Ans. Charge on deutron (q_d) = charge on proton (q_p)

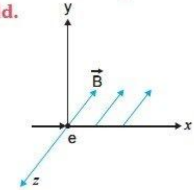
Radius of circular path $(r) = \dfrac{P}{Bq}$ $\quad\left(\because qvB = \dfrac{mv^2}{r}\right)$

$$r \propto \frac{1}{q} \quad \text{[for constant momentum } (P)\text{]}$$

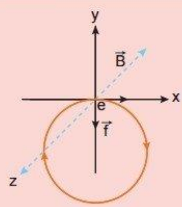
So, $$\frac{r_p}{r_d} = \frac{q_d}{q_p} = \frac{q_p}{q_p} = 1$$

Hence, $r_p : r_d = \mathbf{1 : 1}$

Q. 7. An electron moves along +x direction. It enters into a region of uniform magnetic field $\vec{B}$ directed along –z direction as shown in fig. Draw the shape of trajectory followed by the electron after entering the field. *[CBSE 2020 (55/5/1)]*



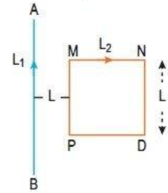
Ans.



Alternatively: Circular path in the *X-Y* plane in clockwise sense. ½ + ½

Note: If the student just writes, force on the electron will be along negative *Y* axis, *i.e.*, $F = -e(v\hat{i}) \times (B(-\hat{k}) = evB(-\hat{j})$ award ½ mark only *[CBSE Marking Scheme 2020 (55/5/1)]*

Q. 8. A square shaped current carrying loop *MNOP* is placed near a straight long current carrying wire *AB* as shown in the figure. The wire and the loop lie in the same plane. If the loop experiences a net force F towards the wire, find the magnitude of the force on the side 'NO' of the loop. *[CBSE 2020 (55/5/1)]*



Ans. Magnitude of force on side NO is $= F$

Alternatively

Let force on side *MP* be $= F_1$

Force on side $NO = F$ ½

Magnitude of net force $= F_1 - \dfrac{F_1}{2} = \dfrac{F_1}{2} = F$ ½

Therefore force on side $NO = \dfrac{F_1}{2} = F$ *[CBSE Marking Scheme 2020 (55/5/1)]*

Q. 9. A square coil of side 10 cm consists of 20 turns and carries a current of 12 A. The coil is suspended vertically and normal to the plane of the coil makes an angle of 30° with the direction of uniform horizontal magnetic field of magnitude 0.80 T. What is the magnitude of the torque experienced by the coil? *[NCERT]*

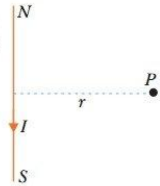
Ans. Torque on coil $\tau = NIAB \sin\theta$

Here $N = 20; A = 10\text{ cm} \times 10\text{ cm} = 100\text{ cm}^2 = 100 \times 10^{-4}\text{ m}^2$

$I = 12\text{ A}, \theta = 30°, B = 0.80\text{ T}$

$\therefore \quad \tau = (20) \times (12) \times (100 \times 10^{-4}) \times 0.80 \sin 30° = 24 \times 0.8 \times \left(\frac{1}{2}\right) \times 10^{-1} = \mathbf{0.96\ Nm}$

Q. 10. 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?

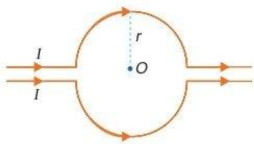


Ans. Given $I = 50$ A, $r = 2.5$ m

$$B = \frac{\mu_0 I}{2\pi r} = \frac{4\pi \times 10^{-7} \times 50}{2\pi \times 2.5} = \mathbf{4 \times 10^{-6}\ T}$$

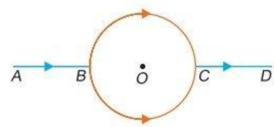
By right hand palm rule the magnetic field is directed vertically upward.

Q. 11. What is the value of magnetic field at point O due to current flowing in the wires as shown in figure? *[HOTS]*



Ans. Zero, because the upper and lower current carrying conductors are identical and so the magnetic fields caused by them at the centre O will be equal and opposite.

Q. 12. What is the magnetic field at point O due to current carrying wires shown in figure? *[HOTS]*



Ans. The magnetic field due to straight wires AB and CD is zero since either $\theta = 0°$ or $180°$ and that due to a semi-circular arc are equal and opposite; hence net field at O is zero.

Q. 13. 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? *[NCERT]*

Ans. Magnetic force, $F = BIl \sin\theta$

Magnetic force per unit length,

$$f = \frac{F}{l} = BI \sin\theta = 0.15 \times 8 \times \sin 30° = \mathbf{0.6\ N/m}$$

Q. 14. A proton and an electron travelling along parallel paths enter a reion of uniform magnetic field, acting perpendicular to their paths. Which of them will move in a circular path with higher frequency? *[CBSE 2018]*

Ans. Electron

Reason: When the charge particle enters perpendicular to the magnetic field it traces circular path.

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

$$\Rightarrow \quad r = \frac{m(\omega r)}{qB} \quad (\because v = \omega r)$$

$$\Rightarrow \quad \omega = \frac{qB}{m} \quad \Rightarrow \quad 2\pi\upsilon = \frac{qB}{m}$$

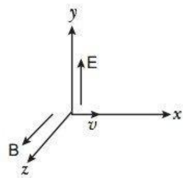
$$\Rightarrow \quad \upsilon = \frac{qB}{2\pi m} \quad \Rightarrow \quad \upsilon \propto \frac{q}{m}$$

Since, electron has less mass, so it will move with high frequency.

Very Short Answer Questions

Each of the following questions are of 2 marks.

Q. 1. **A particle of charge q is moving with velocity v in the presence of crossed Electric field E and Magnetic field B as shown. Write the condition under which the particle will continue moving along x-axis. How would the trajectory of the particle be affected if the electric field is switched off?** [*CBSE Sample Paper 2018*]



Ans. Consider a charge q moving with velocity v in the presence of electric and magnetic fields. The force on an electric charge q due to both of them is

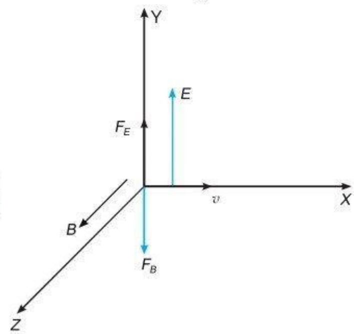
$$\vec{F} = q\left[\vec{E}(r) + \vec{v} \times \vec{B}(r)\right]$$

where, v = velocity of the charge

r = location of the charge at a given time t

$E(r)$ = Electric field

$B(r)$ = Magnetic field



Let us consider a simple case in which electric and magnetic fields are perpendicular to each other and also perpendicular to the velocity of the particle.

$$\vec{F}_E = q\vec{E} = qE\,\hat{j}$$

$$\vec{F}_B = q\vec{v}\times\vec{B} = q(v\,\hat{i}\times B\,\hat{k}) = -qvB\,\hat{j}$$

$$\therefore \qquad \vec{F} = q(E - vB)\,\hat{j}$$

Thus, electric and magnetic forces are in opposite directions.

Suppose we adjust the values of E and B such that magnitudes of the two forces are equal, then the total force on the charge is zero and the charge will move in the fields undeflected. This happens when

$$qE = qvB \qquad \text{or} \quad v = \frac{E}{B}$$

This condition can be used to select charged particles of a particular velocity out of a beam containing charges moving with different speeds (irrespective of their charge and mass). The crossed E and B fields therefore serve as a velocity selector.

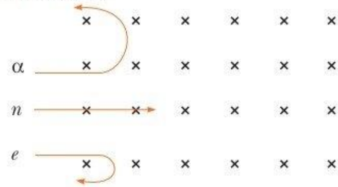
Trajectory becomes helical about the direction of magnetic field.

Q. 2. ***(i)*** **Write the expression for the magnetic force acting on a charged particle moving with velocity v in the presence of magnetic field B.**

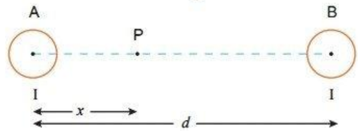
(ii) **A neutron, an electron and an alpha particle moving with equal velocities, enter a uniform magnetic field going into the plane of the paper as shown. Trace their paths in the field and justify your answer.** [*CBSE Delhi 2016*]

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

(*ii*) Force on alpha particle and electron are opposite to each other, magnitude of mass per charge ratio of alpha particle is more than electron (*i.e.*, $r \propto \frac{m}{q}$) hence radius of alpha particle is more than radius of electron.



Q. 3. Two long straight parallel wires *A* and *B* separated by a distance *d*, carry equal current *I* flowing in same direction as shown in the figure.

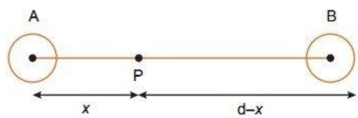


(*a*) Find the magnetic field at a point *P* situated between them at a distance *x* from one wire.

(*b*) Show graphically the variation of the magnetic field with distance *x* for $0 < x < d$.

[*CBSE 2020 (55/1/1)*]

Ans. (*a*)



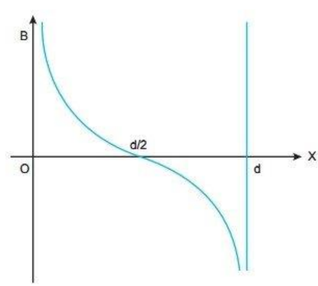
Magnetic field at *P* due to long straight wire, $B = \frac{\mu_0 I}{2\pi x}$

$$\overrightarrow{B_P} = \overrightarrow{B_A} + \overrightarrow{B_B} = \frac{\mu_0 I}{2\pi x}(\text{upwards}) + \frac{\mu_0 I}{2\pi(d-x)}(\text{downwards})$$

$$= \frac{\mu_0 I}{2\pi}\left(\frac{1}{x} - \frac{1}{d-x}\right)$$

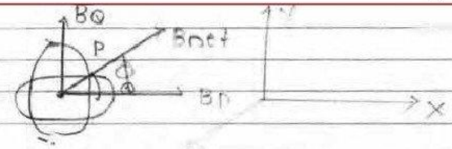
$$= \frac{\mu_0 I}{2\pi}\left(\frac{d-x-x}{x(d-x)}\right) = \frac{\mu_0 I}{2\pi}\frac{(d-2x)}{x(d-x)} \text{ upwards as } B_A > B_B$$

(*b*)



Q. 4. **Two identical circular coils, *P* and *Q* each of radius *R*, carrying currents 1 A and $\sqrt{3}$ A respectively, are placed concentrically and perpendicular to each other lying in the *XY* and *YZ* planes. Find the magnitude and direction of the net magnetic field at the centre of the coils.** **[*CBSE (AI) 2017*]**

Ans.



The magnetic field due to the coil P at the centre

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

$$B_Q = \frac{\mu_0 I}{2R} = \frac{\mu_0 \times \sqrt{3}}{2R} = \frac{\sqrt{3}\mu_0}{2R}$$

$$B_{net} = \sqrt{B_1^2 + B_2^2} = \sqrt{\frac{\mu_0^2}{4R^2} + \frac{3\mu_0^2}{4R^2}} = \sqrt{\frac{4\mu_0^2}{4R^2}}$$

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

The direction is along B_{net} making 45° 60° with the Bp.

$$\tan\phi = \frac{B_Q}{B_P} = \frac{\sqrt{3}\mu_0}{2R} \times \frac{2R}{\mu_0} = \sqrt{3}$$

$$\phi = 60°$$ in the plane of the two coils

[*Topper's Answer 2017*]

Q. 5. **An electron is revolving around the nucleus in a circular orbit with a speed of 10^7 m s^{-1}, If the radius of the orbit is 10^{-10}m, find the current constituted by the revolving electron in the orbit.** **[*CBSE 2023 (55/1/1)*]**

Ans. Here, $v = 10^7$ ms^{-1}, $r = 10^{-10}$ m

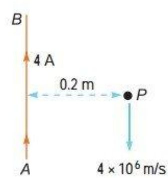
Time period of electron to revolve in orbit, $T = \dfrac{2\pi r}{v}$

Now, current, $I = \dfrac{e}{T} = \dfrac{e}{\frac{2\pi r}{v}} = \dfrac{ev}{2\pi r} = \dfrac{1.6\times10^{-19}\times10^7}{2\times3.14\times10^{-10}} = \dfrac{16\times100}{628\times10}\times10^{-2}$

$= 2.54 \times 10^{-3}$ A

= 2.54 mA

Q. 6. **A long straight wire *AB* carries a current of 4 A. A proton *P* travels at 4×10^6 ms^{-1} parallel to the wire 0.2 m from it and in a direction opposite to the current as shown in the figure. Calculate the force which the magnetic field due to the current carrying wire exerts on the proton. Also specify its direction.** **[*CBSE 2019 (55/4/1)*]**



Ans. Given, $I = 4$ A, $r = 0.2$ m, $v = 4\times10^6$ m/s

Magnetic field at Point *P* due current carrying straight wire *AB*

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

Force acting on the moving proton in the magnetic field

$$F = Bqv\ \text{Sin}\theta$$

Therefore, $$F = \frac{\mu_\circ}{2\pi}\frac{I}{r} \times qv \sin\theta$$

$$= \frac{2\times10^{-7}\times4\times1.6\times10^{-19}\times4\times10^{6}\sin 90}{0.2}$$

$$= \mathbf{2.56 \times 10^{-18}\ N}$$

Direction of force at point P is towards right. (away from AB)

Q. 7. An alpha particle is projected with velocity $\vec{v} = (3.0 \times 10^5\ \text{m/s})\ \hat{i}$ into a region in which magnetic field $\vec{B} = [(0.4\ \text{T})\ \hat{i} + (0.3\ \text{T})\ \hat{j}\ ]$ exists. Calculate the acceleration of the particle in the region. $\hat{i}$, $\hat{j}$ and $\hat{k}$ are unit vectors along x, y and z axis respectively and charge to mass ratio for alpha particle is 4.8×10^7 C/kg. *[CBSE 2023 (55/1/1)]*

Ans. Here, $\vec{v} = 3 \times 10^5$ m/s $\hat{i}$, $\vec{B} = 0.4\ \hat{i} + 0.3\ \hat{j}$ T.

Charge to mass ratio, $\frac{q}{m} = 4.8 \times 10^7$ C/kg [For α-particle]

From Lorentz's force,

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

$$= q(3\times10^5\hat{i})\times(0.4\hat{i} + 0.3\hat{j})$$

$$= q\left(1.2\times10^5(\hat{i}\times\hat{i}) + 0.9\times10^5(\hat{i}\times\hat{j})\right)$$

$$= q(0.9\times10^5\hat{k}) \qquad [\hat{i}\times\hat{i} = 0]$$

Now, $$a = \frac{\vec{F}}{m} = \frac{q}{m}(0.9\times10^5)\hat{k}$$

$$= 4.8\times10^7\times0.9\times10^5\ \hat{k}$$

$$= \mathbf{4.32\times10^{12}\ m/s^2\ \hat{k}}.$$

Q. 8. A wire of length l is in the form of a circular loop A of one turn. This loop is reshaped into loop B of three turns. Find the ratio of the magnetic fields at the centres of loop A and loop B for the same current through them. *[CBSE 2023 (55/3/1)]*

Ans. For circular loop A, $N = 1$, $n = 3$

$$B_A = \frac{\mu_0 I}{2r}$$

For circular loop B, $N = 3$, $I' = I$

As form given, $3\times2\pi r' = L$

$$6\pi r' = L$$

$$\therefore \quad r' = \frac{L}{6\pi} = \frac{1}{3}\left(\frac{L}{2\pi}\right) = \frac{r}{3} \qquad \left[\begin{array}{l}\because 2\pi r = L \\ \therefore r = \dfrac{L}{2\pi}\end{array}\right]$$

Now, $$B_B = \frac{\mu_0 NI'}{2r'} = \frac{\mu_0 3I}{2\left(\frac{r}{3}\right)} = \frac{9\mu_0 I}{2r}$$

Hence, ratio, $$\frac{B_A}{B_B} = \frac{\frac{\mu_0 I}{2r}}{\frac{9\mu_0 I}{2r}} = \mathbf{\frac{1}{9}}$$

Q. 9. A deuteron and an alpha particle having same momentum are in turn allowed to pass through a magnetic field $\vec{B}$, acting normal to the direction of motion of the particles. Calculate the ratio of the radii of the circular paths described by them. **[*CBSE 2019* (*55/1/2*)]**

Ans.

7. Mass of deuteron = 2u (m_D)
Mass of alpha particle = 4u (m_a)
Charge on deuteron = +e (q_D)
charge on α-particle = +2e (q_a)

$\left(\because \frac{mv^2}{r} = qvB\right)$

Radius of path of deuteron, $r_D = \frac{m_D v_D}{q_D B} = \frac{p_D}{q_D B}$

Radius of path of α-particle, $r_\alpha = \frac{m_\alpha v_\alpha}{q_\alpha B} = \frac{p_\alpha}{q_\alpha B}$

So, $\frac{r_D}{r_\alpha} = \frac{p_D}{p_\alpha} \frac{q_\alpha}{q_D} = \frac{2e}{e} = 2$

(as both have same momentum)

So, $r_D : r_\alpha = 2 : 1 = \frac{2}{1}$
(deuteron : α-particle)

[*Topper's Answer 2019*]

Q. 10. State two reasons why a galvanometer can not be used as such to measure current in a given circuit. **[*CBSE Delhi 2010*]**

OR

Can a galvanometer as such be used for measuring the current? Explain.

Ans. A galvanometer cannot be used as such to measure current due to following two reasons.

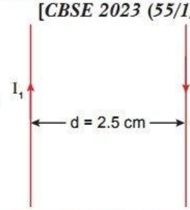
(*i*) A galvanometer has a finite large resistance and is connected in series in the circuit, so it will increase the resistance of circuit and hence change the value of current in the circuit.

(*ii*) A galvanometer is a very sensitive device, it gives a full scale deflection for the current of the order of microampere, hence if connected as such it will not measure current of the order of ampere.

Q. 11. Two long parallel straight wires *A* and *B* are 2.5 cm apart in air. They carry 5.0 A and 2.5 A currents respectively in opposite directions. Calculate the magnitude of the force exerted by wire *A* on a 10 cm length of wire *B*. **[*CBSE 2023* (*55/1/1*)]**

Ans. Here, $d = 2.5\text{ cm} = 2.5 \times 10^{-2}\text{ m}, I_1 = 5\text{A}, I_2 = 2.5\text{ A}$

$l = 10\text{ cm} = 10 \times 10^{-2}\text{ m}.$



When tin current flow in opposite direction, then they repel each other by magnetic force,

$$F = \frac{\mu_0 I_1 I_2 l}{2\pi d} = \frac{4\pi \times 10^{-7} \times 5 \times 2.5 \times 10 \times 10^{-2}}{2\pi \times 2.5 \times 10^{-2}} = \mathbf{10^{-5}\,N}.$$

Q. 12. 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 $\bar{B}$ inside the solenoid near its centre. **[*NCERT*]**

Ans. Given $I = 80\text{ cm} = 0.80\text{ m}, N = 5 \times 400 = 2000, I = 8.0\text{ A}$

Magnetic field inside the solenoid,

$$B = \mu_0 nI = \frac{\mu_0 NI}{l} = \frac{4\pi \times 10^{-7} \times 2000 \times 8.0}{0.80}$$

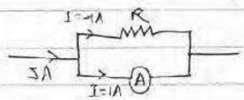
$$= 8\pi \times 10^{-3}\text{ T} = \mathbf{2.5 \times 10^{-2}\text{ T}}$$

Q. 13. An ammeter of resistance 0.8 Ω can measure a current up to 1.0 A. Find the value of shunt resistance required to convert this ammeter to measure a current up to 5.0A.[*CBSE 2020 (55/2/1)*]

Ans. Let the shunt resistance be of R Ω and it is connected in parallel with ammeter of resistance 0.8 Ω.

In the converted ammeter, 5 A current can enter.

∵ ammeter can take upto 1A, remaining 4A flows through shunt.



∵ R and ammeter are in parallel,

$4R = 1 \times 0.8$

$\Rightarrow R = \frac{0.8}{4} = 0.2\ \Omega$.

∴ value of shunt = 0.2 Ω (Ans)

[*Topper's Answer 2020*]

Short Answer Questions

Each of the following questions are of 3 marks.

Q. 1. Write any two important points of similarities and differences each between Coulomb's law for the electrostatic field and Biot-Savart's law for the magnetic field. [*CBSE (F) 2015*]

Ans. Similarities:

Both electrostatic field and magnetic field:

(*i*) follows the principle of superposition.

(*ii*) depends inversely on the square of distance from source to the point of interest.

Differences:

(*i*) Electrostatic field is produced by a scalar source (q) and the magnetic field is produced by a vector source $(I\vec{dl})$.

(*ii*) Electrostatic field is along the displacement vector between source and point of interest; while magnetic field is perpendicular to the plane, containing the displacement vector and vector source.

(*iii*) Electrostatic field is angle independent, while magnetic field is angle dependent between source vector and displacement vector.

Q. 2. A proton, a deuteron and an alpha particle, are accelerated through the same potential difference and then subjected to a uniform magnetic field $\vec{B}$, perpendicular to the direction of their motions. Compare (*i*) their kinetic energies, and (*ii*) if the radius of the circular path described by proton is 5 cm, determine the radii of the paths described by deuteron and alpha particle. [*CBSE 2019 (55/4/1)*]

Ans. (*i*) Since $qV = \frac{1}{2}mv^2$

For proton, $\frac{1}{2}m_p v_1^2 = qV$

For deuteron, $\frac{1}{2}m_d v_2^2 = qV$

For alpha particle $\frac{1}{2}m_\alpha v_3^2 = 2qV$

$(K.E.)_p : (K.E.)_d : (K.E.)_\alpha = \mathbf{1 : 1 : 2}$

(*ii*) We have, $Bqv = \frac{mv^2}{r}$ So, $r_p = \frac{mv}{Bq} = 5$ cm;

$$r_p : r_d : r_\alpha = v_p : v_d : v_\alpha = 1 : \sqrt{2} : \sqrt{2}$$

$\therefore$ $$r_d = 5\sqrt{2}\text{ cm}, \quad r_\alpha = 5\sqrt{2}\text{ cm}$$

Q. 3. (*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 counter-torque that must be applied to prevent the coil from turning.**

(*b*) **Would your answer change, if the circular coil in (*a*) were replaced by a planar coil of some irregular shape that encloses the same area?**
(All other particulars are also unaltered). **[*NCERT*]**

Ans. (*a*) Given $N = 30$, $A = \pi r^2 = \pi \times (8.0 \times 10^{-2})^2\ \text{m}^2$

$$I = 6.0\ A,\ B = 1.0\ \text{T},\ \theta = 60°$$

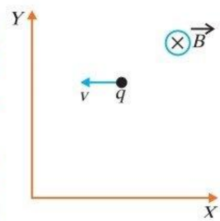
Torque $$\tau = NIAB \sin\theta$$
$$= 30 \times 6.0 \times \pi \times (8.0 \times 10^{-2})^2 \times 1.0 \times \sin 60°$$
$$= 30 \times 6.0 \times 3.14 \times 64 \times 10^{-4} \times \left(\frac{\sqrt{3}}{2}\right) = \mathbf{3.13\ Nm}$$

(*b*) As the expression for torque contains only area not the shape of coil, so torque on a planar loop will remain the same provided magnitude of area is same.

Q. 4. (*i*) **A point charge q moving with speed v enters a uniform magnetic field B that is acting into the plane of the paper as shown. What is the path followed by the charge q and in which plane does it move?**

(*ii*) **How does the path followed by the charge get affected if its velocity has a component parallel to $\vec{B}$?**

(*iii*) **If an electric field $\vec{E}$ is also applied such that the particle continues moving along the original straight line path, what should be the magnitude and direction of the electric field $\vec{E}$?** **[*CBSE (F) 2016*]**



Ans. (*i*) The force experienced by the charge particle is given by $\vec{F} = q(\vec{v} \times \vec{B})$ when $\vec{v}$ is perpendicular to $\vec{B}$, the force on the charge particle acts as the centripetal force and makes it move along a circular path. Path followed by charge is anticlockwise in *X*-*Y* plane. The point charge moves in the plane perpendicular to both $\vec{v}$ and $\vec{B}$.

(*ii*) A component of velocity of charge particle is parallel to the direction of the magnetic field, the force experienced due to that component will be zero. This is because $F = qvB \sin 0° = 0$. Thus, particle will move in straight line.

Also, the force experienced by the component perpendicular to $\vec{B}$ moves the particle in a circular path. The combined effect of both the components will move the particle in a helical path.

(*iii*) Magnetic force on the charge, q

$$\vec{F}_B = q(\vec{v} \times \vec{B}) = q(v(-\hat{i}) \times B(-\hat{k})) = qvB(-\hat{j})$$

Hence, for moving charge, q in its original path

$$\vec{F}_E + \vec{F}_B = 0$$
$$\vec{F}_E = qvB(\hat{j}) \qquad \therefore \quad \vec{E} = vB(\hat{j})$$

Taking magnitude both sides

$$|\vec{E}| = q\frac{vB}{q} = vB$$

Direction of Lorentz magnetic force is (–ve) y-axis. Therefore, direction of $\vec{E}$ is along (+ve) y-axis.

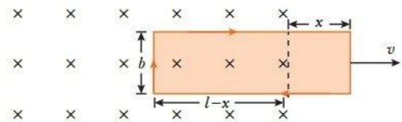
Q. 5. A rectangular loop which was initially inside the region of uniform and time - independent magnetic field, is pulled out with constant velocity v as shown in the figure.

(a) Sketch the variation of magnetic flux, the induced current, and power dissipated as Joule heat as function of time.

(b) If instead of rectangular loop, circular loop is pulled out; do you expect the same value of induced current? Sketch the variation of flux in this case with time. Justify your answer.

[*CBSE Sample Paper 2021*]

Ans. (*a*) We know that



$$\phi = \vec{B}\cdot\vec{A} = Blb = \text{constant}$$

at t, $$\phi = \vec{B}.\vec{A} = B(l-x)b$$

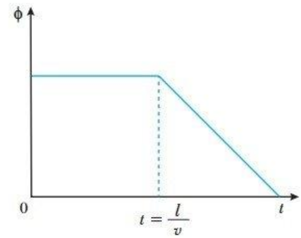
$$\phi = Bb(l-vt) = Bbl - Bvbt$$

$$\phi = \begin{cases} Blb & t=0 \\ Blb - Bbvt & t=t \end{cases}$$

Now, $$\varepsilon = -\frac{d\phi}{dt} = \frac{d}{dt}(Blb - Bvbt)$$

$$\varepsilon = Bvb$$

$$i = \frac{\varepsilon}{R} = \frac{Bvb}{R}$$

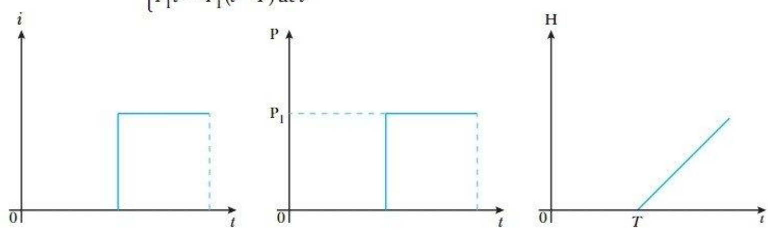


$$\varepsilon = \begin{cases} 0 \Rightarrow i = 0 \text{ at } t=0 \\ Bvb \Rightarrow i = \dfrac{Bvb}{R} = \text{constant at } t \end{cases}$$

$$P = VI$$

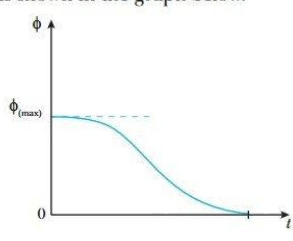
$$P = \begin{cases} 0 \text{ at } t=0 \\ (Bvb)\left(\dfrac{Bvb}{R}\right) = P_1 \text{ (let) at } t \end{cases}$$

$$H = Pt = \begin{cases} 0 \text{ at } t=0 \\ P_1 t = P_1(t-T) \text{ at } t \end{cases}$$



(*b*) When a circular loop is pulled out of a region of uniform magnetic field, the rate of change of area is not constant and hence the induced current varies accordingly.

The variation of flux is shown in the graph below.



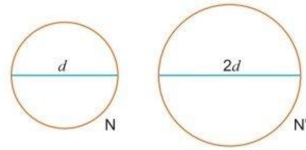
Q. 6. A circular coil of 'N' turns and diameter 'd' carries a current 'I'. It is unwound and rewound to make another coil of diameter '$2d$', current 'I' remaining the same. Calculate the ratio of the magnetic moments of the new coil and the original coil. [*CBSE (AI) 2012*]

Ans. We know,

magnetic moment (m) = NIA

where N = Number of turns

Then, length of wire remains same



Thus, $N \times \left[2\pi\left(\frac{d}{2}\right)\right] = N'\left[2\pi\left(\frac{2d}{2}\right)\right] \Rightarrow N' = \frac{N}{2}$

Now, $m_A = NIA_A = NI(\pi r_A^2) = \frac{1}{4}NI\pi d^2$

Similarly, $m_B = N'I\,A_B = \frac{NI}{2}(\pi r_B^2) = \frac{1}{2}(NI\pi d^2)$

$$\frac{m_B}{m_A} = \frac{\frac{1}{2}}{\frac{1}{4}} = \frac{2}{1} \Rightarrow \frac{m_B}{m_A} = \mathbf{\frac{2}{1}}$$

Q. 7. An α-particle and a proton of the same kinetic energy are in turn allowed to pass through a magnetic field $\vec{B}$, acting normal to the direction of motion of the particles. Calculate the ratio of radii of the circular paths described by them. [*CBSE 2019 (55/5/3)*]

Ans. The radius of circular path is given by

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

Let m_p and v_p are the mass of proton and velocity. Also m_α and v_α is the mass and velocity of α-particle.

According to question

$$\frac{1}{2}m_p v_p^2 = K \quad ...(i)$$

Also, $$\frac{1}{2}m_\alpha {v^2}_\alpha = K \quad ...(ii)$$

From equation (*i*), we have

$$m_p\, {v^2}_p = 2K$$

Momentum of proton $= m_p v_p = \sqrt{m_p 2K}$

Now, $r_p = \frac{\sqrt{2m_p K}}{qB}$

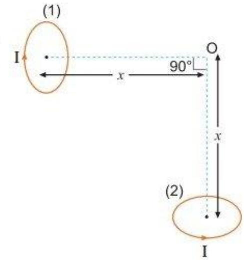
Similarly, $r_\alpha = \frac{\sqrt{2m_\alpha K}}{q_\alpha \beta}$ $\quad [\because q_\alpha = 2q_p]$

Now, $\frac{r_\alpha}{r_p} = \frac{\sqrt{2m_\alpha K}}{2q_p B} \times \frac{qpB}{\sqrt{2m_p K}}$ $\quad [\because m_\alpha = 4m_p]$

$$= \frac{1}{2}\sqrt{\frac{m_\alpha}{m_p}} = \frac{1}{2}\sqrt{\frac{4m_p}{m_p}} = \frac{1}{2} \times 2 = 1:1$$

$\therefore \quad r_\alpha : r_p = \mathbf{1:1}$

Q. 8. Two small identical circular loops, marked (1) and (2), carrying equal currents, are placed with the geometrical axes perpendicular to each other as shown in the figure. Find the magnitude and direction of the net magnetic field produced at the point *O*. **[*CBSE (F) 2013, 2014*]**

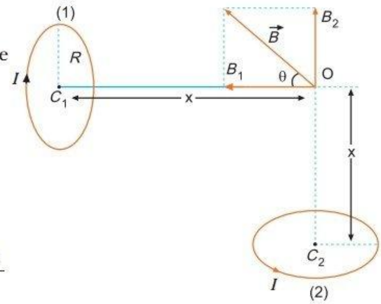


Ans. Magnetic field due to coil 1 at point O,

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

Magnetic field due to coil 2 at point O,

$$\vec{B}_2 = \frac{\mu_0 I R^2}{2(R^2+x^2)^{3/2}} \text{ along } \overrightarrow{C_2 O}$$



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

$$B = \sqrt{B_1^2 + B_2^2} = \sqrt{2}\, B_1 \text{ (as } B_1 = B_2)$$

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

As $R << x$,

$$B = \frac{\sqrt{2}\mu_0 I R^2}{2x^3} = \frac{\mu_0}{4\pi}\,\frac{2\sqrt{2}\,.\,I(\pi R^2)}{x^3} = \boldsymbol{\frac{\mu_0}{4\pi}\frac{2\sqrt{2}\,.\,IA}{x^3}}$$

where $A = \pi R^2$ is area of loop.

$$\tan\theta = \frac{B_2}{B_1} \Rightarrow \tan\theta = 1 \quad (\because B_2 = B_1) \Rightarrow \quad \theta = \boldsymbol{\frac{\pi}{4}}$$

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

Q. 9. Two identical coils *P* and *Q* each of radius *R* are lying in perpendicular planes such that they have a common centre. Find the magnitude and direction of magnetic field at the common centre of the two coils, if they carry currents equal to *I* and $\sqrt{3}$ *I* respectively. **[*CBSE (F) 2016, 2019 (55/5/1)*] [*HOTS*]**

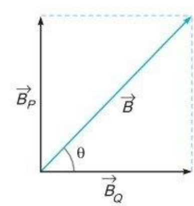
Ans. Given that two identical coils are lying in perpendicular planes and having common centre. P and Q carry current I and $\sqrt{3}\,I$ respectively.

Now, magnetic field at the centre of P due to its current I,

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

And, magnetic field at centre of Q due to its current $\sqrt{3}\,I$,

$$\vec{B}_Q = \frac{\mu_0\sqrt{3}I}{2R}$$



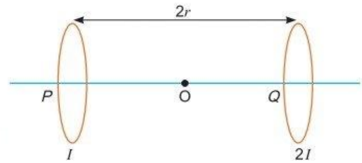
$$\therefore \qquad |B_{net}| = \sqrt{B_P^2 + B_Q^2}$$

$$= \sqrt{\left(\frac{\mu_0 I}{2R}\right)^2 + \left(\frac{\mu_0\sqrt{3}I}{2R}\right)^2} = \frac{\mu_0 I}{2R}\times 2 = \boldsymbol{\frac{\mu_0 I}{R}}$$

For direction,

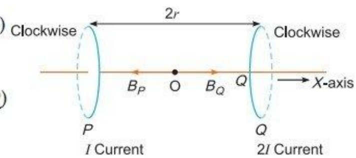
$$\therefore \qquad \tan\theta = \frac{|\vec{B}_P|}{|\vec{B}_Q|} = \left|\frac{\frac{\mu_0 I}{2R}}{\frac{\mu_0\sqrt{3}I}{2R}}\right| = \frac{1}{\sqrt{3}} \quad \Rightarrow \quad \theta = \tan^{-1}\left(\frac{1}{\sqrt{3}}\right) = \mathbf{30°}$$

Q. 10. **Two identical circular loops, P and Q, each of radius r and carrying currents I and $2I$ respectively are lying in parallel planes such that they have a common axis. The direction of current in both the loops is clockwise as seen from O which is equidistant from the both loops. Find the magnitude of the net magnetic field at point O.** **[*CBSE (Delhi) 2012*] [*HOTS*]**



Ans. As we know,

$$|\vec{B}_P| = \frac{\mu_0 r^2 I}{2(r^2+r^2)^{3/2}} = \frac{\mu_0 I}{4\sqrt{2}r} \text{ (Pointing towards } P)$$



$$|\vec{B}_Q| = \frac{\mu_0 (2I) r^2}{2(r^2+r^2)^{3/2}} = \frac{\mu_0 2I}{4\sqrt{2}r} \text{ (Pointing towards } Q)$$

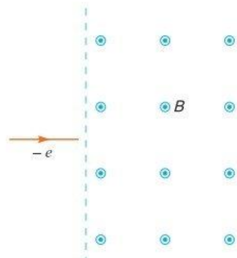
$$|\vec{B}| = |\vec{B}_Q| - |\vec{B}_P| = \boldsymbol{\frac{\mu_0 I}{4\sqrt{2}r}}$$

So, magnetic field at point O has a magnitude $\dfrac{\mu_0 I}{4\sqrt{2}r}$.

Q. 11. (*a*) **An electron moving horizontally with a velocity of 4×10^4 m/s enters a region of uniform magnetic field of 10^{-5} T acting vertically upward as shown in the figure. Draw its trajectory and find out the time it takes to come out of the region of magnetic field.**

(*b*) **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 magnetic field B. What is the magnitude of the magnetic field?**

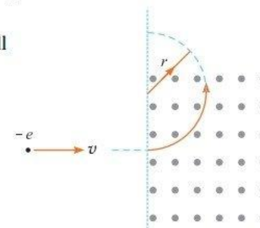
[*CBSE (F) 2015*] [*HOTS*]



Ans. (*a*) From Flemings left hand rule, the electron deflects in anticlockwise direction.

As the electron comes out the magnetic field region, it will describe a semi-circular path.

Magnetic force provides a centripetal force. So,

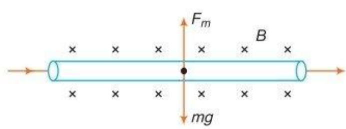


$$evB = \frac{mv^2}{r} \quad \text{or} \quad eB = \frac{mv}{r}$$

Time taken, $T = \dfrac{\pi r}{v} = \dfrac{\pi m}{eB}$

$$T = \frac{3.14 \times 9.1 \times 10^{-31}}{1.6 \times 10^{-19} \times 10^{-5}}$$

$$= \frac{3.14 \times 9.1 \times 10^{-7}}{1.6} = \mathbf{1.78 \times 10^{-6}\ s}$$



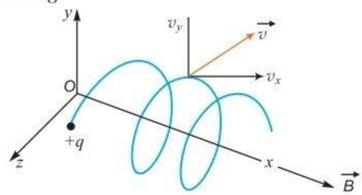
(*b*) If Ampere's force acts in upward direction and balances the weight, that is,

$$F_m = mg$$

$$BIl = mg \Rightarrow B = \frac{mg}{Il} = \frac{0.2 \times 10}{2 \times 1.5} = \frac{2}{3} = \mathbf{0.67\ T}$$

Q. 12. **A uniform magnetic field $\vec{B}$ is set up along the positive x-axis. A particle of charge 'q' and mass 'm' moving with a velocity $\vec{v}$ enters the field at the origin in X-Y plane such that it has velocity components both along and perpendicular to the magnetic field $\vec{B}$. Trace, giving reason, the trajectory followed by the particle. Find out the expression for the distance moved by the particle along the magnetic field in one rotation.** **[*CBSE Allahabad 2015*] [*HOTS*]**

Ans. If component v_x of the velocity vector is along the magnetic field, and remain constant, the charge particle will follow a helical trajectory; as shown in fig.



If the velocity component v_y is perpendicular to the magnetic field B, the magnetic force acts like a centripetal force qv_yB.

So, $qv_yB = \frac{mv_y^2}{r} \Rightarrow v_y = \frac{qBr}{m}$

Since tangent velocity $v_y = r\omega$

$\Rightarrow \quad r\omega = \frac{qBr}{m} \quad \Rightarrow \quad \omega = \frac{qB}{m}$

Time taken for one revolution, $T = \frac{2\pi}{\omega} = \frac{2\pi m}{qB}$

and the distance moved along the magnetic field in the helical path is

$$x = v_x.T = v_x.\frac{2\pi m}{qB}$$

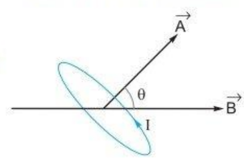
Q. 13. ***(a)*** ***(i)*** **A circular loop of area $\vec{A}$, carrying a current I is placed in a uniform magnetic field $\vec{B}$. Write the expression for the torque $\vec{\tau}$ acting on it in a vector form.**

(ii) **If the loop is free to turn, what would be its orientation of stable equilibrium? Show that in this orientation, the flux of net field (external field + the field produced by the loop) is maximum.**

(b) **Find out the expression for the magnetic field due to a long solenoid carrying a current I and having n number of turns per unit length.** [*CBSE (F) 2013*] [*HOTS*]

Ans. (*a*) (*i*) Torque acting on the current loop $\vec{\tau} = \vec{m} \times \vec{B} = I(\vec{A} \times \vec{B})$

(*ii*) If magnetic moment $\vec{m} = I\vec{A}$ is in the direction of external magnetic field *i.e.*, $\theta=0°$.



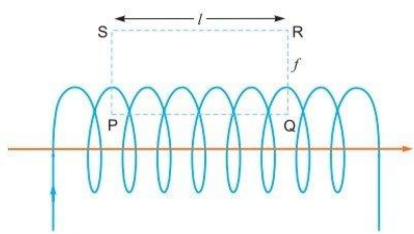
Magnetic flux $\phi_B = (\vec{B}_{ext} + B_C) \cdot \vec{A}$

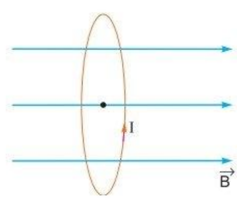
$$\phi_{max} = \left[|\vec{B}_{ext}| + \frac{\mu_0 I}{2r}\right] |A| \cos 0°$$

where r is radius of the loop.

(*b*) On applying Ampere's circuital law $\oint \vec{B}.\vec{dl} = \mu_0$ [Total current]

$$\Rightarrow \int_{PQ} \vec{B}.\vec{dl} + \int_{QR} \vec{B}.\vec{dl} + \int_{RS} \vec{B}.\vec{dl} + \int_{SP} \vec{B}.\vec{dl} = \mu_0 [n\ell I]$$





As no magnetic field exists in direction QR, RS and SP, so

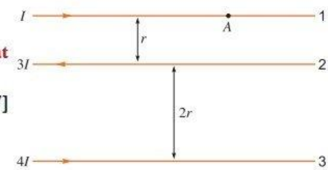
$$\int_0^l |\vec{B}| dl + 0 + 0 + 0 = \mu_0 n\ell I$$

$$\Rightarrow \quad |\vec{B}|\ell = \mu_0 n\ell I \quad \Rightarrow \quad \boldsymbol{B = \mu_0 nI}$$

Q. 14. The figure shows three infinitely long straight parallel current carrying conductors. Find the

(i) magnitude and direction of the net magnetic field at point A lying on conductor 1,

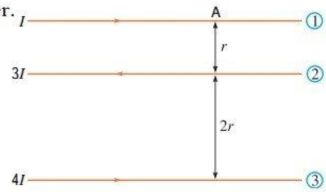
(ii) magnetic force on conductor 2. **[CBSE (F) 2017]**



Ans. (i) Magnetic field,

$$B_2 = \frac{\mu_0}{4\pi}\frac{2(3I)}{r} = \frac{\mu_0(6I)}{4\pi r} \text{ into the plane of the paper.}$$

$$B_3 = \frac{\mu_0}{4\pi}\frac{2(4I)}{3r} = \frac{\mu_0}{4\pi}\left(\frac{8I}{3r}\right) \text{ out of the plane of the paper.}$$



$$B_A = B_2 - B_3$$

$$= \boldsymbol{\frac{\mu_0}{4\pi}\frac{10I}{3r}} \text{ into the paper.}$$

(ii) Magnetic force per unit length on wire (2)

$$F = \frac{\mu_0}{2\pi r}.3I^2 - \frac{\mu_0 12I^2}{2\pi(2r)}$$

$$= \frac{3}{2}\frac{\mu_0 I^2}{\pi r} - 3\frac{\mu_0 I^2}{\pi r} = -\boldsymbol{\frac{3}{2}\frac{\mu_0 I^2}{\pi r}}$$

Hence, $F = \frac{3}{2}\frac{\mu_0 I^2}{\pi r}$ in the direction of wire (1).

Q. 15. (a) State the condition under which a charged particle moving with velocity v goes undeflected in a magnetic field B.

(b) An electron, after being accelerated through a potential difference of 10^4 V, enter a uniform magnetic field of 0.04 T, perpendicular to its direction of motion. Calculate the radius of curvature of its trajectory. **[CBSE (AI) 2017]**

Ans. (a) Force in magnetic field on a charged particle

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

If $F = 0$,

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

$$\Rightarrow \qquad \sin\theta = 0 \quad \Rightarrow \theta = \pm n\pi$$

So, magnetic field will be parallel or antiparallel to the velocity of charged particle.

(b) For a charged particle moving in a constant magnetic field and $\vec{v} \perp \vec{B}$

$$\frac{mv^2}{r} = qvB \quad \Rightarrow \quad r = \frac{mv}{qB} = \frac{p}{qB} \qquad ...(i)$$

If e is accelerated through a potential difference of 10^4 V, then

K. E of electron $= eV$

$$\Rightarrow \qquad \frac{p^2}{2m} = eV \quad \Rightarrow \quad p = \sqrt{2meV} \qquad ...(ii)$$

From (i) & (ii)

$$\Rightarrow \quad r = \frac{\sqrt{2meV}}{qB}$$

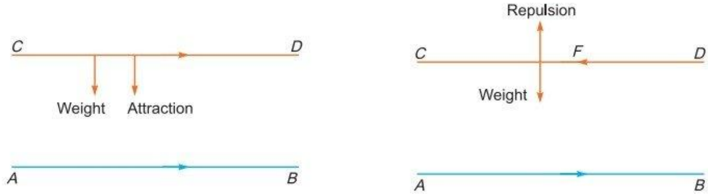
$$= \frac{\sqrt{2\times 9.1\times 10^{-31}\times 1.6\times 10^{-19}\times 10^4}}{1.6\times 10^{-19}\times 0.04}$$

$$= \frac{5.39\times 10^{-23}}{6.4\times 10^{-21}}\text{ m} = \mathbf{8.4\times 10^{-3}\ m}$$

Q. 16. A wire *AB* is carrying a steady current of 12 A and is lying on the table. Another wire *CD* carrying 5 A is held directly above *AB* at a height of 1 mm. Find the mass per unit length of the wire *CD* so that it remains suspended at its position when left free. Give the direction of the current flowing in *CD* with respect to that in *AB*. [Take the value of $g = 10 \text{ ms}^{-2}$]

[*CBSE (AI) 2013*]

Ans. Current carrying conductors repel each other, if current flows in the opposite direction.



Current carrying conductors attract each other if current flows in the same direction.

If wire *CD* remain suspended above *AB* then

$$F_{repulsion} = \text{Weight}$$

$$\frac{\mu_0 I_1 I_2 l}{2\pi r} = mg \qquad \text{where } r = \text{Separation between the wires}$$

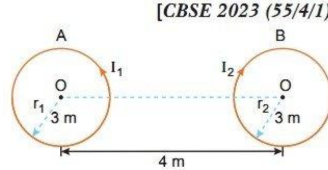
$$\therefore \qquad \frac{m}{l} = \frac{\mu_0 I_1 I_2}{2\pi r g}$$

$$= \frac{2 \times 10^{-7} \times 12 \times 5}{1 \times 10^{-3} \times 10}$$

$$= \mathbf{1.2 \times 10^{-3} \ kg / m}$$

Current in *CD* should be in opposite direction to that in *AB*.

Q. 17. Two circular loops *A* and *B*, each of radius 3 m, are placed coaxially at a distance of 4 m. They carry currents of 3 A and 2 A in opposite directions respectively. Find the net magnetic field at the centre of loop *A*. [*CBSE 2023 (55/4/1)*]



Ans. Given, $I_1 = 3$ A, $I_2 = 2$ A

$x = 4$ m, $r_1 = 3$ m, $r_2 = 3$ m

Magnetic field at centre of *A* due to *A*,

$$B_1 = \frac{\mu_o I_1}{2r} = \frac{4\pi \times 10^{-7} \times 3}{2 \times 3} = 2\pi \times 10^{-7} \text{ T (outward)}$$

Magnetic field at centre of *A* due to *B*,

$$B_2 = \frac{\mu_o I_2 R^2}{2(x^2 + R^2)^{3/2}} \frac{4\pi \times 10^{-7} \times 2 \times 9}{2\,(16+9)^{3/2}} = \frac{4\pi \times 10^{-7} \times 9}{125} \text{ T (inward)}$$

Now, net magnetic field at centre of *A*,

$$\therefore \quad B = B_1 - B_2 = 2\pi \times 10^{-7}\left(1 - \frac{18}{125}\right)$$

$$= 2\pi \times 10^{-7}\left(\frac{125-18}{125}\right)$$

$$= \frac{2\pi \times 10^{-7} \times 107}{125} = \mathbf{5.4 \times 10^{-7} \ T} \text{ (outward)}$$

Q. 18. The magnitude F of the force between two straight parallel current carrying conductors kept at a distance d apart in air is given by

$$F = \frac{\mu_0 I_1 I_2}{2\pi d}$$

where I_1 and I_2 are the currents flowing through the two wires.

Use this expression, and the sign convention that the:

"Force of attraction is assigned a negative sign and force of repulsion is assigned a positive sign".

Draw graphs showing dependence of F on

(*i*) $I_1 I_2$ when d is kept constant

(*ii*) d when the product $I_1 I_2$ is maintained at a constant positive value.

(*iii*) d when the product $I_1 I_2$ is maintained at a constant negative value.

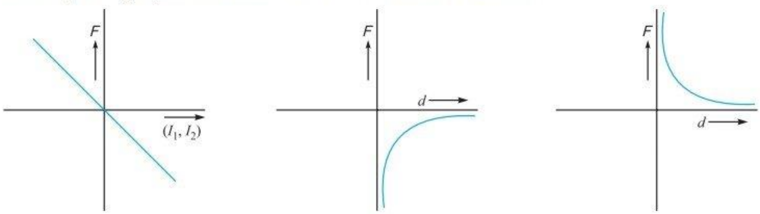
[*CBSE Sample Paper*] [*HOTS*]

Ans. We know that F is an **attractive (–ve)** force when the currents I_1 and I_2 are 'like' currents *i.e.*, when the product $I_1 I_2$ is positive.

Similarly F is a **repulsive (+ve)** force when the currents I_1 and I_2 are 'unlike' currents, *i.e.*, when the product $I_1 I_2$ is negative.

Now $F \propto (I_1 I_2)$, when d is kept constant and $F \propto \frac{1}{d}$ when $I_1 I_2$ is kept constant.

The required graphs, therefore, have the forms shown below:



(*i*) (*ii*) (*iii*)

Q. 19. (*a*) Briefly explain how a galvanometer is converted into an ammeter. **[*CBSE 2023 (55/2/1)*]**

(*b*) A galvanometer coil has a resistance of 15 Ω and it shows full scale deflection for a current of 4 mA. Convert it into an ammeter of range 0 to 6 A. **[*CBSE 2019 (55/4/1)*]**

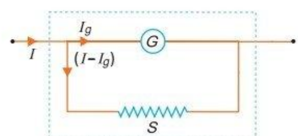
Ans. (*a*) By connecting a small resistance called shunt (S) in parallel to coil of the galvanometer. The value of S is related to the maximum current (I) to be measured as $S = \frac{I_g G}{I - I_g}$.

(*b*) Given,

$$G = 15\,\Omega$$

$$I_g = 4 \times 10^{-3}\,\text{A}$$

$$I = 6\,\text{A}$$



$$\because \quad I_g G = (I - I_g) S$$

$$S = \frac{I_g G}{I - I_g} = \frac{4 \times 10^{-3} \times 15}{6 - 4 \times 10^{-3}}$$

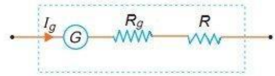
$$= 0.01\,\Omega$$

The galvanometer can be converted into ammeter of given range by connecting a shunt resistance of 0.01 Ω in parallel.

Q. 20. **(a) Briefly explain how a galvanometer is converted into a voltmeter.**

(b) A voltmeter of a certain range is constructed by connecting a resistance of 980 Ω in series with a galvanometer. When the resistance of 470 Ω is connected in series, the range gets halved. Find the resistance of the galvanometer. **[*CBSE 2019 (55/4/1)*]**

Ans. (a) A galvanometer may be converted into voltmeter by connecting a high value resistance R in series with coil of the galvanometer. The value of (R) is related to the maximum voltage (V) to be measured as $R = \frac{V}{I_g} - G$.



Voltmeter

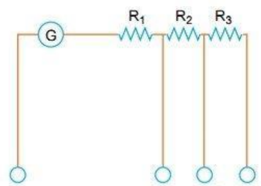
(b)
$$I_g = \frac{V}{R_g + R}$$

$$\Rightarrow \quad \frac{V}{R_g + 980} = \frac{V}{2(R_g + 470)}$$

$$\Rightarrow \quad 2R_g + 940 = R_g + 980 \quad \Rightarrow \quad R_g = \mathbf{40\,\Omega}$$

Q. 21. **A multirange voltmeter can be constructed by using a galvanometer circuit as shown in the figure. We want to construct a voltmeter that can measure 2 V, 20 V and 200 V using a galvanometer of resistance 10 Ω and that produces maximum deflection for current of 1 mA. Find the value of R_1, R_2 and R_3 that have to be used.**

[*NCERT Exemplar, CBSE Sample Paper 2018*]



Ans. Here, $G = 10\ \Omega$, $I_g = 1\text{ mA} = 10^{-3}\text{ A}$

Case (*i*), $\quad V = 2\text{ V}$

$$R_1 = \frac{V}{I_g} - G = \frac{2}{10^{-3}} - 10 = 1990\ \Omega \approx \mathbf{2\ k\,\Omega}$$

Case (*ii*) $\quad V = 20\text{ V}$

$$(R_1 + R_2) = \frac{20}{10^{-3}} - 10 = 20{,}000 - 10 \approx 20\text{ k}\Omega$$

$\therefore \quad R_2 = 20\text{ k}\Omega - 2\text{ k}\Omega = \mathbf{18\ k\,\Omega}$

Case (*iii*) $\quad V = 200\text{ V}$

$$\therefore \quad R_1 + R_2 + R_3 = \frac{200}{10^{-3}} - 10 \approx 200\text{ k}\Omega$$

$$\therefore \quad R_3 = 200\text{ k}\Omega - 20\text{ k}\Omega \approx \mathbf{180\ k\,\Omega}$$

Long Answer Questions

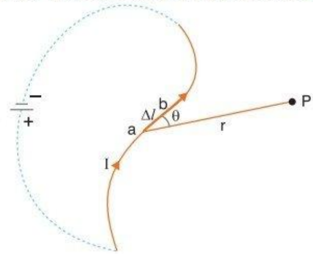
Each of the following questions are of 5 marks.

Q. 1. **State and explain Biot-Savart law. Use it to derive an expression for the magnetic field produced at a point near a long current carrying wire.** **[*CBSE 2019 (55/3/1)*]**

Ans. **Biot-Savart law:** Suppose the current I is flowing in a conductor and there is a small current element 'ab' of length Δl. According to Biot-Savart the magnetic field (ΔB) produced due to this current element at a point P distant r from the element is given by

$$\Delta B \propto \frac{I \Delta l \sin\theta}{r^2} \text{ or } \Delta B = \frac{\mu}{4\pi} \frac{I \Delta l \sin\theta}{r^2} \qquad ...(i)$$

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



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

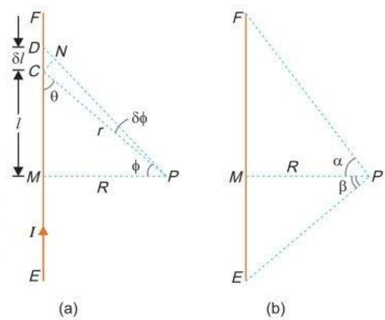
As in most cases the medium surrounding the conductor is air, therefore, in general, Biot-Savart law is written as

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

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

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

Derivation of formula for magnetic field due to a current carrying wire using Biot-Savart law: Consider a wire EF carrying current I in upward direction. The point of observation is P at a finite distance R from the wire. If PM is perpendicular dropped from P on wire; then $PM = R$. The wire may be supposed to be formed of a large number of small current elements. Consider a small element CD of length δl at a distance l from M.



(a) (b)

Let $\angle CPM = \phi$

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

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

The perpendicular dropped from C on PD is CN. The angle formed between element $I\,\vec{\delta l}$ and $\vec{r}\,(=\vec{CP})$ is $(\pi - \theta)$. Therefore according to Biot-Savart law, the magnetic field due to current element $I\vec{\delta l}$ at P is

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

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

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

∴ From equation (*i*)

$$\delta B = \frac{\mu_0}{4\pi}\frac{I\,r\,\delta\phi}{r^2} = \frac{\mu_0}{4\pi}\frac{I\,\delta\phi}{r} \qquad ...(ii)$$

Again from fig.

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

From equation (*ii*),

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

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

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

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

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

This is expression for magnetic field due to current carrying wire of finite length.

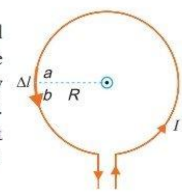
If the wire is of infinite length (or very long), then $\alpha = \beta \Rightarrow \pi/2$

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

Q. 2. (*i*) State Biot-Savart Law. Using this law, find an expression for the magnetic field at the centre of a circular coil of *N*-turns, radius *R*, carrying current *I*. [*CBSE 2019 (55/1/1), 2023 (55/1/1)*]

(*ii*) Sketch the magnetic field for a circular current loop, clearly indicating the direction of the field. [*CBSE (F) 2010, Central 2016, 2023 (55/1/1)*]

Ans. (*i*) **Biot-Savart Law:** Refer to above question



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

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

where θ is angle between current element *ab* and the line joining the element to the centre O. Here $\theta = 90°$ because current element at each point of circular path is perpendicular to the radius. Therefore magnetic field produced at O, due to current element *ab* is

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

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

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

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

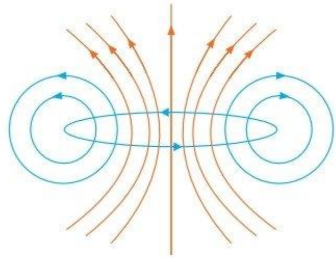
$$\therefore \quad B = \frac{\mu_0}{4\pi}\frac{I}{R^2}.2\pi R \quad \text{or} \quad B = \frac{\mu_0 I}{2R}$$

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

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

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

(*ii*) **Magnetic field lines due to a circular current loop:**

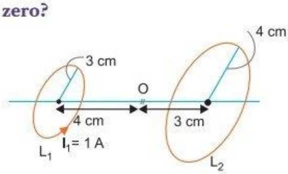


Q. 3. (*i*) **Derive an expression for the magnetic field at a point on the axis of a current carrying circular loop.** [*CBSE 2019 (55/3/1), 2023 (55/3/1)*]

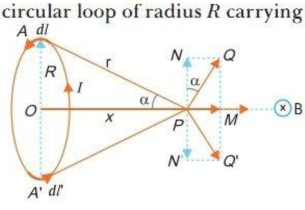
OR

Using Biot-Savart's law, derive an expression for magnetic field at any point on axial line of a current carrying circular loop. Hence, find magnitude of magnetic field intensity at the centre of circular coil. [*CBSE Sample Paper 2020*]

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



Ans. (*i*) **Magnetic field at the axis of a circular loop:** Consider a circular loop of radius R carrying current I, with its plane perpendicular to the plane of paper. Let P be a point of observation on the axis of this circular loop at a distance x from its centre O. Consider a small element of length dl of the coil at point A. The magnitude of the magnetic induction dB at point P due to this element is given by



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

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

$$\overrightarrow{dB} = \frac{\mu_0 I}{4\pi}\frac{dl\sin 90^\circ}{r^2} = \frac{\mu_0 I\,dl}{4\pi r^2}.$$

If we consider the magnetic induction produced by the whole of the circular coil, then by symmetry the components of magnetic induction perpendicular to the axis will be cancelled out, while those parallel to the axis will be added up. Thus the resultant magnetic induction $\vec{B}$ at axial point P is along the axis and may be evaluated as follows:

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

$$d\vec{B}_x = \frac{\mu_0 I\, dl}{4\pi r^2}\sin\alpha$$

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

$$\therefore \quad d\vec{B}_x = \frac{\mu_0 I dl}{4\pi r^2}\cdot\frac{R}{r} = \frac{\mu_0 IR}{4\pi r^3}dl = \frac{\mu_0 IR}{4\pi (R^2 + x^2)^{3/2}}dl$$

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

$$\vec{B} = \oint \frac{\mu_0 IR}{4\pi (R^2 + x^2)^{3/2}}dl = \frac{\mu_0 IR}{4\pi (R^2 + x^2)^{3/2}}\oint dl$$

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

Therefore, $$B = \frac{\mu_0 IR}{4\pi (R^2 + x^2)^{3/2}}(2\pi R)$$

$$\vec{B} = B_x\hat{i} = \frac{\mu_0 IR^2}{2(R^2 + x^2)^{3/2}}\hat{i}. \qquad \left[\text{At centre}, x = 0, \vec{B} = \frac{\mu_0 I}{2R}\right]$$

If the coil contains N turns, then

$$\boldsymbol{B = \frac{\mu_0 NIR^2}{2(R^2 + x^2)^{3/2}}} \textbf{ tesla.}$$

(ii) The magnetic field, $B = \frac{\mu_0 NIa^2}{2(a^2 + x^2)^{3/2}}$

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

$\therefore$ Magnetic field at O due to coil L_1 is

$$B_1 = \frac{\mu_0 \times 1 \times (3\times 10^{-2})^2}{2\left[(3\times 10^{-2})^2 + (4\times 10^{-2})^2\right]^{3/2}} = \frac{\mu_0(9\times 10^{-4})}{2\times 125\times 10^{-6}}$$

Magnetic field at O due to coil L_2 is

Here $a_2 = 4$ cm, $x_2 = 3$ cm

$$B_2 = \frac{\mu_0 \times I_2(4\times 10^{-2})^2}{2\left[(4\times 10^{-2})^2 + (3\times 10^{-2})^2\right]^{3/2}}$$

$$= \frac{\mu_0 I_2 \times 16\times 10^{-4}}{2\times 125\times 10^{-6}}$$

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

$$B_1 = B_2$$

$$\Rightarrow \quad \frac{\mu_0 \times 9\times 10^{-4}}{2\times 125\times 10^{-4}} = \frac{\mu_0 I_2\times 16\times 10^{-4}}{2\times 125\times 10^{-4}} \Rightarrow I_2 = \boldsymbol{\frac{9}{16}}\textbf{ A}$$

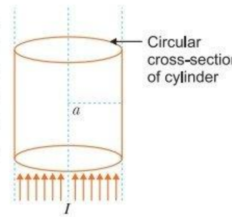
Q. 4. **(a)** **A straight thick long wire of uniform circular cross-section of radius 'a' is carrying a steady current I. The current is uniformly distributed across the cross-section. Use Ampere's circuital law to obtain a relation showing the variation of the magnetic field (B_r) inside and outside the wire with distance r, ($r \le a$) and ($r > a$) of the field point from the centre of its cross-section. What is the magnetic field at the surface of this wire? Plot a graph showing the nature of this variation.**

(b) **Calculate the ratio of magnetic field at a point $\frac{a}{2}$ above the surface of the wire to that at a point $\frac{a}{2}$ below its surface. What is the maximum value of the field of this wire?**

[*CBSE Delhi 2010; Chennai 2015*]

Ans. **(a)** **Magnetic field due to a straight thick wire of uniform cross-section:** Consider an infinitely long cylindrical wire of radius a, carrying current I. Suppose that the current is uniformly distributed over whole cross-section of the wire. The cross-section of wire is circular. Current per unit cross-sectional area.

$$i = \frac{I}{\pi a^2} \qquad \ldots(i)$$



Magnetic field at external points ($r > a$): We consider a circular path of radius r ($> a$) passing through external point P concentric with circular cross-section of wire. By symmetry the strength of magnetic field at every point of circular path is same and the direction of magnetic field is tangential to path at every point. So line integral of magnetic field $\vec{B}$ around the circular path

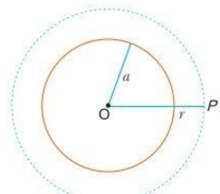
$$\oint \vec{B}.\vec{dl} = \oint B\, dl \cos 0° = B\, 2\pi r$$

Current enclosed by path = Total current on circular cross-section of cylinder = I

By Ampere's circuital law

$$\oint \vec{B}.\vec{dl} = \mu \times \text{current enclosed by path}$$

$$\Rightarrow \qquad B\, 2\pi r = \mu_0 \times I \quad \Rightarrow \quad B = \frac{\mu_0 I}{2\pi r}$$

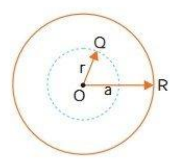


This expression is same as the magnetic field due to a long current carrying straight wire.

This shows that *for external points the current flowing in wire may be supposed to be concerned at the axis of cylinder.*

Magnetic Field at Internal Points ($r < a$) : Consider a circular path of radius r ($<a$), passing through internal point Q concentric with circular cross-section of the wire. In this case the assumed circular path encloses only a path of current carrying circular cross-section of the wire.

$$\therefore \text{ Current enclosed by path} = i \times \pi r^2 = \left(\frac{I}{\pi a^2}\right) \times \pi r^2 = \frac{Ir^2}{a^2}$$



$\therefore$ By Ampere's circuital law

$$\oint \vec{B}.\vec{dl} = \mu_0 \times \text{ current closed by path}$$

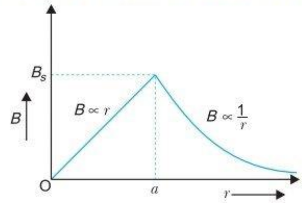
$$\Rightarrow \qquad B.2\pi r = \mu_0 \times \frac{Ir^2}{a^2} \quad \Rightarrow \quad B = \frac{\mu_0 I r}{2\pi a^2}$$

Clearly, magnetic field strength inside the current carrying wire is directly proportional to distance of the point from the axis of wire.

At surface of cylinder $r = a$, so magnetic field at surface of wire

$$B_S = \frac{\mu_0 I}{2\pi a} \text{ (maximum value)}$$

The variation of magnetic field strength (B) with distance (r) from the axis of wire for internal and external points is shown in figure.



(b) $B_{Outside} = \frac{\mu_0 I}{2\pi r} = \frac{\mu_0 I}{2\pi\left(a + \frac{a}{2}\right)} = \frac{\mu_0 I}{3\pi a}$

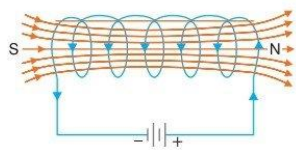
$$B_{inside} = \frac{\mu_0 I r}{2\pi a^2} = \frac{\mu_0 I (a/2)}{2\pi a^2} = \frac{\mu_0 I}{4\pi a}$$

$$\therefore \quad \frac{B_{outside}}{B_{inside}} = \frac{\mathbf{4}}{\mathbf{3}}$$

Maximum value of magnetic field is at the surface given by $B_S = \frac{\mu_0 I}{2\pi a}$.

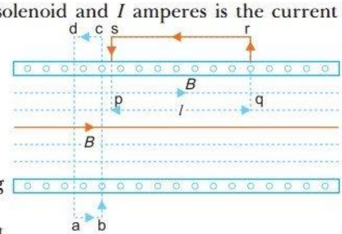
Q. 5. Using Ampere's circuital law find an expression for the magnetic field at a point on the axis of a long solenoid with closely wound turns. *[CBSE (F) 2010, 2019(55/2/1)]*

Ans. Magnetic field due to a current carrying long solenoid:



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

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



$$B = \mu_0 n I$$

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

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

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

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

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

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

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

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

Field inside the solenoid: Consider a closed path $pqrs$ The line integral of magnetic field $\vec{B}$ along path $pqrs$ is

$$\oint_{pqrs} \vec{B}.\vec{dl} = \int_{pq} \vec{B}.\vec{dl} + \int_{qr} \vec{B}.\vec{dl} + \int_{rs} \vec{B}.\vec{dl} + \int_{sp} \vec{B}.\vec{dl} \qquad ...(i)$$

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

$\therefore \quad \int_{pq} \vec{B}.\vec{dl} = \int B\,dl = Bl \qquad$ where, $pq = l$ (say)

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

$\therefore \quad \int_{qr} \vec{B}.\vec{dl} = \int_{sp} \vec{B}.d\vec{l} = \int B\,dl \cos 90^o = 0$

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

$\therefore \quad \int_{rs} \vec{B}.\vec{dl} = 0$

In view of these, equation (*i*) gives

$\therefore \quad \int_{pqrs} \vec{B}.\vec{dl} = \int_{pq} \vec{B}.\vec{dl} = Bl \qquad$ ...(*ii*)

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

$\Rightarrow \quad Bl = \mu_0\,(nl\,I) \quad \therefore B = \mu_0\,\boldsymbol{nI}$

Q. 6. Derive an expression for the force acting on a current carrying straight conductor kept in a magnetic field. State the rule which is used to find the direction of this force. Give the condition under which this force is (1) maximum, and (2) minimum. [*CBSE 2023 (55/1/1)*]

Ans. Force on a current carrying conductor on the basis of force on a moving charge: Consider a metallic conductor of length L, cross-sectional area A placed in a uniform magnetic field B and its length makes an angle θ with the direction of magnetic field B. The current in the conductor is I. According to free electron model of metals, the current in a metal is due to the motion of free electrons. When a conductor is placed in a magnetic field, the magnetic field exerts a force on every free-electron. The sum of forces acting on all electrons is the net force acting on the conductor. If v_d is the drift velocity of free electrons, then

current, $I = neAv_d \quad$ where n is number of free electrons per unit volume. $\qquad$ ...(*i*)

magnetic force on each electron $= ev_d B \sin\theta$

Its direction is perpendicular to both $\vec{v}_d$ and $\vec{B}$

Volume of conductor $V = AL$

Therefore, the total number of free electrons in the conductor $= nAL$

Net magnetic force on each conductor

$$F = (ev_d B \sin\theta)\,.\,(nAL) = (neAv_d).\,BL \sin\theta$$

Using equation (*i*), We get $F = IBL \sin\theta$

This is the general formula for the force acting on a current carrying conductor.

In vector form, $\quad \vec{\boldsymbol{F}} = I\,\vec{\boldsymbol{L}} \times \vec{\boldsymbol{B}}$

(1) Force will be maximum when $\sin\theta = 1$ or $\theta = 90°$. That is when length of conductor is perpendicular to magnetic field.

(2) For minimum, when, $\sin\theta = 0°$ or $\theta = 0°$ or $180°$

i.e., when length of conductor is parallel or anti parallel to magnetic field.

Q. 7. Two long straight parallel conductors carry steady current I_1 and I_2 separated by a distance d. If the currents are flowing in the same direction, show how the magnetic field set up in one produces an attractive force on the other. Obtain the expression for this force. Hence define one ampere. [*CBSE Delhi 2016*]

OR

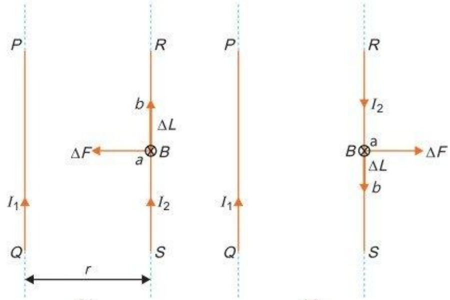
Derive an expression for the force per unit length between two long straight parallel current carrying conductors. Hence define SI unit of current (ampere).

[*CBSE (AI) 2009, 2010, 2012, Patna 2015, 2020 (55/3/1)*]

Ans. Suppose two long thin straight conductors (or wires) PQ and RS are placed parallel to each other in vacuum (or air) carrying currents I_1 and I_2 respectively. It has been observed experimentally that when the currents in the wire are in the same direction, they experience an attractive force (fig. *a*) and when they carry currents in opposite directions, they experience a repulsive force (fig. *b*).

Let the conductors PQ and RS carry currents I_1 and I_2 in same direction and placed at separation r. Consider a current–element 'ab' of length ΔL of wire RS. The magnetic field produced by current-carrying conductor PQ at the location of other wire RS

$$B_1 = \frac{\mu_0 I_1}{2\pi r}$$



(a) (b)

According to Maxwell's right hand rule or right hand palm rule number 1, the direction of B_1 will be perpendicular to the plane of paper and directed downward. Due to this magnetic field, each element of other wire experiences a force. The direction of current element is perpendicular to the magnetic field; therefore the magnetic force on element ab of length ΔL

$$\Delta F = B_1 I_2 \Delta L \sin 90^o = \frac{\mu_0 I_1}{2\pi r} I_2 \Delta L$$

$\therefore$ The total force on conductor of length L will be

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

$\therefore$ Force acting per unit length of conductor

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

According to Fleming's left hand rule, the direction of magnetic force will be towards PQ *i.e.*, the force will be attractive.

On the other hand if the currents I_1 and I_2 in wires are in opposite directions, the force will be repulsive. The magnitude of force in each case remains the same.

Definition of SI unit of Current (ampere): In SI system of fundamental unit of current 'ampere' is defined assuming the force between the two current carrying wires as standard.

The force between two parallel current carrying conductors of separation r is

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

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

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

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

Q. 8. Derive an expression for torque acting on a rectangular current carrying loop kept in a uniform magnetic field B. Indicate the direction of torque acting on the loop.

[CBSE Delhi 2013; (F) 2009, 2019 (55/1/1), 2020 (55/1/1)]

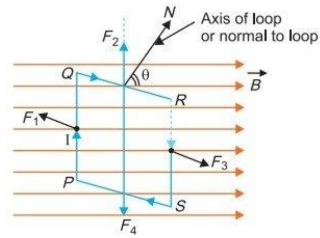
OR

Deduce the expression for the torque $\vec{\tau}$ acting on a planar loop of area $\vec{A}$ and carrying current I placed in a uniform magnetic field $\vec{B}$.

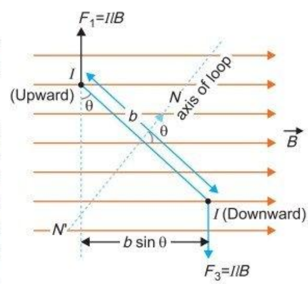
If the loop is free to rotate, what would be its orientation in stable equilibrium?

[CBSE Ajmer 2015]

Ans. **Torque on a current carrying loop:** Consider a rectangular loop *PQRS* of length l, breadth b suspended in a uniform magnetic field $\vec{B}$. The length of loop = $PQ = RS = l$ and breadth $QR = SP = b$. Let at any instant the normal to the plane of loop make an angle θ with the direction of magnetic field $\vec{B}$ and I be the current in the loop. We know that a force acts on a current carrying wire placed in a magnetic field. Therefore, each side of the loop will experience a force.



The net force and torque acting on the loop will be determined by the forces acting on all sides of the loop. Suppose that the forces on sides *PQ*, *QR*, *RS* and *SP* are $\vec{F}_1, \vec{F}_2, \vec{F}_3$ and $\vec{F}_4$ respectively. The sides *QR* and *SP* make angle (90°– θ) with the direction of magnetic field. Therefore each of the forces $\vec{F}_2$ and $\vec{F}_4$ acting on these sides has same magnitude $F' = Blb \sin (90° - \theta) = Blb \cos \theta$. According to Fleming's left hand rule the forces $\vec{F}_2$ and $\vec{F}_4$ are equal and opposite but their line of action is same. Therefore these forces cancel each other *i.e.*, the resultant of $\vec{F}_2$ and $\vec{F}_4$ is zero.



The sides *PQ* and *RS* of current loop are perpendicular to the magnetic field, therefore the magnitude of each of forces $\vec{F}_1$ and $\vec{F}_3$ is $F = IlB \sin 90° = IlB$.

According to Fleming's left hand rule the forces $\vec{F}_1$ and $\vec{F}_3$ acting on sides *PQ* and *RS* are equal and opposite, but their lines of action are different; therefore the resultant force of $\vec{F}_1$ and $\vec{F}_3$ is zero, but they form a couple called the ***deflecting couple***. When the normal to plane of loop makes an angle with the direction of magnetic field the perpendicular distance between F_1 and F_3 is $b \sin \theta$.

∴ Moment of couple or Torque,

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

But lb = area of loop $= A$ (say)

∴ Torque, $\tau = IAB \sin \theta$

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

In vector form $\vec{\tau} = NI\vec{A} \times \vec{B}$

The magnetic dipole moment of rectangular current loop $= M = NIA$

∴ $\vec{\tau} = \vec{M} \times \vec{B}$

Direction of torque is perpendicular to direction of area of loop as well as the direction of magnetic field *i.e.*, along $I\vec{A} \times \vec{B}$.

The current loop would be in stable equilibrium, if magnetic dipole moment is in the direction of the magnetic field $(\vec{B})$.

Q. 9. **Draw the labelled diagram of a moving coil galvanometer. Prove that in a radial magnetic field, the deflection of the coil is directly proportional to the current flowing in the coil.** **[*CBSE (F) 2012*]**

OR

(*a*) Draw a labelled diagram of a moving coil galvanometer. Describe briefly its principle and working.

(*b*) Answer the following:

(*i*) Why is it necessary to introduce a cylindrical soft iron core inside the coil of a galvanometer?

(*ii*) Increasing the current sensitivity of a galvanometer may not necessarily increase its voltage sensitivity. Explain, giving reason. **[*CBSE (AI) 2014*]**

OR

Explain, using a labelled diagram, the principle and working of a moving coil galvanometer. What is the function of (*i*) uniform radial magnetic field, (*ii*) soft iron core?

Define the terms (*i*) current sensitivity and (*ii*) voltage sensitivity of a galvanometer. Why does increasing the current sensitivity not necessarily increase voltage sensitivity?

[*CBSE Allahabad 2015, 2019 (55/1/2)*]

Ans.

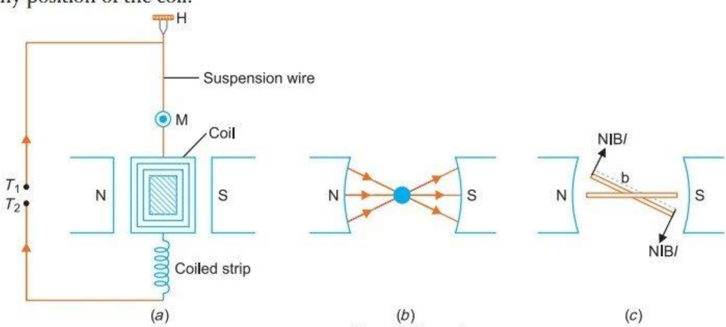
- **Moving coil galvanometer:** A galvanometer is used to detect current in a circuit.

Construction: It consists of a rectangular coil wound on a non-conducting metallic frame and is suspended by phosphor bronze strip between the pole-pieces (*N* and *S*) of a strong permanent magnet.

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

One end of coil is attached to suspension wire which also serves as one terminal (T_1) of galvanometer. The other end of coil is connected to a loosely coiled strip, which serves as the other terminal (T_2). The other end of the suspension is attached to a torsion head which can be rotated to set the coil in zero position. A mirror (*M*) is fixed on the phosphor bronze strip by means of which the deflection of the coil is measured by the lamp and scale arrangement. The levelling screws are also provided at the base of the instrument.

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



(*a*) (*b*) Magnetic lines of force of radial magnetic field (*c*)

Principle and working: When current (*I*) is passed in the coil, torque τ acts on the coil, given by $\tau = NIAB \sin\theta$

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

A current carrying coil, in the presence of a magnetic field, experiences a torque, which produces proportionate deflection.

i.e., Deflection, $\theta \propto \tau$ (Torque)

Q. 9. Draw the labelled diagram of a moving coil galvanometer. Prove that in a radial magnetic field, the deflection of the coil is directly proportional to the current flowing in the coil. [*CBSE (F) 2012*]

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[*CBSE Allahabad 2015, 2019 (55/1/2)*]

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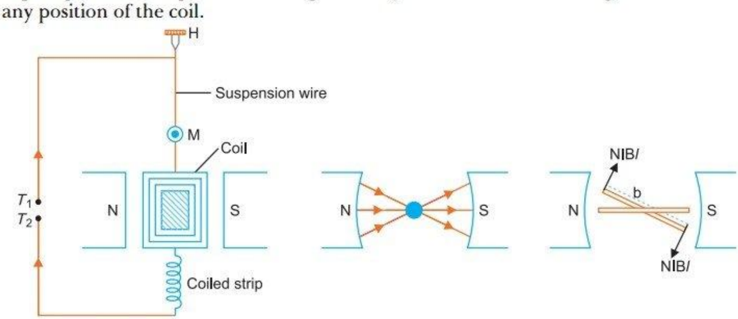


(*a*) (*b*) (*c*)

Magnetic lines of force of radial magnetic field

Principle and working: When current (*I*) is passed in the coil, torque τ acts on the coil, given by

$\tau = NIAB \sin\theta$

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

A current carrying coil, in the presence of a magnetic field, experiences a torque, which produces proportionate deflection.

i.e., Deflection, $\theta \propto \tau$ (Torque)

When the magnetic field is radial, as in the case of cylindrical pole pieces and soft iron core, then in every position of coil the plane of the coil, is parallel to the magnetic field lines, so that $\theta = 90°$ and $\sin 90° = 1$. The coil experiences a uniform coupler.

Deflecting torque, $\tau = NIAB$

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

For equilibrium, deflecting torque = restoring torque

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

$\therefore$ $$\theta = \frac{NAB}{C} I \qquad ...(i)$$

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

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

Importance (or function) of uniform radial magnetic field: Torque for current carrying coil in a magnetic field is $\tau = NIAB \sin\theta$

In radial magnetic field $\sin\theta = 1$, so torque is $\tau = NIAB$

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

- The cylindrical, soft iron core makes the field radial and increases the strength of the magnetic field, *i.e.*, the magnitude of the torque.

Sensitivity of galvanometer :

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

Sensitivity, $$S_I = \left(\frac{\theta}{I}\right) = \frac{NAB}{C} \qquad ...(ii)$$

Voltage sensitivity: It is defined as the deflection of coil per unit potential difference across its ends

i.e., $$S_V = \frac{\theta}{V} = \frac{NAB}{R_g . C}, \qquad ...(iii)$$

where R_g is resistance of galvanometer.

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

Dividing (*iii*) by (*ii*)

$$\frac{S_V}{S_I} = \frac{1}{G} \Rightarrow S_V = \frac{1}{G} S_I$$

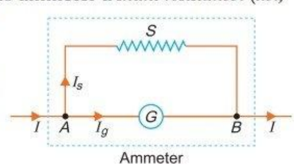
Clearly the voltage sensitivity depends on current sensitivity and the resistance of galvanometer. If we increase current sensitivity then it is not certain that voltage sensitivity will be increased. Thus, the increase of current sensitivity does not imply the increase of voltage sensitivity.

Q. 10. With the help of a circuit, show how a moving coil galvanometer can be converted into an ammeter of a given range. Write the necessary mathematical formula. *[CBSE 2023 (55/2/1)]*

Ans. Conversion of galvanometer into ammeter

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

The resistance of an ammeter is to be made as low as possible so that it may read current without any appreciable error. Therefore to convert a galvanometer into ammeter a *shunt resistance*. (*i.e.,* small resistance in parallel) is connected across the coil of galvanometer.



Ammeter

Let G be the resistance of galvanometer and I_g the current required for full scale deflection. Suppose this galvanometer is to converted into ammeter of range I ampere and the value of shunt required is S. If I_s is current in shunt, then from fig.

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

Also potential difference across A and B

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

Substituting value of I_S from (*i*), we get

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

or $IS - I_g S = I_g G$ or $IS = I_g (S+G)$

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

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

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

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

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

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

Remark: An ideal ammeter has zero resistance.

Q. 11. A galvanometer of resistance G is converted into a voltmeter to measure upto V volts by connecting a resistance R_1 in series with the coil. If a resistance R_2 is connected in series with it, then it can measure upto $V/2$ volts. Find the resistance, in terms of R_1 and R_2, required to be connected to convert it into a voltmeter that can read upto 2 V. Also find the resistance G of the galvanometer in terms of R_1 and R_2. [*CBSE Delhi 2015*]

OR

To convert a given galvanometer into a voltmeter of ranges $2V$, V and $\frac{V}{2}$ volt, resistance R_1, R_2 and R_3 ohm respectively, are required to be connected in series with the galvanometer. Obtain the relationship between R_1, R_2 and R_3. [*CBSE 2020 (55/3/1)*]

Ans. Let I_g be the current through galvanometer at full deflection

To measure V volts, $V = I_g (G + R_1)$ ...(*i*)

For $\frac{V}{2}$ volts, $\frac{V}{2} = I_g (G + R_2)$ ...(*ii*)

and 2 V volts, $2\text{ V} = I_g (G + R_3)$ ...(*iii*)

To measure for conversion of range dividing (*i*) by (*ii*),

$$2 = \frac{G + R_1}{G + R_2} \Rightarrow G = R_1 - 2R_2$$

Putting the value of G in (*i*), we have

$$I_g = \frac{V}{R_1 - 2R_2 + R_1} \Rightarrow I_g = \frac{V}{2R_1 - 2R_2}$$

Substituting the value of G and I_g in equation (*iii*), we have

$$2V = \frac{V}{2R_1 - 2R_2}(R_1 - 2R_2 + R_3)$$

$$4R_1 - 4R_2 = R_1 - 2R_2 + R_3$$

$$\mathbf{R_3 = 3R_1 - 2R_2}$$

Questions for Practice

1. **Choose and write the correct option in the following questions.**

(*i*) A current loop in a magnetic field

(*a*) can be in equilibrium in two orientations, both the equilibrium states are unstable.

(*b*) can be in equilibrium in two orientations, one stable while the other is unstable.

(*c*) experiences a torque whether the field is uniform or non uniform in all orientations.

(*d*) can be in equilibrium in one orientation.

(*ii*) A charge particle after being accelerated through a potential difference '*V*' enters in a uniform magnetic field and moves in a circle of radius *r*. If *V* is doubled, the radius of the circle will become **[*CBSE 2020 (55/5/1)*]**

(*a*) $2r$ (*b*) $\sqrt{2}r$

(*c*) $4r$ (*d*) $r/\sqrt{2}$

(*iii*) Two parallel conductors carrying current of 4.0 A and 10.0 A are placed 2.5 cm apart in vacuum. The force per unit length between them is **[*CBSE 2022 (55/2/4), Term-1*]**

(*a*) 6.4×10^{-5} N/m (*b*) 6.4×10^{-2} N/m

(*c*) 4.6×10^{-4} N/m (*d*) 3.2×10^{-4} N/m

(*iv*) The coil of a moving coil galvanometer is wound over a metal frame in order to **[*CBSE Sample Paper-2022, Term-1*]**

(*a*) reduce hysteresis (*b*) increase sensitivity

(*c*) increase moment of inertia (*d*) provide electromagnetic damping

(*v*) Two wires of the same length are shaped into a square of side '*a*' and a circle with radius '*r*'. If they carry same current, the ratio of their magnetic moment is **[*CBSE Sample Paper-2022, Term-1*]**

(*a*) $2 : \pi$ (*b*) $\pi : 2$

(*c*) $\pi : 4$ (*d*) $4 : \pi$

2. ***In the following questions, a statement of Assertion (A) is followed by a statement of Reason (R). Choose the correct answer out of the following choices.***

(a) ***Both A and R are true and R is the correct explanation of A.***

(b) ***Both A and R are true but R is not the correct explanation of A.***

(c) ***A is true but R is false.***

(d) ***A is false and R is also false.***

(*i*) **Assertion (*A*) :** Two parallel conducting wires carrying currents in same direction, come close to each other.

Reason (*R*) : Parallel currents attract and anti parallel currents repel.

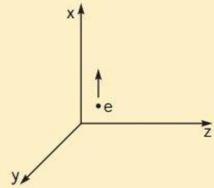
(*ii*) **Assertion (*A*) :** An electron moving along the direction of magnetic field experiences no force.

Reason (*R*) : The force on electron moving along the direction of magnetic field is

$$F = qvB \sin 0° = 0$$

3. An electron with charge $-e$ and mass m travels at a speed v in a plane perpendicular to a magnetic field of magnitude B. The electron follows a circular path of radius R. In a time t, the electron travels halfway around the circle. What is the amount of work done by the magnetic field? **[*CBSE Sample Paper 2021*]**

4. A beam of electrons projected along $+x$-axis, experiences a force due to a magnetic field along the $+y$-axis. What is the direction of the magnetic field?

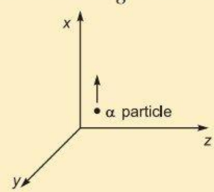


5. A horizontal overhead power line carries a current of 90 A in east to west direction. What is the magnitude and direction of the magnetic field due to the current at a distance 1.5 m below the line? *[NCERT]*

6. 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 magnetic field $\vec{B}$ at the centre of the coil? *[NCERT]*

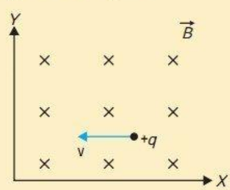
7. Two long and parallel straight wires A and B carrying currents of 8.0 A and 5.0 A in the same direction are separated by a distance of 4.0 cm. Estimate the force on a 10 cm section of wire A. *[NCERT]*

8. A beam of α particles projected along + x-axis, experiences a force due to a magnetic field along the + y-axis. What is the direction of the magnetic field? *[CBSE (AI) 2010]*



9. Two long and parallel straight wires carrying currents of 2 A and 5 A in the opposite directions are separated by a distance of 1 cm. Find the nature and magnitude of the magnetic force between them. *[CBSE (F) 2011]*

10. A point charge is moving with a constant velocity perpendicular to a uniform magnetic field as shown in the figure. What should be the magnitude and direction of the electric field so that the particle moves undeviated along the same path?



11. (*a*) Obtain the conditions under which an electron does not suffer any deflection while passing through a magnetic field.

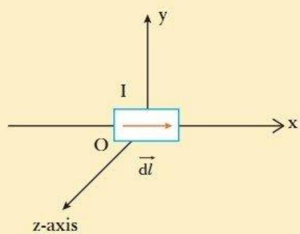
(*b*) Two protons P and Q moving with the same speed pass through the magnetic fields $\vec{B}_1$ and $\vec{B}_2$ respectively, at right angles to the field directions. If $|\vec{B}_2| > |\vec{B}_1|$, which of the two protons will describe the circular path of smaller radius? Explain. *[CBSE 2019 (55/5/1)]*

12. Consider the current (I) carrying circular coil placed in YZ plane with its centre at the origin. Derive expression for the value of magnetic field due to it at point $(x, 0, 0)$. *[CBSE 2020 (55/1/1)]*

13. Show that a current carrying solenoid behaves like a small bar magnet. Obtain the expression for the magnetic field at an external point lying on its axis. *[CBSE 2020 (55/4/1)]*

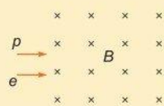
14. (*a*) Depict the magnetic field lines due to a circular current carrying loop showing the direction of field lines.

(*b*) A current I is flowing in a conductor placed along the x-axis as shown in the figure. Find the magnitude and direction of the magnetic field due to a small current element $\vec{dl}$ lying at the origin at points (*i*) $(0, d, 0)$ and (*ii*) $(0, 0, d)$. *[CBSE 2020 (55/4/3)]*



15. A proton, a deuteron and an alpha particle, are accelerated through the same potential difference and then subjected to a uniform magnetic field $\vec{B}$, perpendicular to the direction of their motions. Compare (*i*) their kinetic energies, and (*ii*) if the radius of the circular path described by deuteron is 5 cm, determine the radii of the paths described by proton and alpha particle.

16. An electron and a proton enter a region of uniform magnetic field B with uniform speed v in a perpendicular direction (fig.).



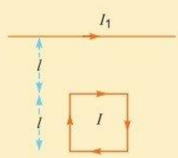
(*i*) Show the trajectories followed by two particles.

(*ii*) What is the ratio of the radii of the circular paths of electron to proton? *[CBSE (F) 2010]*

17. Write the expression for the magnetic moment $(\vec{M})$ 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.

[HOTS][CBSE Delhi 2010]



18. 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 $4.8 \times 10^6\ ms^{-1}$ normal to the field. Explain why the path of electron is a circle. Determine the radius of the circular orbit. ($e = 1.6 \times 10^{-19}$ C, $m = 9.1 \times 10^{-31}$ kg). **[*NCERT*]**

19. Two moving coil meters M_1 and M_2 have the following particulars:

$$R_1 = 10\ \Omega,\ N_1 = 30,\ A_1 = 3.6 \times 10^{-3}\ m^2,\ B_1 = 0.25\ T$$
$$R_2 = 14\ \Omega,\ N_2 = 42,\ A_2 = 1.8 \times 10^{-3}\ m^2,\ B_2 = 0.50\ T$$

(The spring constants are identical for the two meters).

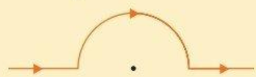
Determine the ratio of (*a*) current sensitivity and (*b*) voltage sensitivity of M_1 and M_2. **[*NCERT*]**

20. (*a*) State and explain the law used to determine magnetic field at a point due to a current element. Derive the expression for the magnetic field due to a circular current carrying loop of radius r at its centre.

(*b*) A long wire with a small current element of length 1 cm is placed at the origin and carries a current of 10 A along the *X*-axis. Find out the magnitude and direction of the magnetic field due to the element on the *Y*-axis at a distance 0.5 m from it.

21. (*a*) Derive the expression for the magnetic field due to a current carrying coil of radius r at a distance x from the centre along the *X*-axis.

(*b*) A straight wire carrying a current of 5 A is bent into a semicircular arc of radius 2 cm as shown in the figure. Find the magnitude and direction of the magnetic field at the centre of the arc.



22. A long straight wire carries a current of 35 A. What is the magnitude of magnetic field $\vec{B}$ at a point 20 cm from the wire? **[*NCERT*]**

23. (*i*) Write the principle and explain the working of a moving coil galvanometer. A galvanometer as such cannot be used to measure the current in a circuit. Why?

(*ii*) Why is the magnetic field made radial in a moving coil galvanometer? How is it achieved? **[*CBSE 2023 (55/3/1)*]**

Answers

1. (*i*) (*b*) (*ii*) (*b*) (*iii*) (*d*) (*iv*) (*d*) (*v*) (*c*)

2. (*i*) (*a*) (*ii*) (*a*)

3. Zero **5.** 1.2×10^{-5} T

6. 3.14×10^{-4} T **7.** 2×10^{-5} N **9.** 20×10^{-5} N, repulsive

15. (*i*) 1 : 1 : 2 (*ii*) $\frac{5}{\sqrt{2}}$ cm, 5 cm **18.** 4.2 cm **19.** (*a*) 1.4 (*b*) 1

20. (*b*) 4×10^{-8} T **21.** (*b*) 7.85×10^{-5} T **22.** 3.5×10^{-5} T