NCERT SOLUTIONS

Class 12 Physics

Chapter 4: Moving Charges and Magnetism

Detailed Step-by-Step Exercise Solutions

Q1 **A circular coil of wire consisting of 100 turns, each of radius 8.0 cm carries a current of 0.40 A. What is the magnitude of the magnetic field B at the centre of the coil?**

Solution

The magnetic field at the centre of a circular coil of N turns, radius r and current I follows directly from the Biot–Savart law applied around the loop.

Step 1: Note the given quantities.

$$N = 100, \quad r = 8.0 \text{ cm} = 0.08 \text{ m}, \quad I = 0.40 \text{ A}.$$

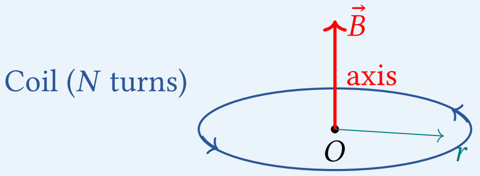
Step 2: Apply the formula for field at the centre of a coil.

$$B = \frac{\mu_0 N I}{2r}, \qquad \mu_0 = 4\pi \times 10^{-7} \text{ T m A}^{-1}.$$

Step 3: Substitute.

$$B = \frac{(4\pi \times 10^{-7})(100)(0.40)}{2 \times 0.08} = \frac{4\pi \times 10^{-7} \times 40}{0.16} = \pi \times 10^{-4} \text{ T} \approx 3.14 \times 10^{-4} \text{ T}.$$

The direction is along the axis of the coil, set by the right–hand thumb rule.



Therefore, the magnitude of the magnetic field at the centre of the coil is 3.14×10^{-4} T.

Expert's Solution — Anita Desai, B.Tech ECE, BITS Pilani

Using Biot–Savart on a single element and exploiting symmetry:
The standard formula already follows from Biot–Savart, but here we derive it directly to expose what the $1/(2r)$ really means.

Step 1: Field from one current element.
For a single element $\vec{dl}$ on the loop, distance r from the centre, the angle between $\vec{dl}$ and the radius vector is 90°, so

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

Step 2: Integrate around the full circumference.
By symmetry every element contributes the same magnitude in the same direction (along the axis), so

$$B = \int dB = \frac{\mu_0\,I}{4\pi\,r^2}(2\pi r) = \frac{\mu_0\,I}{2r}.$$

Step 3: Multiply by N turns.

$$B = \frac{\mu_0\,N\,I}{2r} = \frac{(4\pi\times10^{-7})(100)(0.40)}{2(0.08)} \approx 3.14\times10^{-4}\ \text{T}.$$

Did You Know?

This is roughly six times the Earth's magnetic field at the surface ($\sim 5\times10^{-5}$ T), so a small compass placed at the centre would clearly swing toward the coil's axis. Hand–cranked dynamos used in old telephone exchanges generated fields in this same range.

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

Solution

A long straight wire produces circular field lines centred on the wire; the magnitude depends only on the perpendicular distance.

Step 1: Note the given quantities.

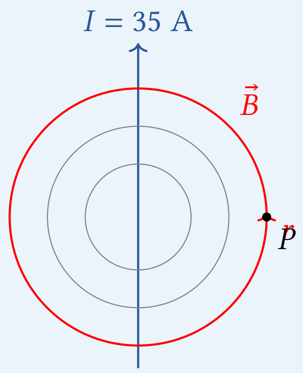
$$I = 35\text{ A}, \qquad r = 20\text{ cm} = 0.20\text{ m}.$$

Step 2: Use the long–wire formula (from Ampère's circuital law).

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

Step 3: Substitute.

$$B \;=\; \frac{(4\pi\times10^{-7})(35)}{2\pi(0.20)} \;=\; \frac{2\times10^{-7}\times35}{0.20} \;=\; 3.5\times10^{-5}\text{ T}.$$



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

Expert's Solution — Ramesh Iyengar, PhD Theoretical Physics, TIFR Mumbai

Via Ampère's circuital law from first principles:

We can short–circuit the calculation by recognising the cylindrical symmetry of the problem. The field magnitude is constant on every circle concentric with the wire.

Step 1: Choose a circular Amperian loop of radius r centred on the wire.

By symmetry $\vec{B}$ is tangent to this loop with the same magnitude B everywhere on it.

$$\oint \vec{B}\cdot d\vec{l} \;=\; B\,(2\pi r) \;=\; \mu_0\, I_{\text{enc}}.$$

Step 2: Solve for B.

$$B \;=\; \frac{\mu_0\, I}{2\pi r} \;=\; \frac{(4\pi\times10^{-7})(35)}{2\pi(0.20)} \;=\; 3.5\times10^{-5}\text{ T}.$$

Step 3: Direction by the right–hand rule.

If the right thumb points along I, the fingers curl in the direction of $\vec{B}$ on every circle.

Did You Know?

A field of 3.5×10^{-5} T is comparable in magnitude to the horizontal component of Earth's magnetic field. This is why a compass placed near a current–carrying wire deflects noticeably — the very effect Oersted observed in 1820 when he discovered the link between electricity and magnetism.

Q3 A long straight wire in the horizontal plane carries a current of 50 A in the north–to–south direction. Give the magnitude and direction of B at a point 2.5 m east of the wire.

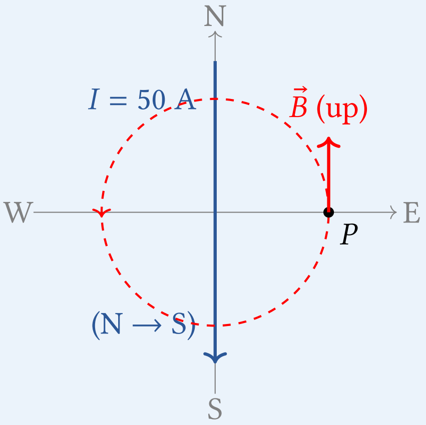
Solution

Step 1: Magnitude.

$$I = 50\ \text{A}, \qquad r = 2.5\ \text{m}.$$

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

Step 2: Direction — right–hand thumb rule.
Point the right thumb along the current (N ⟶ S, i.e. towards the south). The fingers then curl from the west, dip below the wire, come up on the east side, and pass overhead back to the west.
So at the point 2.5 m east of the wire, the field points *vertically upward.*



Therefore, $|\vec{B}| = 4 \times 10^{-6}$ T, directed vertically upward.

Expert's Solution — Vikram Singh, B.Sc Physics, Delhi University

Vector form of Biot–Savart for a quick direction check:
The result direction can also be obtained by treating the field as $\vec{B} \propto \vec{I} \times \hat{r}$, where $\hat{r}$ points *from* the wire *to* the field point.

Step 1: Set up unit vectors.
Take $\hat{x}$ = East, $\hat{y}$ = North, $\hat{z}$ = vertical up. The current flows along $-\hat{y}$ (north → south), and the field point is at $+\hat{x}$ from the wire.

Step 2: Compute $\vec{I} \times \hat{r}$.

$$(-\hat{y}) \times (+\hat{x}) \;=\; -(\hat{y} \times \hat{x}) \;=\; -(-\hat{z}) \;=\; +\hat{z}.$$

So $\vec{B}$ at P points along $+\hat{z}$, i.e. vertically upward.

Step 3: Magnitude — same as before.

$$B \;=\; \frac{\mu_0 I}{2\pi r} \;=\; 4 \times 10^{-6}\ \mathrm{T}.$$

Did You Know?

This is why high–tension overhead transmission lines, which carry hundreds of amperes, must be kept far from sensitive magnetic instruments. Even at 2.5 m the field is already an appreciable fraction of Earth's, and at 25 cm it would be a hundred times stronger.

Q4 A horizontal overhead power line carries a current of 90 A in the east–to–west direction. What is the magnitude and direction of the magnetic field due to the current 1.5 m below the line?

Solution

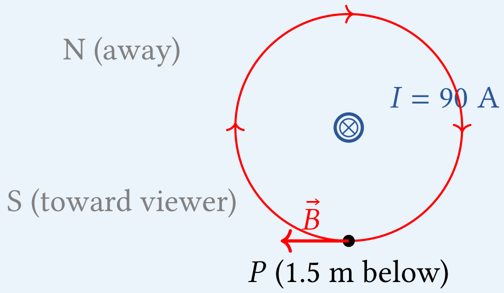
Step 1: Magnitude.

$$I = 90\ \mathrm{A}, \qquad r = 1.5\ \mathrm{m}.$$

$$B \;=\; \frac{\mu_0 I}{2\pi r} \;=\; \frac{(4\pi \times 10^{-7})(90)}{2\pi(1.5)} \;=\; 1.2 \times 10^{-5}\ \mathrm{T}.$$

Step 2: Direction.
Point the right thumb along the current (E → W). The fingers curl: above the wire they point north, below the wire they point south.

(viewed from the south; current ⊗ goes E to W into the page)



At a point directly below the wire, the tangent to the field circle points horizontally toward the south.
Therefore, $|\vec{B}| = 1.2 \times 10^{-5}$ T, directed horizontally toward the south.

Expert's Solution — Priya Nair, M.Sc Physics, IISc Bangalore

Cross–product method (vector Biot–Savart):
Set up axes with $\hat{x}$ = East, $\hat{y}$ = North, $\hat{z}$ = vertical up.
Step 1: Identify $\vec{I}$ and $\hat{r}$.
Current direction: $-\hat{x}$ (east to west).
Position of field point relative to the wire: $-\hat{z}$ (1.5 m straight below), so $\hat{r} = -\hat{z}$.
Step 2: Use $\vec{B} \propto \vec{I} \times \hat{r}$.

$$(-\hat{x}) \times (-\hat{z}) \;=\; \hat{x} \times \hat{z} \;=\; -\hat{y}.$$

So $\vec{B}$ at P points along $-\hat{y}$, that is, towards the south.
Step 3: Magnitude.

$$B \;=\; \frac{\mu_0 I}{2\pi r} \;=\; 1.2 \times 10^{-5}\ \text{T}, \quad \text{southward.}$$

Did You Know?

The direction of $\vec{B}$ here is opposite to that found in Q4.3. The reason is geometric: the orientation of the current relative to the field point has flipped, even though the formula is the same. Always pin down the geometry before plugging numbers.

Q5 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?

Solution

Step 1: Recall the force law.
A current–carrying wire of length l in a field B at angle θ experiences a force

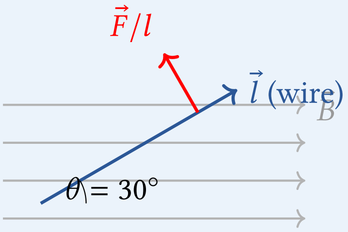
$$F = BIl\sin\theta.$$

Step 2: Force per unit length.

$$\frac{F}{l} = B\,I\,\sin\theta.$$

Step 3: Substitute the given values.
$B = 0.15$ T, $I = 8$ A, $\theta = 30^\circ$, so $\sin\theta = 0.5$.

$$\frac{F}{l} = 0.15\times 8\times 0.5 = 0.6\ \text{N m}^{-1}.$$



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

Expert's Solution — Arun Kumar, B.Tech ME, IIT Kanpur

Vector form: $\vec{F}/l = I\,(\hat{l}\times\vec{B})$:
Writing the force law as a cross product makes the direction transparent without needing the right–hand rule explicitly.

Step 1: Place the wire along $\hat{l}$ and $\vec{B}$ along a chosen axis.
Let $\vec{B} = B\hat{x}$ and let the wire be in the xy–plane making 30° with $\hat{x}$. Then

$$\hat{l} = \cos 30^\circ\,\hat{x} + \sin 30^\circ\,\hat{y}.$$

Step 2: Compute $\hat{l}\times\vec{B}$.

$$\hat{l}\times\vec{B} = (\cos 30^\circ\,\hat{x} + \sin 30^\circ\,\hat{y})\times B\hat{x} = B\sin 30^\circ\,(\hat{y}\times\hat{x}) = -B\sin 30^\circ\,\hat{z}.$$

Step 3: Magnitude per unit length.

$$\left|\frac{\vec{F}}{l}\right| = I\,B\,\sin 30^\circ = 8\times 0.15\times 0.5 = 0.6\ \text{N m}^{-1}.$$

The force is perpendicular to the plane containing the wire and $\vec{B}$.

★ **Did You Know?**

Notice what happens at the two extremes: at $\theta = 0^\circ$ (wire parallel to $\vec{B}$) the force vanishes, and at $\theta = 90^\circ$ it is maximum. This $\sin\theta$ factor explains why a charged particle moving *along* field lines experiences no magnetic force at all.

Q6 A 3.0 cm wire carrying a current of 10 A is placed inside a solenoid perpendicular to its axis. The magnetic field inside the solenoid is given to be 0.27 T. What is the magnetic force on the wire?

Solution

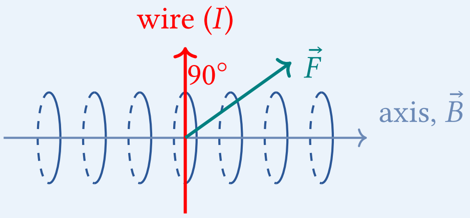
Step 1: Note the data.

$$l = 3.0 \text{ cm} = 0.03 \text{ m}, \quad I = 10 \text{ A}, \quad B = 0.27 \text{ T}, \quad \theta = 90^\circ.$$

Step 2: Apply $F = BIl\sin\theta$.

$$F = 0.27 \times 10 \times 0.03 \times \sin 90^\circ = 0.27 \times 10 \times 0.03 \times 1 = 8.1 \times 10^{-2} \text{ N}.$$

The direction of $\vec{F}$ is perpendicular to both the wire and the solenoid axis, given by Fleming's left–hand rule.



Therefore, the magnetic force on the wire is 8.1×10^{-2} N.

Expert's Solution — Kavita Joshi, B.Tech EE, IIT Bombay

Special–case limit of $F = BIl\sin\theta$ at $\theta = 90^\circ$:
When the wire is perpendicular to $\vec{B}$, the force law collapses to its maximum value, and we can read off the answer almost by inspection.
Step 1: Setting $\sin\theta = 1$ at $\theta = 90^\circ$.

$$F_{\text{max}} = BIl.$$

This is also the result you get directly from $\vec{F} = I\vec{l} \times \vec{B}$ when $\vec{l} \perp \vec{B}$.
Step 2: Plug in.

$$F = (0.27)(10)(0.03) = 0.081\ \text{N} = 8.1 \times 10^{-2}\ \text{N}.$$

Step 3: Dimensional check.

$$[B][I][l] = \text{T} \cdot \text{A} \cdot \text{m} = \frac{\text{N}}{\text{A m}} \cdot \text{A} \cdot \text{m} = \text{N}.\checkmark$$

★ **Did You Know?**

This $F = BIl$ is exactly the principle behind a moving-coil loudspeaker. The varying current in a coil sitting in a permanent magnet's field produces a varying force that drives the speaker cone — and hence the air — in step with the audio signal.

Q7 **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.**

Solution

Step 1: Note the data.

$$I_A = 8.0\ \text{A}, \quad I_B = 5.0\ \text{A}, \quad d = 4.0\ \text{cm} = 0.04\ \text{m}, \quad L = 10\ \text{cm} = 0.10\ \text{m}.$$

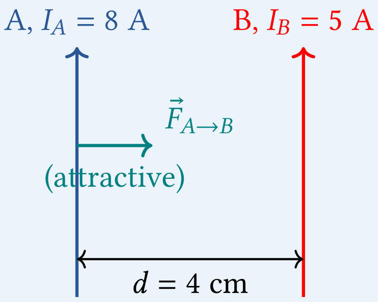
Step 2: Force per unit length between two parallel currents.

$$\frac{F}{L} = \frac{\mu_0 I_A I_B}{2\pi d}.$$

Step 3: Total force on the 10 cm section of A.

$$F = \frac{\mu_0 I_A I_B L}{2\pi d} = \frac{(4\pi \times 10^{-7})(8.0)(5.0)(0.10)}{2\pi(0.04)} = \frac{2 \times 10^{-7} \times 40 \times 0.10}{0.04} = 2 \times 10^{-5}\ \text{N}.$$

Since the currents are in the same direction, the force on A is *attractive* towards B.



Therefore, the force on a 10 cm section of wire A is 2×10^{-5} N, attractive (directed towards wire B).

Expert's Solution — Sanjay Gupta, PhD Physics, JNU

Building it up: $\vec{B}$ from B, then $\vec{F}$ on A using $\vec{F} = I\vec{L} \times \vec{B}$:
This two–step approach makes the origin of the force more transparent than the direct formula.
Step 1: Field at the location of A due to B.
A long straight wire B at distance d creates a field of magnitude

$$B_B = \frac{\mu_0 I_B}{2\pi d} = \frac{(4\pi \times 10^{-7})(5.0)}{2\pi(0.04)} = 2.5 \times 10^{-5} \text{ T},$$

oriented perpendicular to the plane of the two wires.
Step 2: Force on a length L of A in this field.
Wire A carries I_A perpendicular to $\vec{B}_B$, so

$$F = I_A L B_B = (8.0)(0.10)(2.5 \times 10^{-5}) = 2 \times 10^{-5} \text{ N}.$$

Step 3: Direction.
By Fleming's left–hand rule (or $\hat{I}_A \times \hat{B}_B$), the force on A points from A toward B — the parallel–currents–attract result.

> **Did You Know?**
>
> This very experiment historically defined the SI unit of current. Until 2019, one ampere was defined as that current which, flowing in two infinite parallel wires 1 m apart, produces a force of 2×10^{-7} N per metre between them. The redefinition in 2019 fixed the elementary charge instead, but the calculation lives on.

Q8 A closely wound solenoid 80 cm long has 5 layers of windings of 400 turns each. The diameter of the solenoid is 1.8 cm. If the current carried is 8.0 A, estimate the magnitude of B inside the solenoid near its centre.

Solution

The diameter (1.8 cm) is far smaller than the length (80 cm), so the long–solenoid formula applies.
Step 1: Total number of turns.

$$N = 5 \times 400 = 2000.$$

Step 2: Number of turns per unit length.

$$n = \frac{N}{l} = \frac{2000}{0.80} = 2500 \text{ m}^{-1}.$$

Step 3: Long–solenoid field formula.

$$B = \mu_0 n I.$$

Step 4: Substitute.

$$B = (4\pi \times 10^{-7})(2500)(8.0) = 4\pi \times 10^{-7} \times 2 \times 10^{4} = 8\pi \times 10^{-3} \approx 2.5 \times 10^{-2} \text{ T}.$$

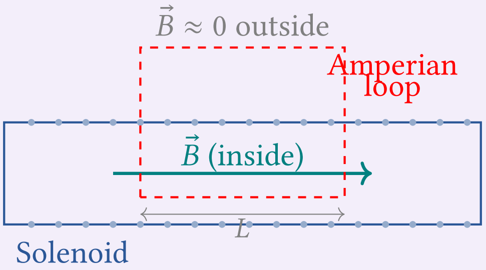
Therefore, the magnitude of B inside the solenoid near its centre is 2.5×10^{-2} T.

Expert's Solution — Shalini Menon, M.Sc Physics, University of Hyderabad

Derivation from Ampère's circuital law (showing why $B = \mu_0 nI$):

Step 1: Take a rectangular Amperian loop.

Choose one long side of length L *inside* the solenoid (parallel to the axis), the other long side outside it (where $\vec{B} \approx 0$ for an ideal long solenoid), and the short sides crossing the wall (perpendicular to $\vec{B}$).



Step 2: Evaluate $\oint \vec{B} \cdot d\vec{l}$.

Only the inside long side contributes:

$$\oint \vec{B} \cdot d\vec{l} = B L.$$

Step 3: Enclosed current.

The loop encloses nL turns, each carrying I:

$$I_{\text{enc}} = nLI.$$

Step 4: Apply the law.

$$B L = \mu_0 n L I \implies B = \mu_0 n I.$$

Plugging in the numbers reproduces $B = 2.5 \times 10^{-2}$ T.

Did You Know?

Notice how the diameter of the solenoid never enters the formula — only the turns–per–metre matter. That is what makes solenoids so useful for producing controlled, uniform fields in lab equipment from MRI machines to particle–beam guides.

Q9 **A square coil of side 10 cm consists of 20 turns and carries a current of 12 A. The coil is suspended vertically and the normal to the plane of the coil makes an angle of 30° with the direction of a uniform horizontal magnetic field of magnitude 0.80 T. What is the magnitude of torque experienced by the coil?**

Solution

Step 1: Note the data.

$$\text{side } a = 0.10 \text{ m}, \quad N = 20, \quad I = 12 \text{ A}, \quad B = 0.80 \text{ T}, \quad \theta = 30^\circ.$$

Step 2: Area of the square coil.

$$A = a^2 = (0.10)^2 = 0.01 \text{ m}^2.$$

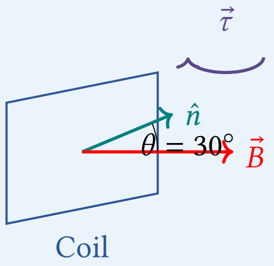
Step 3: Torque on a current loop.

$$\tau = N\,B\,I\,A\,\sin\theta.$$

Here θ is the angle between $\vec{B}$ and the area vector $\hat{n}$, which is exactly the angle given.

Step 4: Substitute.

$$\tau = 20 \times 0.80 \times 12 \times 0.01 \times \sin 30^\circ = 20 \times 0.80 \times 12 \times 0.01 \times 0.5 = 0.96 \text{ N m}.$$



Therefore, the magnitude of the torque experienced by the coil is 0.96 N m.

Expert's Solution — Deepak Verma, B.Tech EE, IIT Madras

Using the magnetic dipole moment $\vec{\mu}$:
A current loop is mathematically a magnetic dipole, and the torque expression has the same form as for an electric dipole in an electric field.

Step 1: Magnetic moment of the coil.

$$\mu = N\,I\,A = 20 \times 12 \times 0.01 = 2.4 \text{ A m}^2.$$

Step 2: Torque from $\vec{\tau} = \vec{\mu} \times \vec{B}$.
The magnitude is

$$\tau = \mu\,B\,\sin\theta = 2.4 \times 0.80 \times 0.5 = 0.96 \text{ N m}.$$

Step 3: Direction.

$\vec{\tau}$ is perpendicular to both $\vec{\mu}$ and $\vec{B}$ and tries to align $\vec{\mu}$ with $\vec{B}$.

★ **Did You Know?**

Treating a current loop as a dipole is more than a calculational shortcut — it is the foundation on which all of magnetism is built. The same expression $\tau = \mu B \sin\theta$ describes a tiny atomic loop, an electric motor armature, or a needle in a compass.

Q10 Two moving coil meters, M_1 and M_2, have the following particulars:

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

(The spring constants are identical for the two meters.) Determine the ratio of (a) current sensitivity and (b) voltage sensitivity of M_2 and M_1.

Solution

Recall the sensitivity formulas.
For a moving–coil galvanometer with N turns, area A, field B, spring constant k and coil resistance R:

$$S_I \equiv \frac{\phi}{I} = \frac{NBA}{k}, \qquad S_V \equiv \frac{\phi}{V} = \frac{NBA}{kR}.$$

(a) Ratio of current sensitivities.
Since $k_1 = k_2 = k$,

$$\frac{S_{I,2}}{S_{I,1}} = \frac{N_2 B_2 A_2}{N_1 B_1 A_1} = \frac{42 \times 0.50 \times 1.8 \times 10^{-3}}{30 \times 0.25 \times 3.6 \times 10^{-3}}.$$

Numerator: $42 \times 0.50 \times 1.8 = 37.8$.
Denominator: $30 \times 0.25 \times 3.6 = 27.0$.

$$\frac{S_{I,2}}{S_{I,1}} = \frac{37.8}{27.0} = 1.4.$$

(b) Ratio of voltage sensitivities.

$$\frac{S_{V,2}}{S_{V,1}} = \frac{N_2 B_2 A_2}{N_1 B_1 A_1} \cdot \frac{R_1}{R_2} = 1.4 \times \frac{10}{14} = 1.4 \times \frac{5}{7} = 1.0.$$

Therefore, the ratio of current sensitivities is $S_{I,2}/S_{I,1} = 1.4$, and the ratio of voltage sensitivities is $S_{V,2}/S_{V,1} = 1.0$.

Expert's Solution — Pooja Reddy, M.Sc Applied Physics, IIT Roorkee

Dimensional / structural argument — why S_V involves R:
Step 1: Where the sensitivities come from physically.
The deflection ϕ of a galvanometer coil follows from balancing magnetic torque against the restoring torque of the suspension:

$$NBIA = k\phi \implies \phi = \frac{NBA}{k}I.$$

So $S_I = \phi/I = NBA/k$ falls out immediately. To respond to a voltage V we must remember that the same current $I = V/R$ flows through the coil resistance R, giving $S_V = \phi/V = NBA/(kR)$.
Step 2: Build the ratios as products of independent factors.
Define $K \equiv NBA/k$. Then

$$\frac{S_{I,2}}{S_{I,1}} = \frac{K_2}{K_1}, \qquad \frac{S_{V,2}}{S_{V,1}} = \frac{K_2/R_2}{K_1/R_1} = \frac{K_2}{K_1} \cdot \frac{R_1}{R_2}.$$

Step 3: Insert numbers.

$$\frac{K_2}{K_1} = \frac{42}{30} \cdot \frac{0.50}{0.25} \cdot \frac{1.8}{3.6} = 1.4 \times 2 \times 0.5 = 1.4.$$

$$\frac{S_{V,2}}{S_{V,1}} = 1.4 \cdot \frac{10}{14} = 1.0.$$

Did You Know?

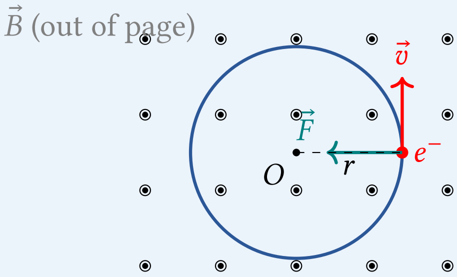
This calculation tells you something practically important: M_2 is more sensitive in current but exactly as sensitive in voltage, because its higher resistance cancels its higher current sensitivity. When choosing a galvanometer, you must specify whether you are measuring tiny currents or tiny voltages — the same instrument is not optimal for both.

Q11 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 4.8×10^6 m s^{-1} normal to the field. Explain why the path of the electron is a circle. Determine the radius of the circular orbit. ($e = 1.6 \times 10^{-19}$ C, $m_e = 9.1 \times 10^{-31}$ kg.)

Solution

Why the path is a circle.
The magnetic force on a moving charge is $\vec{F} = q\vec{v} \times \vec{B}$, always perpendicular to $\vec{v}$. So it does no work and cannot change $|v|$; it only turns the velocity vector. With $\vec{v} \perp \vec{B}$, the force has constant magnitude evB, points always toward a fixed centre, and so produces uniform circular

motion.



Step 1: Equate magnetic force to centripetal force.

$$evB \;=\; \frac{m_e v^2}{r} \quad\Longrightarrow\quad r \;=\; \frac{m_e v}{eB}.$$

Step 2: Insert numbers.

$$B \;=\; 6.5\text{ G} \;=\; 6.5\times10^{-4}\text{ T}.$$

$$r \;=\; \frac{(9.1\times10^{-31})(4.8\times10^{6})}{(1.6\times10^{-19})(6.5\times10^{-4})}.$$

Numerator: $9.1\times4.8 = 43.68$, so 4.368×10^{-24}.
Denominator: $1.6\times6.5 = 10.4$, so 1.04×10^{-22}.

$$r \;=\; \frac{4.368\times10^{-24}}{1.04\times10^{-22}} \;=\; 4.2\times10^{-2}\text{ m} \;=\; 4.2\text{ cm}.$$

Therefore, the radius of the circular orbit is $r = 4.2$ cm.

Expert's Solution — Aditya Nambiar, B.Tech Engineering Physics, IIT Bombay

Energy conservation viewpoint — why $|v|$ is constant:
The standard derivation uses Newton's second law for circular motion. A complementary view uses the work–energy theorem to first establish that the speed cannot change, after which the geometry of the orbit follows.

Step 1: Power delivered by the magnetic force.

$$P \;=\; \vec{F}\cdot\vec{v} \;=\; q(\vec{v}\times\vec{B})\cdot\vec{v} \;=\; 0,$$

because $\vec{v}\times\vec{B}$ is perpendicular to $\vec{v}$. So kinetic energy is constant, hence $|v|$ is constant.

Step 2: Constant force magnitude implies a circle.
With $|v|$ fixed and $\vec{v}\perp\vec{B}$, the force $|F| = evB$ is also fixed, and is always normal to $\vec{v}$. A particle subjected to a constant–magnitude normal force traces a circular arc; over an extended interval this closes up into a complete circle.

Step 3: Radius from $F = mv^2/r$.

$$r \;=\; \frac{m_e v}{eB} \;=\; \frac{(9.1\times10^{-31})(4.8\times10^{6})}{(1.6\times10^{-19})(6.5\times10^{-4})} \;\approx\; 4.2\text{ cm}.$$

★ **Did You Know?**

This is exactly the principle that confines plasma in a tokamak fusion reactor: charged particles spiral around field lines instead of escaping, with a radius (the Larmor radius) set by their momentum. The same physics also bends cosmic-ray protons in the Earth's magnetic field, sparing us from much of their flux.

Q12 In Exercise 4.11, find the frequency of revolution of the electron in its circular orbit. Does the answer depend on the speed of the electron? Explain.

Solution

Step 1: Connect period, radius and speed.
Using the radius from Q4.11, $r = m_e v/(eB)$, the period of one revolution is

$$T = \frac{2\pi r}{v} = \frac{2\pi}{v}\cdot\frac{m_e v}{eB} = \frac{2\pi m_e}{eB}.$$

Step 2: Frequency.

$$\nu = \frac{1}{T} = \frac{eB}{2\pi m_e}.$$

Notice the v has cancelled — the frequency is independent of the electron's speed. This frequency is called the *cyclotron frequency*.
Step 3: Compute.

$$\nu = \frac{(1.6\times10^{-19})(6.5\times10^{-4})}{2\pi(9.1\times10^{-31})}.$$

Numerator: $1.6\times6.5 = 10.4$, i.e. 1.04×10^{-22}.
Denominator: $2\pi\times9.1\times10^{-31}\approx5.717\times10^{-30}$.

$$\nu = \frac{1.04\times10^{-22}}{5.717\times10^{-30}} \approx 1.82\times10^{7}\ \text{Hz} \approx 18\ \text{MHz}.$$

Therefore, $\nu\approx18$ MHz, and the answer does *not* depend on the speed of the electron.

Expert's Solution — Lakshmi Pillai, PhD Condensed Matter Physics, IIT Kharagpur

Direct route via the angular frequency of circular motion:
Step 1: Newton's second law in tangential–centripetal form.

$$evB = m_e\omega^2 r, \qquad v = \omega r.$$

Substituting $v = \omega r$:

$$e(\omega r)B = m_e \omega^2 r \implies \omega = \frac{eB}{m_e}.$$

Step 2: Convert to frequency.

$$\nu = \frac{\omega}{2\pi} = \frac{eB}{2\pi m_e}.$$

The cancellation of r (and hence v) is now explicit at the level of the equations: faster electrons travel on larger circles, but the time per revolution is the same.
Step 3: Numerical value.

$$\nu = \frac{(1.6 \times 10^{-19})(6.5 \times 10^{-4})}{2\pi(9.1 \times 10^{-31})} \approx 1.82 \times 10^{7}\ \text{Hz} = 18\ \text{MHz}.$$

★ **Did You Know?**

This speed–independence is the principle behind the cyclotron, a particle accelerator invented by Ernest Lawrence in 1932. The accelerating voltage between two D–shaped electrodes is reversed at exactly this frequency, so the particle gets a kick every half–turn no matter how fast it has become — until relativistic effects eventually break the tuning.

Q13

(a) A circular coil of 30 turns and radius 8.0 cm carrying a current of 6.0 A is suspended vertically in a uniform horizontal magnetic field of magnitude 1.0 T. The field lines make an angle of 60° with the normal of the coil. Calculate the magnitude of the counter–torque that must be applied to prevent the coil from turning.

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

Solution

(a) Magnitude of the counter–torque.
Step 1: Note the data.

$$N = 30, \quad r = 0.08\ \text{m}, \quad I = 6.0\ \text{A}, \quad B = 1.0\ \text{T}, \quad \theta = 60^\circ.$$

Step 2: Area of the circular coil.

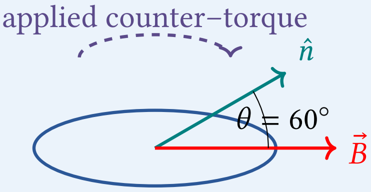
$$A \;=\; \pi r^2 \;=\; \pi(0.08)^2 \;=\; 6.4\pi\times 10^{-3}\ \mathrm{m}^2 \;\approx\; 0.0201\ \mathrm{m}^2.$$

Step 3: Torque on a current loop.

$$\tau \;=\; N\,B\,I\,A\,\sin\theta.$$

Step 4: Substitute.

$$\tau \;=\; 30\times 1.0\times 6.0\times 0.0201\times \sin 60^\circ \;=\; 30\times 6.0\times 0.0201\times 0.866 \;\approx\; 3.13\ \mathrm{N\,m}.$$



To prevent the coil from turning, the applied torque must equal τ in magnitude and oppose it in direction.
The required counter–torque has magnitude $\tau \approx 3.13$ N m.

(b) Does the shape matter?
The torque formula $\tau = NBIA\sin\theta$ depends on the coil's shape only through the area A. As long as the loop is planar and encloses the same area, the magnetic moment $\vec{\mu} = NIA\hat{n}$ is identical, so $\vec{\tau} = \vec{\mu}\times\vec{B}$ is unchanged.
Therefore, the answer does not change.

Expert's Solution — Ritika Banerjee, PhD Optics, IISc Bangalore

Why the shape independence of (b) is exact, not approximate:
The standard solution invokes $\tau = NBIA\sin\theta$ and waves at the formula. We can prove the shape independence directly by integrating the force law around an arbitrary planar loop, which is a useful exercise in vector calculus.
Step 1: Force on an element $d\vec{l}$ of a current–carrying loop in $\vec{B}$.

$$d\vec{F} \;=\; I\,d\vec{l}\times\vec{B}.$$

Step 2: Torque about the centre of the loop.

$$d\vec{\tau} \;=\; \vec{r}\times d\vec{F} \;=\; I\,\vec{r}\times(d\vec{l}\times\vec{B}).$$

Integrating around the loop and using the BAC–CAB identity (and $\vec{B}$ uniform), the result is

$$\vec{\tau} \;=\; I\,\vec{A}\times\vec{B}, \qquad \vec{A} \;=\; \tfrac{1}{2}\oint \vec{r}\times d\vec{l}.$$

Step 3: Recognise $\vec{A}$.
The integral on the right is precisely the vector area enclosed by the loop — the same quantity for any planar loop bounding the given area. So shape drops out.
Step 4: Numerical part.

For the circular coil,

$$\tau = NIAB\sin\theta = 30 \times 6.0 \times (\pi \times 0.0064) \times 1.0 \times \sin 60^\circ \approx 3.13 \text{ N m}.$$

★ **Did You Know?**

This shape independence is what makes the moving–coil galvanometer work — the manufacturer can choose a rectangular coil for ease of winding without affecting the torque. The same logic also lies behind the magnetic moment of an irregular current loop in atomic physics: only the enclosed area matters.