A LEVEL PHYSICS 9702 · A LEVEL · TOPIC 20 · ~6 MIN READ

Magnetic fields

Magnetic field patterns, the force on a current-carrying conductor F = BIL sin θ, forces on moving charges F = BQv, circular paths, velocity selection and the Hall effect, forces between wires, and electromagnetic induction with Faraday's and Lenz's laws.

Field patterns | F = BIL sin θ | Tesla | F = BQv | Circular orbits r = mv/BQ | Velocity selector | Hall voltage | Forces between wires

RS by Riyaz Sir
mentorriyaz.in

Paper tag = **where it is examined** DATA & FORMULAE given in the exam C1 A1 B1 how marks are awarded

highlight = comes up again and again Test yourself at the end

IN 30 SECONDS

- **Force on a wire: F = BIL sin θ,** with direction from Fleming's left-hand rule. This defines the tesla: 1 T gives 1 N on 1 m carrying 1 A at right angles.
- **Force on a moving charge: F = BQv sin θ,** always perpendicular to the velocity, so a charge moving across a uniform field moves in a circle: r = mv/(BQ).
- **Crossed fields:** a charge passes undeflected when qE = Bqv, so v = E/B (velocity selector). The same balance produces the Hall voltage V_H = BI/(ntq).
- **Induction:** e.m.f. = rate of change of flux linkage, NΔΦ/Δt (Faraday), in a direction that opposes the change (Lenz).

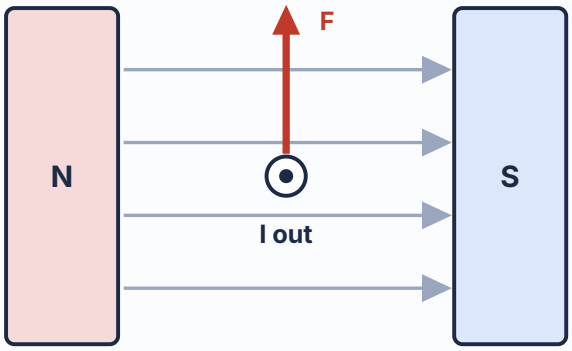
BY THE END YOU CAN

- Sketch field patterns for wires, flat coils, solenoids and bar magnets.
- Use F = BIL sin θ and define magnetic flux density.
- Use F = BQv sin θ and analyse charged particles in magnetic fields, including circular paths, velocity selection and the Hall effect.
- Explain forces between current-carrying wires.
- Define magnetic flux and flux linkage, and use Faraday's and Lenz's laws.

1 Forces on currents and charges

F = BIL sin θ

Magnetic flux density — the force per unit current per unit length on a straight conductor placed at right angles to the field: B = F/(IL).



F = BIL sin θ
F ⊥ to both B and I
(left-hand rule:
First finger Field,
seCond finger Current,
thuMb Motion)

Fleming's left-hand rule: First finger = Field, seCond finger = Current, thuMb = Motion (force).

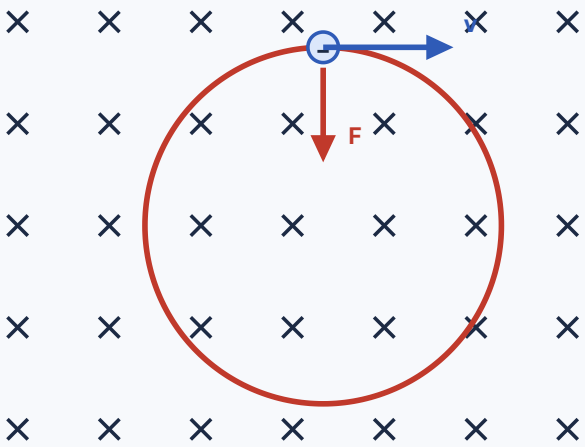
WORKED EXAMPLE

A 0.25 m wire carries 3.0 A at right angles to a 0.040 T field. Find the force.

1. **F = BIL = 0.040 × 3.0 × 0.25 = 0.030 N** A1

- **Two parallel wires:** each sits in the other's field. Currents in the same direction attract; opposite directions repel.

Moving charges



B into page (×)
electron: F = qvB
always ⊥ to v,
so circular motion
$qvB = mv^2/r$
$r = mv/(qB)$

The magnetic force is always perpendicular to v, so it provides a centripetal force.

$$F = BQv \; ; \; r = mv/(BQ)$$

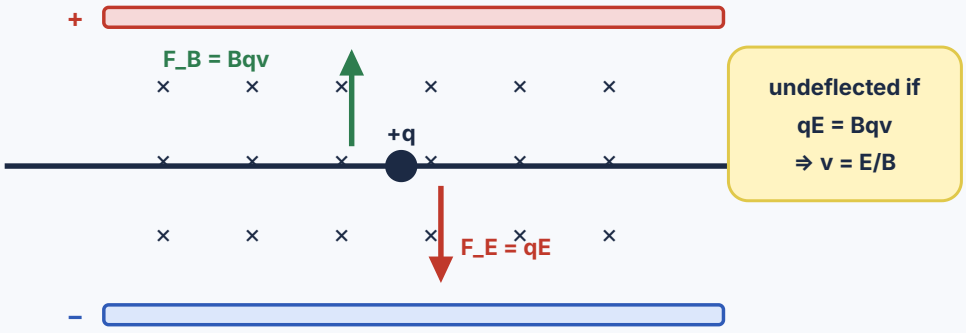
the speed doesn't change, because the force does no work

WORKED EXAMPLE

A proton moves at 3.0×10^6 m s^{-1} perpendicular to a 0.20 T field. Find the radius of its path.

1. $BQv = mv^2/r \Rightarrow r = mv/(BQ)$ **C1**
2. **$r = 1.67 \times 10^{-27} \times 3.0 \times 10^6/(0.20 \times 1.60 \times 10^{-19}) = 0.16$ m** **A1**

Velocity selection and the Hall effect



× = magnetic field into the page; electric field from + plate to – plate.

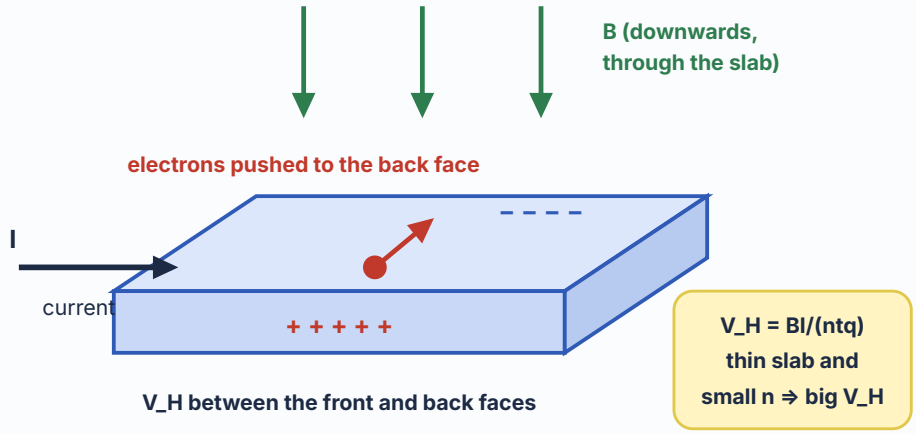
Only particles with speed E/B pass straight through.

Crossed E and B fields: only particles with v = E/B pass straight through.

WORKED EXAMPLE

In a velocity selector $E = 4.0 \times 10^4$ V m^{-1} and B = 0.050 T. Find the speed of undeflected ions.

1. **$v = E/B = 8.0 \times 10^5$ m s^{-1}** **A1** **(it doesn't depend on the charge or mass)**



Charge builds up on one side until the electric force balances the magnetic force.

Charge carriers are pushed sideways until the Hall field balances the magnetic force.

$$V_H = BI/(ntq)$$ DATA & FORMULAE

n = number density of carriers, t = thickness in the direction of B

WORKED EXAMPLE

A semiconductor slab 0.20 mm thick with $n = 5.0 \times 10^{24}$ m^{-3} carries 0.10 A in a 0.50 T field. Find V_H.

1. $V_H = 0.50 \times 0.10/(5.0 \times 10^{24} \times 2.0 \times 10^{-4} \times 1.6 \times 10^{-19})$ C1
2. **$V_H = 3.1 \times 10^{-4}$ V** A1 **(a copper slab would give only about 10^{-8} V, because n is far larger)**

COMMON MISTAKE

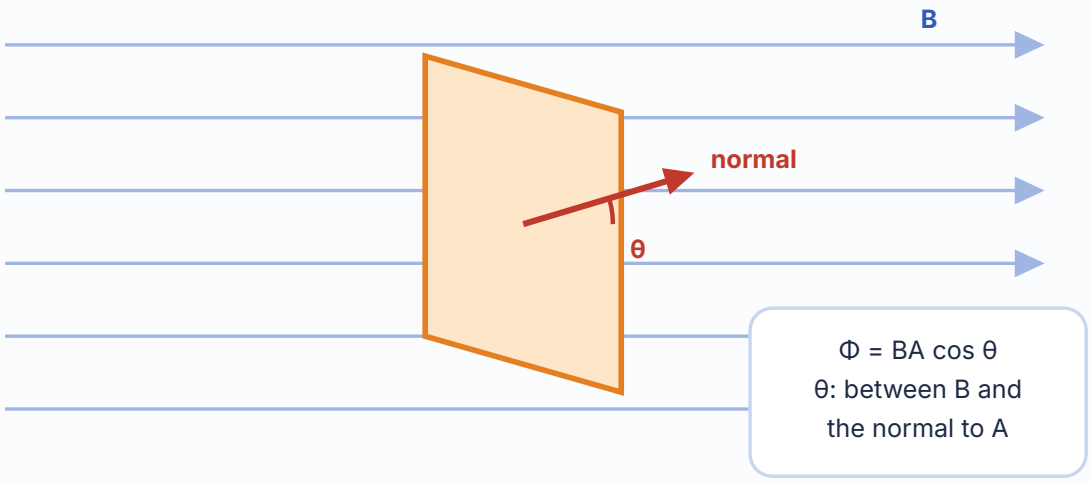
Using the width instead of the thickness t in V_H. t is measured parallel to B.

2 Electromagnetic induction

Flux and Faraday's law

Magnetic flux — the product of the flux density and the area perpendicular to the field: $\Phi = BA$.

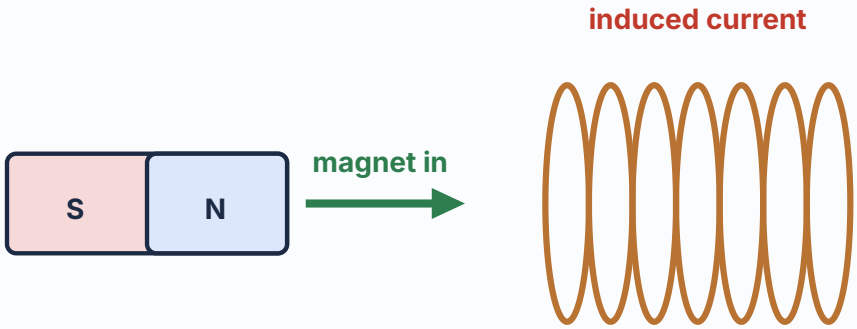
Flux linkage — $N\Phi$ for a coil of N turns.



Flux is the field through an area; tilting the coil reduces it.

$$\Phi = BA \; ; \; E = -\Delta(N\Phi)/\Delta t$$

Faraday's law, with the minus sign showing Lenz's law



coil face nearest the magnet becomes N:
it repels the approaching N pole

The induced current makes a field that opposes the change in flux.

WORKED EXAMPLE

A coil of 200 turns and area 4.0×10^{-4} m² is in a field of 0.30 T, which falls to zero in 0.050 s. Find the average induced e.m.f.

1. $\Delta(N\Phi) = 200 \times 0.30 \times 4.0 \times 10^{-4} = 0.024$ Wb C1
2. **E = 0.024/0.050 = 0.48 V** A1

- **Lenz's law is conservation of energy:** if the induced current helped the change, you'd get energy from nothing.

COMMON MISTAKE

Saying the field "cuts" the coil without describing a change of flux linkage, or omitting "rate of change" in Faraday's law. The 2024 Paper 4 report flagged both.

LINKING QUESTION

Circular motion is in Motion in a circle; electric fields are in Electric fields; and a.c. from rotating coils is in Alternating currents.

Test yourself — cover the answers first

QUICK CHECK

1. State the unit of magnetic flux density.
2. What is the force on a charge moving parallel to a magnetic field?
3. Why doesn't a magnetic field change the speed of a charge?
4. Two parallel wires carry currents in the same direction. Do they attract or repel?
5. State Lenz's law.

EXAM-STYLE

6. An electron ($m = 9.11 \times 10^{-31}$ kg) moves at 2.0×10^{7} m s^{-1} in a circle of radius 0.12 m. Find B.
7. Explain why the Hall voltage is larger in a semiconductor than in a metal.
8. A 50-turn coil of area 2.0×10^{-3} m^2 is turned from perpendicular to parallel to a 0.12 T field in 0.10 s. Find the average e.m.f.

Show answers

1. tesla (T)
2. zero
3. the force is perpendicular to the velocity, so it does no work
4. attract
5. the induced e.m.f. acts to oppose the change producing it
6. $B = mv/(er) = 9.5 \times 10^{-4}$ T
7. n is much smaller, so the carriers move faster for the same current, and $V_H = BI/(ntq)$ is larger
8. $\Delta(N\Phi) = 50 \times 0.12 \times 2.0 \times 10^{-3} = 0.012$ Wb ⇒ 0.12 V

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