IB DP PHYSICS · THEME D FIELDS · D.3 · ~6 MIN READ

D.3 Motion in electromagnetic fields

Charged particles in uniform electric fields (parabolic paths), in uniform magnetic fields (circles), in crossed fields (velocity selectors), the force on a current-carrying wire, and the force between parallel wires.

Charges in E fields | F = qvB sin θ | Circular motion in B | Crossed fields | F = BIL sin θ | Parallel wires

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No tag = **SL and HL** HL ONLY HL students only DATA BOOKLET given in the exam

M1 A1 how marks are awarded highlight = comes up again and again Test yourself at the end

IN 30 SECONDS

- In a **uniform electric field** a charge feels a constant force qE, so it moves like a projectile: a straight line along the field, or a **parabola** across it.
- A charge moving through a **magnetic field** feels **F = qvB sin θ**, always perpendicular to its velocity, so in a uniform field it moves in a **circle** of radius r = mv/qB.
- A current-carrying wire in a field feels **F = BIL sin θ**. Two parallel currents attract (same direction) or repel (opposite), with **F/L = $\mu_0 I_1 I_2 / 2\pi r$**.
- **D.3 is the same at SL and HL.**

BY THE END YOU CAN

- Describe and calculate the motion of a charge in a uniform electric field.
- Use F = qvB sin θ and explain circular motion of a charge in a uniform magnetic field.
- Analyse charges in perpendicular electric and magnetic fields.
- Use F = BIL sin θ and find its direction.
- Calculate the force per unit length between parallel wires.

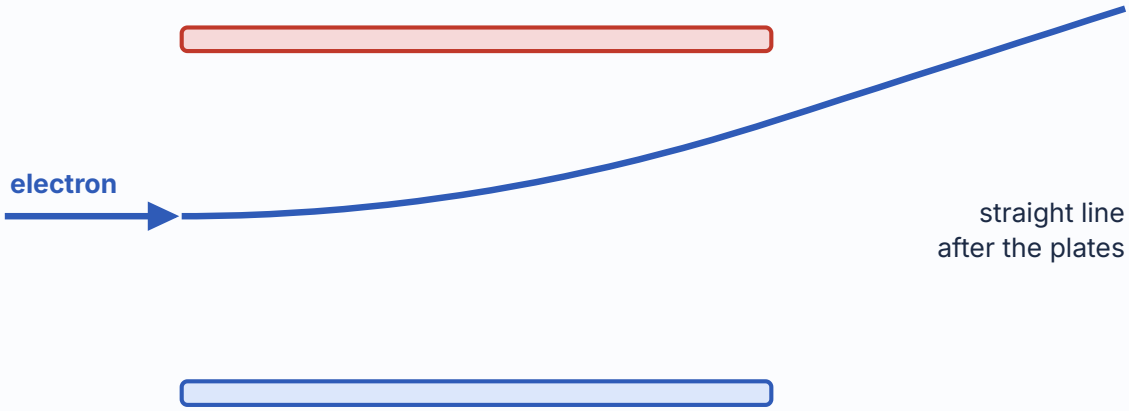
1 Charges in electric fields

- **Accelerating a charge:** moving through a potential difference V, a charge gains kinetic energy qV. For an electron from rest: $\frac{1}{2}mv^2 = eV$.

WORKED EXAMPLE

An electron is accelerated from rest through 500 V. Find its speed.

1. $\frac{1}{2}mv^2 = eV \Rightarrow v = \sqrt{(2eV/m)}$ M1
2. $= \sqrt{(2 \times 1.6 \times 10^{-19} \times 500 / 9.11 \times 10^{-31})} = 1.3 \times 10^7 \text{ m s}^{-1}$ A1



constant force upwards (towards +): parabola, like a projectile

Constant velocity along the plates, constant acceleration across them: a parabola.

WORKED EXAMPLE

An electron enters plates 5.0 cm long at 2.0×10^7 m s^{-1}, at right angles to a field of 2.0×10^4 V m^{-1}. Find its sideways deflection.

1. time between the plates $t = 0.050/2.0 \times 10^7 = 2.5 \times 10^{-9}$ s M1
2. $a = eE/m = 3.5 \times 10^{15}$ m s^{-2} M1
3. **$y = \frac{1}{2}at^2 = 1.1$ cm** A1

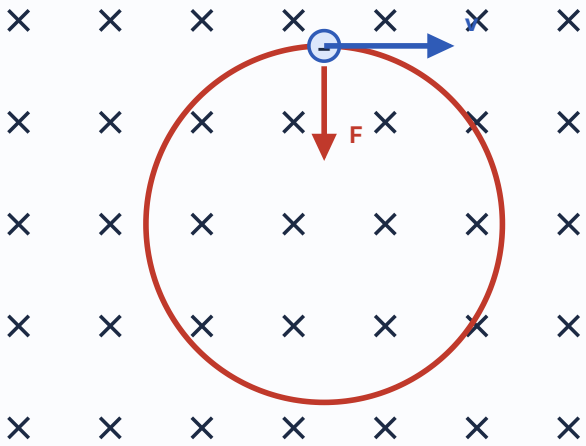
2 Charges in magnetic fields

$$F = qvB \sin\theta$$ DATA BOOKLET

θ = angle between v and B; F is perpendicular to both

- **Direction:** use the left-hand rule (or F = qv × B) for positive charges; reverse it for electrons. A charge moving **parallel** to B feels no force.

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B into page (×)

electron: F = qvB

always ⊥ to v,

so circular motion

$qvB = mv^2/r$

$r = mv/(qB)$

The force is always at 90° to the velocity, so it changes direction but never speed.

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

from $qvB = mv^2/r$ (derive it, it is not in the booklet)

WORKED EXAMPLE

An electron moves at 2.0×10^7 m s^{-1} perpendicular to a 5.0 mT field. Find the radius of its path.

1. $r = mv/qB = 9.11 \times 10^{-31} \times 2.0 \times 10^7/(1.6 \times 10^{-19} \times 5.0 \times 10^{-3})$ M1
2. **= 2.3 cm** A1

- **No work is done** by the magnetic force (it is perpendicular to the motion), so the speed and kinetic energy stay constant.
- **Uses:** mass spectrometers separate ions by $r \propto m/q$; particle accelerators bend beams; the Earth's field steers charged particles into the auroras.

COMMON MISTAKE

Forgetting to reverse the rule for electrons. The left-hand rule gives the direction for **conventional current** (positive charges).

3 Crossed electric and magnetic fields

- **Velocity selector:** with E and B perpendicular to each other and to v, the electric force qE and the magnetic force qvB act in opposite directions. Only particles with **v = E/B** go straight through, whatever their charge or mass.

WORKED EXAMPLE

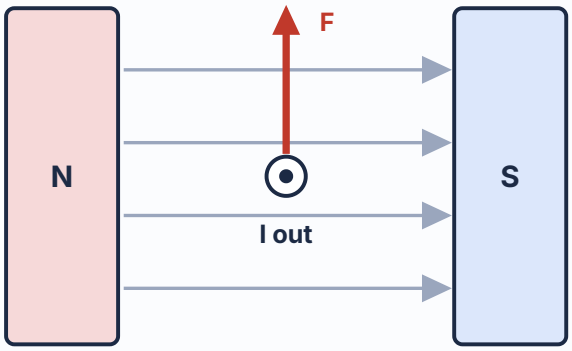
Find the speed selected by $E = 2.0 \times 10^4$ V m^{-1} and B = 0.10 T.

1. $qE = qvB \Rightarrow v = E/B$ M1
2. **$= 2.0 \times 10^5$ m s^{-1}** A1

4 Forces on currents

$$F = BIL \sin \theta$$ DATA BOOKLET

force on a length L of wire carrying current I, at angle θ to B



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

The force is perpendicular to both the field and the current.

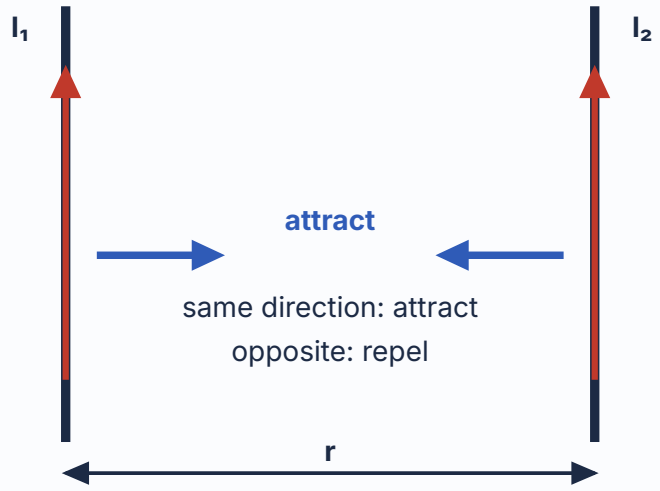
WORKED EXAMPLE

A 20 cm length of wire carries 3.0 A at right angles to a 0.15 T field. Find the force.

1. F = BIL = 0.15 × 3.0 × 0.20 M1
2. **= 0.090 N** A1

$$\frac{F}{L} = \mu_0 \frac{I_1 I_2}{2\pi r}$$ DATA BOOKLET

force per unit length between parallel wires; $\mu_0 = 4\pi \times 10^{-7}$ T m A^{-1}



Each wire sits in the field of the other, so each feels a force.

WORKED EXAMPLE

Two long parallel wires 5.0 cm apart each carry 10 A in the same direction. Find the force per metre.

1. $F/L = 4\pi \times 10^{-7} \times 10 \times 10/(2\pi \times 0.050)$ M1
2. **$= 4.0 \times 10^{-4}$ N m^{-1}, attractive** A1

EXAM TIP

The forces on the two wires are a Newton's third law pair: equal and opposite, even if the currents are different.

LINKING QUESTION

The magnetic force on moving charges is the start of induction in D.4: moving a wire through a field pushes its free electrons along it, creating an emf.

IDEA FOR YOUR IA / EXPLORATION

Measure the force on a current-carrying wire with a top-pan balance and a magnet (current balance), and test $F \propto I$ and $F \propto L$.

Test yourself — cover the answers first

QUICK CHECK

1. What path does a charge follow when it enters a uniform E field at right angles?
2. What force acts on a charge moving parallel to a magnetic field?
3. Why doesn't a magnetic field change a particle's speed?
4. If v doubles, what happens to the radius in a magnetic field?
5. What speed passes undeflected through a velocity selector?
6. Two wires carry currents in opposite directions. Do they attract or repel?

EXAM-STYLE

7. A proton ($m = 1.67 \times 10^{-27}$ kg) moves in a circle of radius 0.20 m in a 0.50 T field. Find its speed and the period.

8. A horizontal 0.50 m wire of mass 20 g is held at right angles to a horizontal 0.40 T field. What current makes it float?

Show answers

1. a parabola
2. none
3. the force is perpendicular to the velocity, so it does no work
4. it doubles
5. v = E/B
6. repel
7. $v = qBr/m = 1.6 \times 10^{-19} \times 0.50 \times 0.20/1.67 \times 10^{-27} = \mathbf{9.6 \times 10^{6}\ m\ s^{-1}}$
   $T = 2\pi r/v = 2\pi m/qB$
   $= \mathbf{1.3 \times 10^{-7}\ s}$ (independent of speed)
8. $BIL = mg$
   $I = 0.020 \times 9.8/(0.40 \times 0.50)$
   $= \mathbf{0.98\ A}$

Stuck on a question?

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Want regular help? Send this to your parent →

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