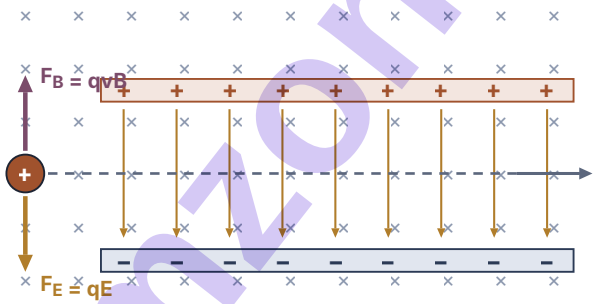
PHYSICS · CLASS 11 · NEW SYLLABUS

UNIT 10

Electromagnetism

Complete Study Booklet



B into page; E downward; undeflected if v = E/B

Long Questions | Short Questions | MCQs | Solved Exercise

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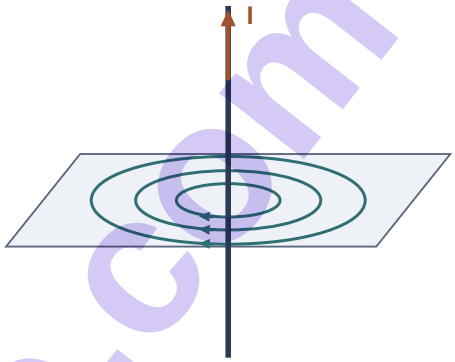
PART A

Long Questions

Q1 What is electromagnetism? Explain briefly.

> A magnetic field is produced around a current-carrying conductor, and a changing magnetic field gives rise to a current in a conductor placed in it. **Electromagnetism** is the area of physics that studies how electric charges and magnetic fields interact.

In 1820 Hans Christian Oersted found that electricity and magnetism are connected. Electromagnetism is crucial for modern technology — phones, computers and medical devices. This unit covers magnetic forces, magnetic flux and electromagnetic induction, and how they affect natural phenomena and technology.



Magnetic field produced by a current

For Your Information

Magnetism began with **lodestone**, a natural mineral (magnetite, Fe_3O_4) discovered in ancient Türkiye. It attracts iron and steel and aligns with the Earth's magnetic poles, which led to the invention of the compass.

Q2 Derive the formula for the force on a current-carrying conductor in a uniform magnetic field. How is the direction of the force found?

Experiments show that the force on a current-carrying conductor in a magnetic field is directly proportional to the current I, the length L and the field strength B:

$$F \propto I \ldots(i), \quad F \propto L \ldots(ii), \quad F \propto B \ldots(iii) \Rightarrow F = kBIL$$

In SI units k = 1, so for a conductor perpendicular to the field:

$$\mathbf{F = BIL \ldots(iv)}$$

Magnetic induction (strength of magnetic field)

From (iv), B = F/IL. The magnetic induction B is numerically equal to the force on a 1 m conductor carrying 1 A placed perpendicular to the field. Its SI unit is the **tesla**: 1 T = 1 N A^{-1} m^{-1}. It is a vector, in the direction of the field.

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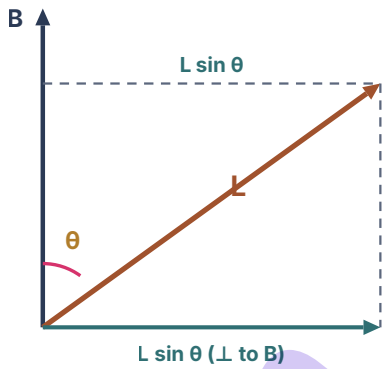
Conductor at an angle θ

Let **L** have magnitude equal to the conductor's length and direction along the current. If **L** makes angle θ with **B**, only the component L sin θ is perpendicular to **B**:

$$F = BIL \sin \theta \quad ...(2)$$

$$\mathbf{F = IL \times B \quad ...(3)}$$

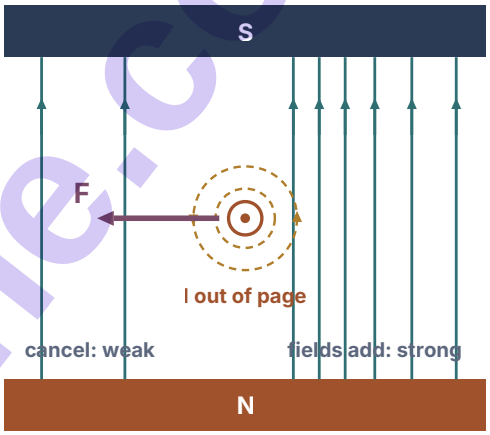
Maximum force (BIL) when the conductor is perpendicular to the field (θ = 90°). **Zero force** when it is along the field (θ = 0°).



Component of L perpendicular to B

Direction of the force

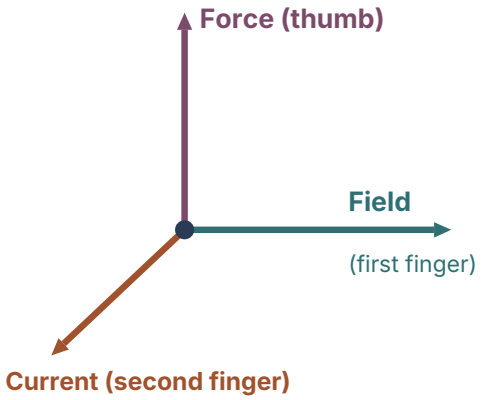
Method I — interaction of fields: a straight conductor carrying current out of the page (⊙) sits in a uniform field between magnet poles. Its own circular field and the external field **reinforce** each other on one side and **cancel** on the other. The conductor moves towards the side where the field is **weaker**. So the force is perpendicular to both the conductor and the field.



Combined field: the wire is pushed towards the weak side

Method II — Fleming's left-hand rule: hold the left hand so that the **first finger** points along the magnetic field and the **second finger** along the current; the **thumb** then points in the direction of the force.

Method III — right-hand rule (vector product): curl the fingers of the right hand from the current (L) to the magnetic field (B) through the smaller angle; the stretched thumb gives the direction of the force.



Fleming's left-hand rule

Interesting Information

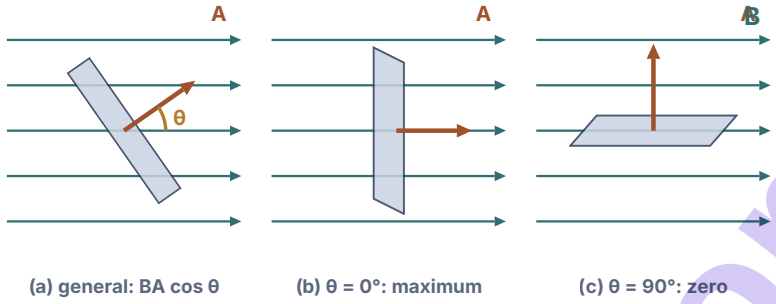
The Earth's magnetic field is roughly that of a giant bar magnet. Its magnetic south pole is near the geographic north pole, and its magnetic north pole is near the geographic south pole.

Q3 **Define magnetic flux and magnetic flux density.**

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Magnetic flux is the number of magnetic field lines passing normally through a surface. Mathematically it is the scalar product of magnetic induction and vector area: $\varphi_B = \mathbf{B}\cdot\mathbf{A} = BA\cos\theta$.

SI unit: **weber** (Wb) = N A^{-1} m. Flux is a scalar.



Magnetic flux: general case, maximum and zero

Case 1 — maximum: vector area A along B (θ = 0°): $\varphi_B = BA\cos 0° = BA$.
Case 2 — zero: vector area perpendicular to B (θ = 90°): $\varphi_B = BA\cos 90° = 0$.

Flux density

Flux passing through unit area held normal to the field: $B = \varphi_B/(A\cos\theta)$; with the surface normal to the field, $\mathbf{B = \varphi/A}$.

Unit: $\dfrac{\mathrm{N\,m^2}}{\mathrm{A\,m}} \div \mathrm{m^2} = \mathrm{Wb\,m^{-2}} = \mathrm{N\,A^{-1}\,m^{-1}} = \mathrm{tesla}$

So magnetic induction and flux density are the same quantity. Flux density is a vector.

Curved surface: divide it into small, nearly flat elements; the total flux is the sum of BA cos θ over all the elements.

Flux	Flux density
Total number of field lines through a given area	Number of lines through unit area held perpendicular to the field
Symbol φ_B; $\varphi_B = \mathbf{B}\cdot\mathbf{A}$	Symbol B; $B = \varphi_B/A$ ($\theta = 0°$)
Scalar; unit Wb	Vector; unit Wb m^{-2} = T

Q4 What is magnetic flux linkage? Discuss its importance.

Magnetic flux linkage is the product of the magnetic flux through a coil and the number of turns in the coil: flux linkage = $N\varphi_B$.

φ_B is the flux through a single loop of area A, and N the number of turns. It measures how much flux is linked with the coil because of its many turns.

Importance: it is central to the design and operation of transformers, electric motors, generators and inductors, and to Faraday's law of electromagnetic induction.

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For Your Information

An ATM or credit card has a magnetic strip containing millions of tiny magnetic domains held in a resin binder. The machine reads the information encoded on the strip to give access to your account.

Q5 **Derive the formula for the magnetic force on a moving charge in a magnetic field.**

Current is a flow of charge, so a charged particle moving across a magnetic field also feels a force. Consider a conductor of length L through which N charged particles, each of charge q, pass in time t:

$$I = \frac{Q}{t} = \frac{Nq}{t} \quad ...(1)$$

The particles move along the conductor with velocity $\mathbf{v} = v\,\hat{L}$ and take time $t = L/v$ to cross it, so

$$I = \frac{Nqv}{L} \quad ...(2)$$

In a uniform field the conductor feels $\mathbf{F} = I\mathbf{L} \times \mathbf{B}$ ...(3). With $\mathbf{L} = L\,\hat{L}$:

$$\mathbf{F} = \frac{Nqv}{L}(L\,\hat{L} \times \mathbf{B}) = Nqv\,\hat{L} \times \mathbf{B} = Nq\mathbf{v} \times \mathbf{B} \quad ...(4)$$

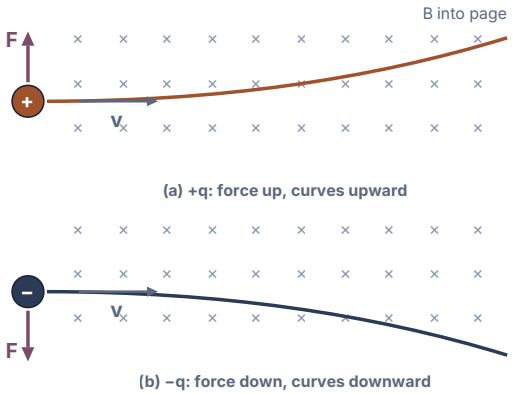
So the force on a single particle is:

$$\mathbf{F} = q\mathbf{v} \times \mathbf{B} \quad ...(5) \qquad F = qvB\sin\theta \quad ...(6)$$

Maximum when $v \perp B$ ($\theta = 90°$); **zero** when v is along B ($\theta = 0°$). Its direction is given by Fleming's left-hand rule or the right-hand rule.

(a) Positive charge (q = +e): $\mathbf{F} = +e\mathbf{v} \times \mathbf{B}$ — it is pushed upward and follows a curved path upward.

(b) Negative charge (q = −e): $\mathbf{F} = -e\mathbf{v} \times \mathbf{B}$ — it is pushed downward and curves downward.



Deflection of charges moving in a magnetic field (B into the page)

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Do You Know?

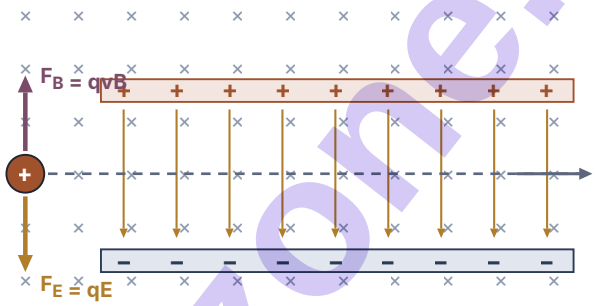
Like electric field lines, magnetic field lines never cross each other; they push each other apart.

Point to Ponder

Why does the picture distort when a bar magnet is brought near an old TV, monitor or oscilloscope screen?
The picture is made by an electron beam. The magnet's field exerts a force on the moving electrons, deflecting the beam and distorting the picture.

Q6 What is a velocity selector? Discuss its construction and working.

A **velocity selector** is a device in which electric and magnetic forces on a moving charged particle balance each other only for one particular velocity, so particles with that velocity pass straight through.



B into page; E downward; undeflected if v = E/B

Velocity selector

Explanation: a positive charge +q enters a uniform field B at right angles with velocity v. The magnetic force acts upward. To balance it, an electric force must act downward.

Construction: a cylindrical tube placed in a magnetic field B. Inside the tube a parallel-plate capacitor gives a uniform electric field E perpendicular to B.

Working

- When the particle enters, the magnetic force acts upward and the electric force (along E) acts downward.
- If the field strengths are adjusted, the two forces cancel.
- With no net force, the particle moves in a straight line at constant velocity (Newton's first law) and leaves the far end of the tube.
- Particles with other velocities are deflected and do not come out.

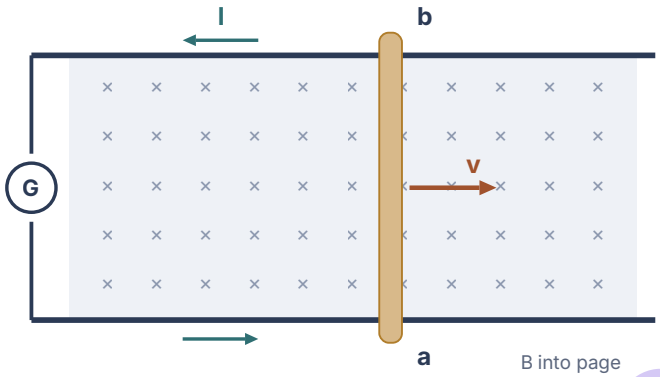
Since v is perpendicular to both B and E:

$$\text{Magnetic force} = qvB, \quad \text{electric force} = qE; \quad \text{for no deflection } qvB = qE \Rightarrow v = \frac{E}{B}$$

Q7 What is motional e.m.f.? Derive an expression for it.

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Motional e.m.f. is the e.m.f. induced across the ends of a conductor because of its motion in a magnetic field.



A conductor moving on copper rails in a magnetic field

A conductor of length L slides along copper rails connected to a galvanometer, in a uniform field directed into the page. As it is dragged with velocity v, the charges inside it move with it, so each feels a magnetic force:

$$\mathbf{F} = q(\mathbf{v} \times \mathbf{B}); \quad \text{with } v \perp B\text{: } F = qvB \ldots(1)$$

By the right-hand rule this pushes positive charges from end a to end b, so the top end (b) becomes positive and the bottom end (a) negative. The potential of b rises and that of a falls; this p.d. drives current in the external circuit.

Expression

The p.d. sets up an electric field along the conductor (downward), giving a force $F_e = qE$ ...(2). In equilibrium the electric and magnetic forces balance:

$$qE = qvB \Rightarrow E = vB \ldots(3)$$

With $E = -\Delta V/\Delta r$, $\Delta V = -E\Delta r$ and $\Delta r = L$:

$$V_b - V_a = -BvL$$

This p.d. is the motional e.m.f., lasting as long as the wire moves in the field:

$$\boldsymbol{\varepsilon = -BvL \ldots(4) \quad \text{and at angle } \theta\text{: } \varepsilon = -BvL \sin\theta \ldots(5)}$$

As charge flows through the external circuit from b to a, E (and the electric force) decreases, so equilibrium is disturbed in favour of the magnetic force, which keeps moving charge from a to b.

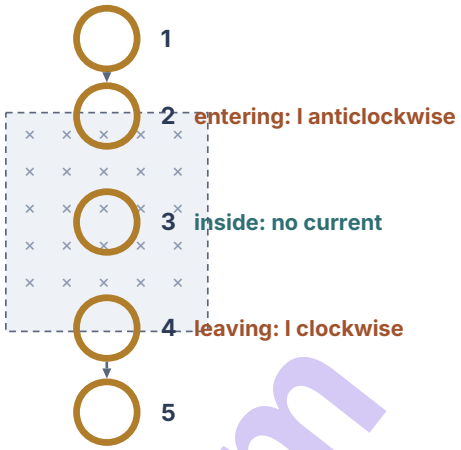
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A copper ring passes through a rectangular region with a constant field into the page. What happens to the current in the ring at positions 2, 3 and 4?

A current is induced only while the flux through the ring is **changing**:

1. **Position 2 (entering):** flux into the page is increasing, so a current is induced — **anticlockwise**, opposing the increase.
2. **Position 3 (fully inside):** the flux is constant, so **no current** flows.
3. **Position 4 (leaving):** flux is decreasing, so a current is induced — **clockwise**, opposing the decrease.

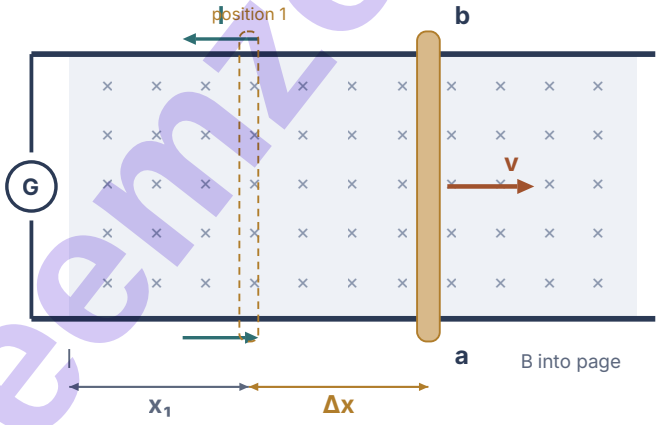
The notes give the reverse (zero at 2 and 4, maximum at 3) using $B = \mu_0 nI$; that is not correct, because induction depends on the change of flux.



Copper ring passing through a field region

Q8 State and explain Faraday's law of electromagnetic induction.

> The average e.m.f. induced in a coil of N loops equals the negative of the rate at which the magnetic flux through the coil changes with time.



Conductor moving from position 1 to position 2 in time Δt

A conductor AB on copper rails moves from position x_1 to x_2, covering Δx in time Δt, perpendicular to the field. Its velocity is v = Δx/Δt, and the motional e.m.f. is:

$$\varepsilon = -BvL = -B\frac{\Delta x}{\Delta t}L$$

Δx × L = ΔA, the change in area of the closed circuit:

$$\varepsilon = -\frac{B\Delta A}{\Delta t} \quad \ldots(1)$$

The field is uniform, so the change in flux is due to the change in area: Δφ = BΔA. Hence:

$$\varepsilon = -\frac{\Delta\varphi}{\Delta t}; \quad \text{for a coil of N turns: } \varepsilon = -N\frac{\Delta\varphi}{\Delta t}$$

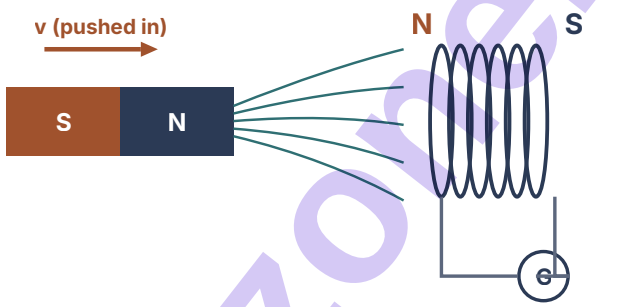
The minus sign shows that the induced e.m.f. opposes the change in flux.

Point to Ponder

An induction (electromagnet) heater works by electromagnetic induction. The coil under the glass top carries a.c., producing changing flux that induces currents in a metal pot, which heats the water. The glass pot and the glass top stay cool because no current can be induced in an insulator.

Q9 State and explain Lenz's law.

The direction of the induced current is always such as to **oppose the change** that causes it.



Pushing a magnet towards a coil

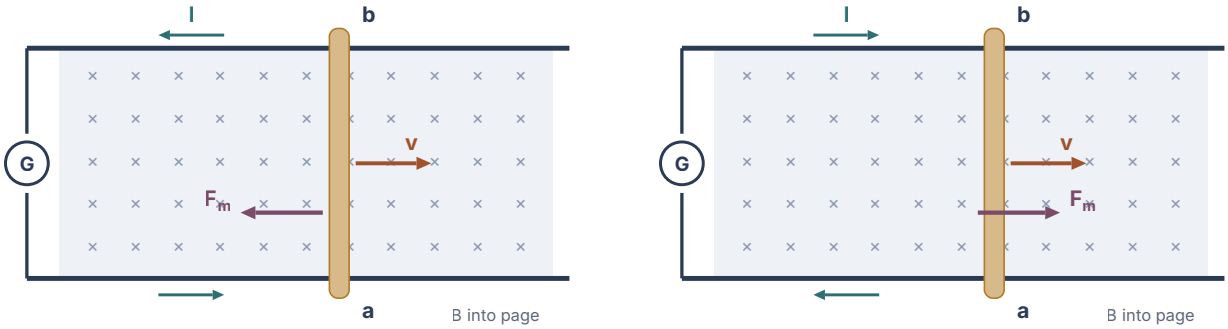
A current in a coil produces a magnetic field like a bar magnet: one end acts as a north pole and the other as a south pole. To oppose a bar magnet's N pole being pushed towards it, the face of the coil nearest the magnet must become a **north** pole, so the two N poles repel. For this the current in the loop flows **anticlockwise** (as seen from the magnet). The push of the magnet is the change; the induced current opposes it. When the magnet is pulled away, the induced current makes a **south** pole on that face, opposing the pull.

Point to Ponder

Neglecting resistance, can a constant current in a coil set up a p.d. across it?
V = IR; if R = 0 then V = 0, whatever the current.

Q10 Explain how Lenz's law is in accordance with the law of conservation of energy.

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(a) real case: F_m opposes v *(b) forbidden case: F_m along v*

Lenz's law is a form of the law of conservation of energy. A rod moving right on two conducting rails has an induced e.m.f., giving an **anticlockwise** current. A current-carrying rod in a field feels a magnetic force:

$$F_m = ILB \sin 90° = ILB$$

By the right-hand rule, F_m is **opposite** to v, so it opposes the motion and tends to stop the rod. An external force equal and opposite to F_m must be applied to keep the rod moving at constant velocity. This applied force supplies the energy for the induced current, so electromagnetic induction obeys conservation of energy.

Lenz's law forbids a **clockwise** current: then F_m would point along v, accelerating the rod, which would induce a stronger current and a larger force — a self-perpetuating process producing energy from nothing, against the law of conservation of energy.

Q11 Describe the factors affecting the induced e.m.f.

1. **Rate of change of magnetic flux:** faster changes in flux give a greater induced e.m.f. (Faraday's law).
2. **Number of turns of the coil:** the induced e.m.f. is proportional to N; more turns give a greater e.m.f.
3. **Relative speed:** moving the coil or magnet faster increases the rate of change of flux, and so the e.m.f.

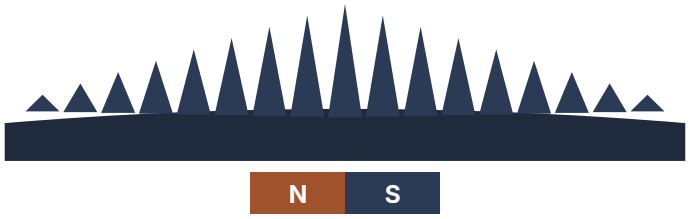
Q12 Write a note on ferrofluids.

A **ferrofluid** is a material with both liquid and magnetic properties — a colloidal suspension of magnetic particles in a carrier fluid (such as oil or water).

1. **Nanoparticles:** the magnetic particles are usually iron oxide ground to about 10 nm.
2. **Stable suspension:** the particles are coated with a surfactant (which reduces surface tension) so they do not clump together. The fluid's viscosity, the tiny particle size and their constant motion stop them settling.
3. **Magnetic properties:** with no magnet nearby it behaves like a liquid. Near a magnet the particles are temporarily magnetized and form structures, so the fluid behaves more like a solid. When the magnet is removed it acts as a liquid again.

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4. **Forces:** magnetic forces compete with surface tension and gravity. In a strong field, chain-like structures form along the field lines; magnetic forces pull the fluid up while gravity and surface tension pull it down. Where the magnetic forces win, **spikes** form.



spikes form along the magnetic field lines

Ferrofluid spikes above a magnet

Experiment

You need laser-printer toner, cooking oil, a test tube, a glass bottle, a small stick and a magnet. Laser toner contains about 40% iron oxide nanoparticles. Mix some toner with cooking oil to make a ferrofluid and pour it into the bottle. On shaking it acts like a liquid. Bring a magnet near the outside of the bottle: the fluid jumps towards it, and held at the side it forms a spiky structure.

Applications

1. **Electronics:** rotary seals in computer hard drives and other rotating shafts. In **loudspeakers** they cool the voice coil (held in place by the magnet) and damp vibrations, improving sound quality.
2. **Medicine:** guided by external magnets to carry drugs to a tumour or other target, reducing side effects; also as contrast agents in MRI.
3. **Other:** damping, and precisely controlling the flow of liquids with magnetic fields.

For Your Information

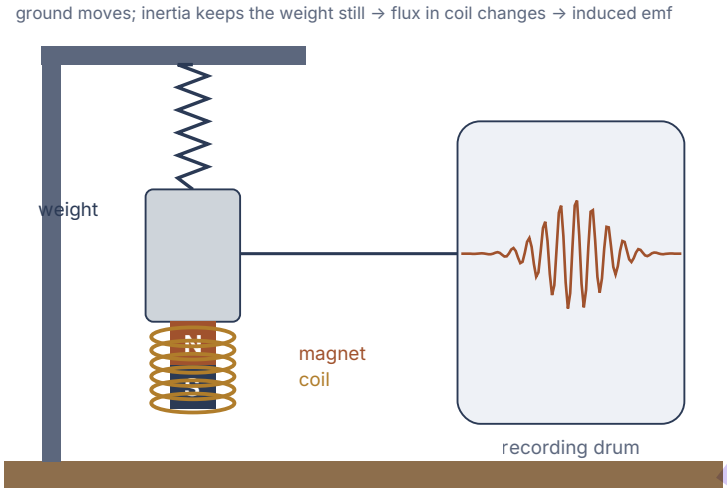
The first ferrofluid was developed by NASA in the early 1960s from ground magnetite, as a way to move liquid fuel in space.

Q13 **What is a seismometer? Discuss its principle and working.**

> A **seismometer** is an instrument that responds to movements of the rocks under the ground or vibrations caused by earthquakes, volcanic eruptions and explosions.

Principle: it uses electromagnetic induction to turn ground motion into electrical signals.

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Principle of a seismometer

Working: a weight hangs from a spring. During an earthquake the ground moves but the weight tends to stay still (inertia), so there is relative motion between the weight and the frame fixed to the ground. The weight carries a magnet that moves inside a coil. By Faraday's law the changing flux induces an e.m.f. and a current in the coil.

Output signal: the induced current is proportional to the velocity of the ground motion. The signals are amplified and recorded, giving the amplitude, frequency and duration of the earthquake waves.

Data analysis: the data give the earthquake's location, magnitude and depth.

Set-up: a seismometer is usually buried 50 – 1000 m underground in a protective **vault** — a steel cylinder about 1 m wide and 2 m deep with a concrete pad at the bottom. Solar panels charge its batteries, GPS gives its location, and the data are sent to a computer.

For Your Information

Most earthquakes are caused by plate tectonics. Shallow ones occur within about 60 km of the surface, intermediate ones down to about 280 km, and deep ones below 280 km.

For Your Information

Two main types of seismic waves: **P-waves** (primary, longitudinal) and **S-waves** (secondary, transverse).

Formula Sheet

#	Formula	Description
1	$\mathbf{F} = I(\mathbf{L} \times \mathbf{B}) \Rightarrow F = ILB \sin\theta$	Force on a current-carrying conductor
2	$B = F/IL = F/qv$	Magnetic induction
3	$\varphi = \mathbf{B}\cdot\mathbf{A} = BA\cos\theta$	Magnetic flux
4	$B = \varphi/A$	Flux density
5	$\mathbf{F} = q(\mathbf{v} \times \mathbf{B}) \Rightarrow F = qvB \sin\theta$	Force on a moving charge
6	$v = E/B$	Velocity selector

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7	$\varepsilon = -vBL \sin\theta$	Motional e.m.f.
8	$\varepsilon = -vBL$	Motional e.m.f. (maximum)
9	$\varepsilon = -N\,\Delta\varphi/\Delta t$	Faraday's law
10	$N\varphi = LI$	Flux linkage of a current-carrying coil
11	$r = mv/qB$	Radius of circular path

Units

#	Unit	Quantity
1	$N\,A^{-1}\,m^{-1}$ = tesla	Magnetic induction B
2	$N\,m\,A^{-1}$ = weber	Magnetic flux
3	$Wb\,m^{-2}$ = tesla	Flux density
4	$Wb\,A^{-1}\,m^{-1}$	Permeability of free space μ_0
5	no unit	Relative permeability μ_r
6	$C\,kg^{-1}$	e/m of electron
7	$N\,m\,rad^{-1}$	Torsional constant
8	$V\,s\,A^{-1}$ = henry = $Wb\,A^{-1}$	Mutual and self inductance

Constants

#	Value	Constant
1	$4\pi \times 10^{-7}\ Wb\,A^{-1}\,m^{-1}$	μ_0, permeability of free space

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PART B

Short Questions

Exercise Short Questions

10.1 **It is said that Lenz's law applies specifically to induced currents and not directly to induced e.m.f. Explain briefly.**

Lenz's law gives the direction of the induced **current**: it opposes the change in flux that causes it. It does not apply directly to e.m.f., which is a potential difference and has no direction of flow as current does; it only tells which way the resulting current will flow.

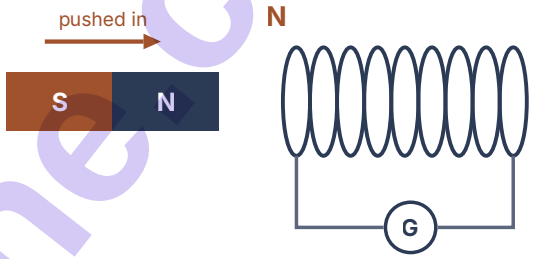
10.2 **A square loop moves through a uniform magnetic field with its normal parallel to the field. Is an e.m.f. induced? Why?**

No. $\varphi = BA\cos\theta$ with $\theta = 0°$, so $\varphi = BA$, which stays constant as the loop moves through the uniform field. $\Delta\varphi = 0$, so $\varepsilon = -\Delta\varphi/\Delta t = 0$.

10.3 **Does the induced e.m.f. always act to decrease the magnetic flux through a circuit?**

No. By Lenz's law it acts to **oppose the change** in flux: if the flux is increasing, it tends to decrease it; if the flux is decreasing, it tends to increase it.

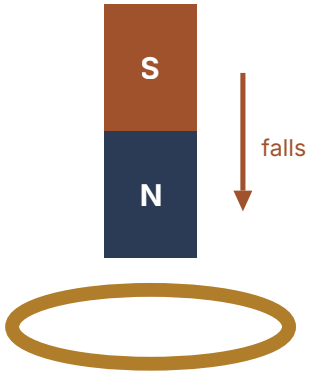
10.4 **When a magnet is pushed into a solenoid, the galvanometer shows a small current. Why? What pole is produced at the left end of the solenoid?**



The current is due to the **changing flux** as the magnet enters, which induces an e.m.f. By Lenz's law, the end facing the incoming N pole becomes a **north** pole, to repel it.

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10.5 **A bar magnet falls through a fixed metal ring. Will it fall with the acceleration of a freely falling body? Why?**



induced current opposes the fall: a < g

No. The falling magnet induces a current in the ring, whose field opposes the motion (Lenz's law). This upward magnetic force partly opposes gravity, so the net force is less than the weight and the acceleration is less than g.

10.6 **Which of two charged particles of the same mass will be deflected most in a magnetic field: (a) fast-moving (b) slow-moving?**

The **slow-moving** one. r = mv/qB, so for the same m, q and B, the radius is proportional to v. The slower particle moves in a smaller circle and is deflected more.

10.7 **An electron and a proton are projected at right angles into a magnetic field with the same velocity. Which is deflected more? Why?**

The **electron**. Both feel F = qvB (θ = 90°) of the same size, but r = mv/qB, so for the same v and B, r ∝ m/q. The electron's mass is about 1/1836 of the proton's, so its radius is much smaller and it is deflected more.

10.8 **Can a single moving proton produce a magnetic field?**

Yes. Any moving charge produces a magnetic field, and a proton is a charged particle. (A moving charge is like a tiny current.)

10.9 **A magnetic field is needed for flux through a coil, yet a magnetic field does not mean flux passes through it. Explain.**

Flux is φ = $\mathbf{B}\cdot\mathbf{A}$ = BA cos θ. If the field lines are **parallel to the plane** of the coil (θ = 90° between B and the area vector), the flux is zero even though a field is present. The lines must cross the coil's surface at some angle.

SLO-Based Additional Short Questions + Past Papers (Punjab Boards)

Q1 **In what direction are the magnetic field lines around a straight wire carrying current towards you?**

By the right-hand rule, the field lines are **anticlockwise** circles around the wire.

Q2 **What kind of field(s) surround a moving electric charge?**

A moving charge is like a current, so it is surrounded by a **magnetic field** (as well as its electric field).

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Q3 What is a velocity selector?

An arrangement of electric and magnetic fields perpendicular to each other, adjusted so that the electric and magnetic forces on a charged particle are equal and opposite. The particle passes undeflected: Bqv = qE ⇒ v = E/B.

Q4 Is it possible to obtain an isolated north pole? Give reasons.

No. Magnetic poles come from currents inside atoms (the spin and orbital motion of electrons). Like a current loop, every magnet has a north on one side and a south on the other, so poles always occur in pairs.

Q5 What is Faraday's law of electromagnetic induction? Write its formula.

The average e.m.f. induced in a coil of N turns equals the negative of the time rate of change of flux through it:

$$\varepsilon = -N\,\Delta\varphi/\Delta t$$

The minus sign shows that the e.m.f. opposes the change in flux.

Q6 What is motional e.m.f.? Write its mathematical relation.

The e.m.f. induced across the ends of a wire moving in a magnetic field: **$\varepsilon = Bv\ell \sin\theta$**, where B is magnetic induction, v the wire's velocity, ℓ its length and θ the angle between v and B.

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PART C

Multiple Choice Questions

Exercise MCQs

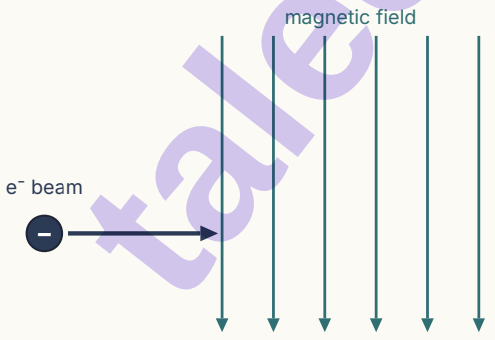
1 **A current flows towards north along a power line. The magnetic field above the wire points towards:**

(a) north
(b) south
(c) east
(d) west

2 **The radius of curvature of a charged particle's path in a uniform magnetic field is directly proportional to the particle's:**

(a) charge
(b) momentum
(c) energy
(d) flux density of the field

3 **A beam of electrons enters a magnetic field as shown. What is the effect on the electrons?**



(a) deflected into the plane of the diagram
(b) deflected out of the plane of the diagram
(c) deflected towards the bottom
(d) deflected towards the top

4 **The force on a 1 m wire carrying 1 A at right angles to a magnetic field is called:**

(a) magnetic field intensity
(b) magnetic flux
(c) magnetic induction
(d) none of these

5 **The unit of flux density is:**

(a) $\mathrm{N\ A^{-1}\ m^{-1}}$
(b) $\mathrm{N\ A\ m^{-1}}$
(c) $\mathrm{N\ m\ A^{-2}}$
(d) N m A

6 **A moving charged particle is surrounded by:**

(a) an electric field only
(b) a magnetic field only
(c) both electric and magnetic fields
(d) no field

7 **The magnetic force on a charge q moving parallel to the field with velocity v is:**

(a) qvB sin θ
(b) qvB
(c) zero
(d) ILB

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8 **The unit N A^{-1} m^{-1} is called:**

(a) weber

(b) tesla

(c) coulomb

(d) none of these

9 **Electrons moving perpendicularly through a uniform magnetic field are:**

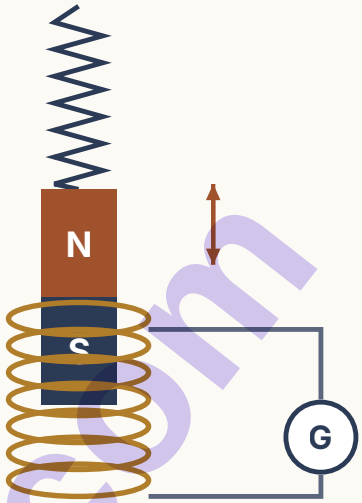
(a) deflected towards the north pole

(b) deflected towards the south pole

(c) deflected along a circular path

(d) not deflected at all

10 **A magnet on a spring oscillates in and out of a coil connected to a galvanometer. The galvanometer shows:**



(a) deflection left and right with constant amplitude

(b) deflection to one side

(c) no deflection

(d) deflection left and right, with the amplitude steadily decreasing

Answer Key — Exercise MCQs

1	c	2	b	3	b	4	c	5	a	6	c
7	c	8	b	9	c	10	d				

Hints

Q1: right-hand grip rule — current north, the field above the wire points east. Q2: r = mv/qB = p/qB. Q3: F = −e v × B; v to the right and B down gives a force out of the page. Q10: the induced current opposes the motion (Lenz), damping the oscillation.

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SLO-Based Additional MCQs + Past Papers (Punjab Boards)

1 **Which quantity is not affected by a magnetic field?**

(a) moving charge
(b) change in magnetic flux
(c) current in a conductor
(d) stationary charge

2 **A magnetic field is detected by a:**

(a) ammeter
(b) galvanometer
(c) AVO meter
(d) magnetic compass

3 **A changing magnetic field produces:**

(a) electric current
(b) changing electric field
(c) magnetic field
(d) conservative field

4 **A 10 cm wire at right angles to a uniform field of 0.5 Wb m^{-2} feels a force of 5 N. The current is:**

(a) 1 A
(b) 10 A
(c) 100 A
(d) 1000 A

5 **A magnetic compass is deflected if kept near a:**

(a) charge in motion
(b) charge at rest
(c) both (a) and (b)
(d) none

6 **If a current passes through a wire, the magnetic lines of force are:**

(a) parallel to the wire
(b) perpendicular to the wire
(c) inclined to the wire
(d) concentric circles

7 **The direction of magnetic lines of force can be found by the:**

(a) right-hand rule
(b) left-hand rule
(c) Hund's rule
(d) left- and right-hand rules

8 **If current flows from top to bottom through a wire, the lines of force (seen from above) are:**

(a) parallel to the wire
(b) perpendicular to the wire
(c) clockwise around the wire
(d) anticlockwise around the wire

9 **The force on a current-carrying conductor in a magnetic field is:**

(a) $F = I(L \times B)$
(b) $F = q(L \times B)$
(c) $F = I(V \times B)$
(d) $F = q(V \times B)$

10 **A straight current-carrying conductor is placed parallel to a magnetic field. The force on it is:**

(a) $F = BIL$
(b) $F = BIL \sin \theta$
(c) $F = BIL \cos \theta$
(d) $F = 0$

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11 **Two free parallel wires carrying currents in opposite directions:**

(a) do not affect each other
(b) attract each other
(c) repel each other
(d) get rotated

12 **Two free parallel wires carrying currents in the same direction:**

(a) repel each other
(b) attract each other
(c) do not affect each other
(d) get rotated

13 **If the current through a wire in a magnetic field is doubled, the force becomes:**

(a) six times
(b) five times
(c) four times
(d) twice

14 **The number of magnetic lines of force through a surface is called:**

(a) magnetism
(b) electric flux
(c) magnetic flux
(d) flux density

15 **Magnetic flux is maximum when:**

(a) the angle between B and A is 45°
(b) B is perpendicular to the plane of area A
(c) B is parallel to the plane of area A
(d) B is a null vector

16 **A 0.50 T field passes through an area of 2 m^2 whose plane is at 60° to the field. The flux is:**

(a) 0.50 Wb
(b) 0.75 Wb
(c) 0.866 Wb
(d) 4 Wb

17 **The number of magnetic lines passing normally through unit area is called:**

(a) magnetism
(b) flux
(c) magnetic flux
(d) flux density

18 **The SI unit of magnetic flux is:**

(a) weber
(b) N m A^{-1}
(c) N m^{-1}
(d) both (a) and (b)

19 **The SI unit of magnetic induction (flux density) is:**

(a) gauss
(b) tesla
(c) ampere
(d) weber

20 **The SI unit of magnetic induction is:**

(a) weber
(b) tesla
(c) gauss
(d) newton

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21 **A charged particle projected perpendicular to a uniform magnetic field follows a:**

(a) helix
(b) ellipse
(c) straight line
(d) circle

22 **The work done by a magnetic field in moving a charge q in a circular path is:**

(a) Fd
(b) maximum
(c) negative
(d) zero

23 **The unit of E is N C^{-1} and of B is N A^{-1} m^{-1}. The unit of E/B is:**

(a) m s^{-2}
(b) m s
(c) m s^{-1}
(d) m^{-1} s^{-1}

24 **The fact that an e.m.f. is produced by moving a coil in a magnetic field was discovered by:**

(a) Michael Faraday
(b) Henry
(c) Oersted
(d) both (a) and (b)

25 **The e.m.f. produced in a conductor moving across a magnetic field is called:**

(a) self e.m.f.
(b) induced e.m.f.
(c) motional e.m.f.
(d) mutual e.m.f.

26 **What is induced when there is relative motion between a coil and a magnet?**

(a) flux
(b) potential
(c) energy
(d) e.m.f.

27 **The induced e.m.f. is directly proportional to the rate of change of:**

(a) magnetic flux
(b) electric flux
(c) force
(d) work

28 **The current produced when a conductor moves across a magnetic field is:**

(a) conventional current
(b) induced current
(c) self current
(d) electronic current

29 **Producing an induced e.m.f. by changing flux is called:**

(a) electric potential
(b) electrostatic induction
(c) electromagnetic induction
(d) electric polarization

30 **Motional e.m.f. depends upon the:**

(a) length of the conductor
(b) strength of the field
(c) speed of the conductor
(d) all of the above

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31 **If the velocity of a conductor in a magnetic field is zero, its motional e.m.f. is:**

(a) zero
(b) vBL
(c) qvB
(d) IBL

32 **"The induced current always opposes the change that causes it" is:**

(a) Faraday's law
(b) Lenz's law
(c) Gauss's law
(d) Joule's law

33 **Lenz's law is consistent with the law of conservation of:**

(a) energy
(b) charge
(c) momentum
(d) mass

34 **Lenz's law deals with the:**

(a) magnitude of induced current
(b) magnitude of induced e.m.f.
(c) direction of induced e.m.f.
(d) direction of induced current

35 **The induced e.m.f. in a coil is linked with:**

(a) nature of the coil
(b) shape of the coil
(c) flux through the coil
(d) change in flux through the coil

Answer Key — Additional MCQs

1	d	2	d	3	a	4	c	5	a	6	d
7	a	8	c	9	a	10	d	11	c	12	b
13	d	14	c	15	b	16	c	17	d	18	d
19	b	20	b	21	d	22	d	23	c	24	a
25	c	26	d	27	a	28	b	29	c	30	d
31	a	32	b	33	a	34	d	35	d		

Hints

Q1: a magnetic field exerts no force on a stationary charge ($F = qvB = 0$); the notes' key gives (a). Q4: $I = F/BL = 5/(0.5 \times 0.1) = 100$ A. Q16: plane at 60° to B ⇒ area vector at 30° ⇒ $\varphi = 0.5 \times 2 \times \cos 30° = 0.866$ Wb. Q22: F ⊥ v, so no work is done. Q23: $(\text{N C}^{-1})/(\text{N A}^{-1}\,\text{m}^{-1}) = \text{A m C}^{-1} = \text{m s}^{-1}$.

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PART D

Solved Exercise

Exercise Numericals

10.1 **A positive particle projected perpendicularly into a magnetic field at 1500 m s^{-1} feels a force F. At what angle with the field should it be projected at 2000 m s^{-1} to feel the same force?**

Given: $v_1 = 1500$ m s^{-1}, $\theta_1 = 90°$ • $v_2 = 2000$ m s^{-1}

$qv_1B \sin\theta_1 = qv_2B \sin\theta_2 \Rightarrow \sin\theta_2 = v_1/v_2 = 1500/2000 = 0.75$

$\theta_2 = \sin^{-1}(0.75) \approx 49°$

10.2 **Electrons accelerated from rest through 15 kV in an oscilloscope pass through a 0.35 T field. Find the maximum force on an electron.**

Given: V = 15 000 V • $e = 1.6 \times 10^{-19}$ C • $m = 9.1 \times 10^{-31}$ kg • B = 0.35 T

$\tfrac{1}{2}mv^2 = eV \Rightarrow v = \sqrt{\left(\frac{2eV}{m}\right)} = \sqrt{\left(\frac{2 \times 1.6 \times 10^{-19} \times 15\,000}{9.1 \times 10^{-31}}\right)} = 7.26 \times 10^7$ m s^{-1}

$F_{max} = evB = 1.6 \times 10^{-19} \times 7.26 \times 10^7 \times 0.35 \approx 4.1 \times 10^{-12}$ N

10.3 **A square coil of side 15 cm with 60 turns is in a uniform 0.8 T field with its plane perpendicular to the field. It is turned through 30° in 2 s. Find the average induced e.m.f.**

Given: N = 60 • $A = (0.15)^2 = 0.0225$ m^2 • B = 0.8 T • $\Delta t = 2$ s

Initially the area vector is along B ($\theta = 0°$); after turning, $\theta = 30°$:

$$\varepsilon_{avg} = \frac{NBA(\cos 0° - \cos 30°)}{\Delta t} = \frac{60 \times 0.8 \times 0.0225 \times (1 - 0.866)}{2}$$

$\varepsilon_{avg} \approx 0.072$ V

The notes write A = 0.0255 m² (a typo for 0.0225 m²) and get 0.08 V.

10.4 **A rod moving through a 0.2 T field has an e.m.f. of 0.8 V across its ends. What field is needed for 2.4 V, other factors being the same?**

$\varepsilon \propto B \Rightarrow B_2 = B_1 \times \frac{\varepsilon_2}{\varepsilon_1} = 0.2 \times \frac{2.4}{0.8}$

$B_2 = 0.6$ T

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10.5 **A copper ring of radius 4.0 cm and resistance 1.0 mΩ is in a field perpendicular to its plane. If the field rises from 0.2 T to 0.4 T in 5 × 10^{-3} s, what current flows in the ring?**

Given: r = 0.04 m • R = 10^{-3} Ω • ΔB = 0.2 T • Δt = 5 × 10^{-3} s

$$|\varepsilon| = \frac{\Delta B \times \pi r^2}{\Delta t} = \frac{0.2 \times 3.14 \times (0.04)^2}{5 \times 10^{-3}} \approx 0.201 \text{ V}$$

$$\mathbf{I = \frac{\varepsilon}{R} = \frac{0.201}{10^{-3}} \approx 201 \text{ A}}$$

10.6 **A coil of 10 turns and area 35 cm^2 in a perpendicular 0.5 T field is pulled out of the field in 1.0 s. Find the induced e.m.f.**

Given: N = 10 • A = 35 × 10^{-4} m^2 • B = 0.5 T • Δt = 1 s

Initial flux linkage $N\varphi_1$ = NBA = 10 × 0.5 × 35 × 10^{-4} = 1.75 × 10^{-2} Wb; final = 0

$$\mathbf{\varepsilon = -\frac{N\,\Delta\varphi}{\Delta t} = -\frac{0 - 1.75 \times 10^{-2}}{1} \approx 1.75 \times 10^{-2} \text{ V}}$$

10.7 **A proton accelerated through 6 × 10^5 V enters perpendicularly a uniform field B = 1.0 Wb m^{-2}. Find the radius of its path (m = 1.67 × 10^{-27} kg, e = 1.6 × 10^{-19} C).**

$$v = \sqrt{\left(\frac{2eV}{m}\right)} = \sqrt{\left(\frac{2 \times 1.6 \times 10^{-19} \times 6 \times 10^5}{1.67 \times 10^{-27}}\right)} \approx 1.07 \times 10^7 \text{ m s}^{-1}$$

$$\mathbf{r = \frac{mv}{eB} = \frac{1.67 \times 10^{-27} \times 1.07 \times 10^7}{1.6 \times 10^{-19} \times 1} \approx 0.112 \text{ m} = 11.2 \text{ cm}}$$

10.8 **A proton enters a uniform field B = 0.300 Wb m^{-2} at 45° to the field with speed 10^4 m s^{-1}. Find the radius of its circular path.**

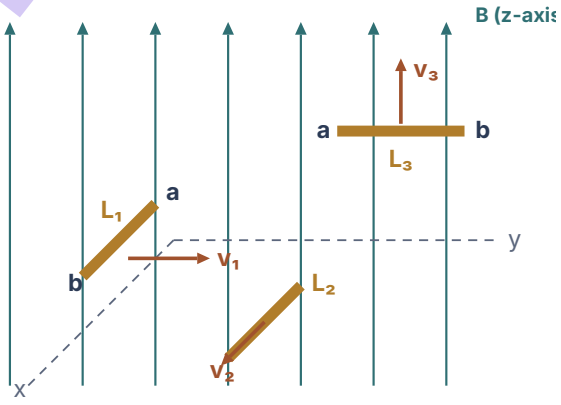
Only the component perpendicular to B makes it circle (it moves along a helix): $v_\perp$ = v sin 45°.

$$r = \frac{mv \sin 45°}{qB} = \frac{1.67 \times 10^{-27} \times 10^4 \times 0.707}{1.6 \times 10^{-19} \times 0.300}$$

$$\mathbf{r \approx 2.46 \times 10^{-4} \text{ m}}$$

The notes give 2.26 × 10^{-4} m, an arithmetic slip; the same working gives 2.46 × 10^{-4} m.

10.9 **Three identical 60 cm rods L_1, L_2, L_3 move in different planes at 2.5 m s^{-1} in a constant field B = 0.5 T along the z-axis, as shown. Find the e.m.f. in each rod and which end is positive.**



ε = vBL sin θ

Rod L_1 (moves ⊥ B): ε_1 = 2.5 × 0.5 × 0.6 = 0.75 V, end a positive

Rods L_2 and L_3 (velocity parallel to B, θ = 0°): $\varepsilon_2 = \varepsilon_3 = 0$

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10.10 **An e.m.f. of 0.5 V is induced across a rod moving in a 0.4 T field. What field is needed for 1.5 V, all else being the same?**

$$B_2 = B_1 \times \frac{\varepsilon_2}{\varepsilon_1} = 0.4 \times \frac{1.5}{0.5}$$

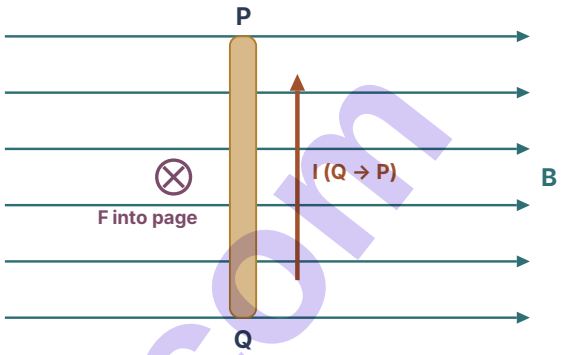
$B_2 = 1.2$ T

10.11 **A charged particle passes undeflected through a velocity selector at 4.96×10^4 m s^{-1}, perpendicular to E and B. If B = 0.114 T, what is E?**

$qE = qvB \Rightarrow E = vB = 4.96 \times 10^4 \times 0.114$

$E \approx 5.65 \times 10^3$ N C^{-1}

10.12 **A conductor PQ of length 2 m is perpendicular to a field of 0.5 T as shown. The force on it is 1 N into the page. Find the magnitude and direction of the current.**



$$F = ILB \sin 90° \Rightarrow I = \frac{F}{LB} = \frac{1}{2 \times 0.5}$$

I = 1 A, flowing from Q to P

(Fleming's left-hand rule: field to the right, force into the page ⇒ current upward, Q → P.)

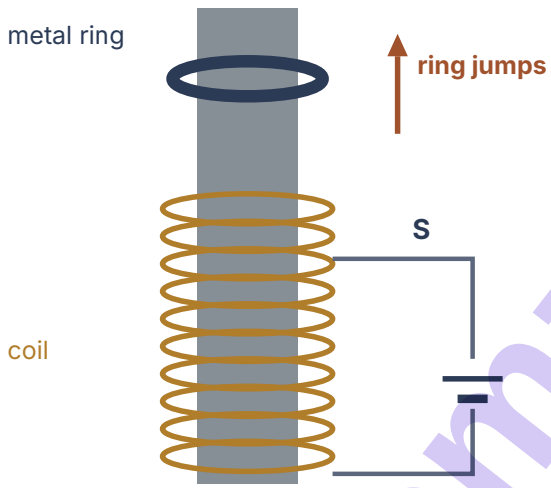
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Constructed Response Questions

10.1 **A charge lies stationary between the opposite poles of two magnets. Is a magnetic force exerted on it? Why?**

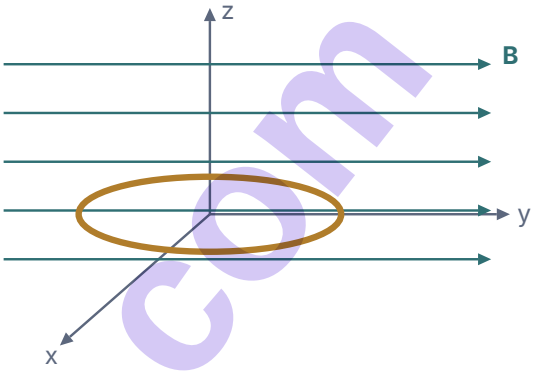
No. A magnetic force acts only on **moving** charges: $\mathbf{F} = q(\mathbf{v} \times \mathbf{B})$. With $v = 0$, $F = q(0 \times B) = 0$.

10.2 **When the switch is closed, a current is set up in the coil and the metal ring jumps up. Why? What happens if the battery polarity is reversed?**



Closing the switch makes the current in the coil grow, so its magnetic field (flux) changes. This induces an e.m.f. and a current in the ring whose field opposes the change (Lenz's law), so the coil repels the ring and it jumps. If the polarity is reversed, the coil's field reverses but the ring's induced current also reverses, so it is still repelled and **still jumps**.

10.3 **A coil lies in the x-y plane with a magnetic field along the y-axis. About which axis should it be rotated to produce an e.m.f.?**



The coil's normal is along z, perpendicular to B, so the flux is initially zero. Rotating about the **x-axis** tilts the normal towards y, so the flux changes and an e.m.f. is induced. Rotating about the y- or z-axis keeps the normal perpendicular to B, so the flux stays zero.

10.4 **Is it possible to change both the area of the loop and the field through it and still have no induced e.m.f.? Give reason.**

Yes. $\varepsilon = -N\,\Delta\varphi/\Delta t$ with $\varphi = BA$. If B is increased and A decreased so that the product BA stays the same, then $\Delta\varphi = 0$ and $\varepsilon = 0$.

10.5 **Does a uniform magnetic field change the kinetic energy of a moving charged particle? Explain.**

No. The magnetic force is always perpendicular to the velocity, so $W = Fd\cos 90° = 0$. No work is done, so the K.E. (speed) stays the same; only the direction changes.

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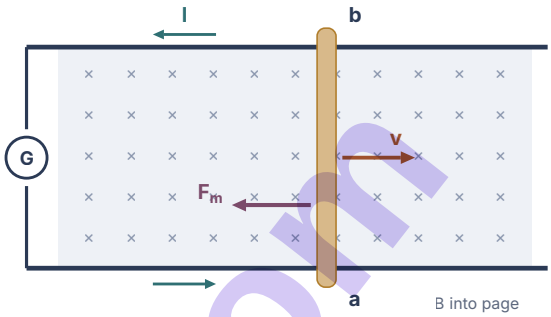
10.6 **Uniform electric and magnetic fields act in the same direction. A proton is projected with uniform velocity in the opposite direction. What happens to it?**

The electric force on the positive proton acts along E, i.e. opposite to its velocity, so it **decelerates**. Its velocity is antiparallel to B ($\theta = 180°$), so the magnetic force $F = qvB \sin 180° = 0$ has no effect. It slows down in a straight line.

10.7 **A conductor in a magnetic field moves when a current is passed through it. Would the reverse happen — a current produced when a conductor is moved across the field?**

Yes. Moving a conductor across a magnetic field induces an e.m.f. in it (motional e.m.f.), which drives a current if the circuit is complete — the principle of the generator.

10.8 **A rod of length L moves with velocity v on conducting rails connected to a bulb. The bulb lights up. Where does the electrical energy come from?**



From the work done in moving the rod. The induced current in the rod feels a magnetic force $F = IBL$ opposing its motion (Lenz's law). To keep the rod moving, an external force must do mechanical work against this force; that work is turned into electrical energy, which the bulb gives out as heat and light.

10.9 **How would you protect a sensitive instrument from stray magnetic fields?**

Enclose it in a magnetic shield made of a material with very high permeability, such as mu-metal (a ferromagnetic alloy). The shield draws the field lines through itself and guides them around the instrument.

Comprehensive Questions

10.1 **Distinguish between magnetic flux and flux density. How are they related?**

See **Long Question Q3**.

10.2 **Find an expression for the force on a current-carrying conductor in a uniform magnetic field.**

See **Long Question Q2**.

10.3 **State and explain Faraday's law and Lenz's law. Describe the factors affecting the induced e.m.f.**

See **Long Question Q8, Q9 and Q11**.

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10.4 **Determine the force on a charged particle moving through a uniform magnetic field.**

See **Long Question Q5**.

10.5 **What is a velocity selector? Explain its working.**

See **Long Question Q6**.

10.6 **Explain how ferrofluids work.**

See **Long Question Q12**.

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