PHOTON ACADEMY

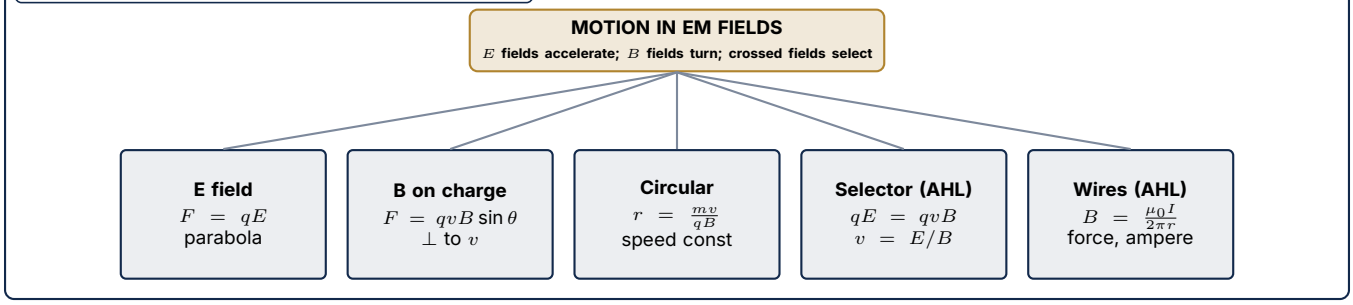
Topic D.3

MOTION IN ELECTROMAGNETIC FIELDS

Every Formula, Trick & Trap on a Page
& IB-Style Quick Reference

Topics Covered	Exam Relevance
Charges in electric fields	P1 & P2 (SL + HL)
Magnetic force (BIL, qvB)	Parabolic deflection
Circular motion in B	$r = mv/qB$
Velocity selector (AHL)	$v = E/B$
Fields from currents & wires (AHL)	$B = \mu_0 I/2\pi r$

The Big Picture — How D.3 Fits Together



§1 — Charged Particles in Uniform Electric Fields

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Force & Acceleration

Force on charge: $F = qE = \dfrac{qV}{d}$

Acceleration: $a = \dfrac{qE}{m} = \dfrac{qV}{md}$

Energy gained (from rest): $qV = \frac{1}{2}mv^2 \Rightarrow v = \sqrt{\dfrac{2qV}{m}}$

Parabolic Motion (perpendicular entry)

Horizontal: $x = v_x t$ (constant velocity, no force)

Vertical: $y = \frac{1}{2}at^2 = \dfrac{qE}{2m}t^2$ (constant acceleration)

Path equation: $y = \dfrac{qE}{2mv_x^2}x^2$ (parabola)

Exit vertical velocity: $v_y = \dfrac{qEL}{mv_x}$

Deflection angle: $\tan\theta = v_y/v_x$

TRICK The parabolic path in an E field is exactly like projectile motion under gravity. Replace g with qE/m.

TRAP Horizontal velocity does NOT change inside the field — electric force acts only vertically. Path is parabolic only while inside; straight line after exit.

§2 — Magnetic Force on Wires and Charges

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Key Formulae

Force on wire: $F = BIL\sin\theta$

Force on moving charge: $F = qvB\sin\theta$

- θ = angle between current/velocity and $\vec{B}$
- Max force when $\theta = 90$; zero when $\theta = 0$ (parallel)
- Direction: **Fleming's Left-Hand Rule** (thuMb = Motion, First = Field, seCond = Current)
- For negative charges: reverse the force direction

Unit of B (tesla): $1\,\text{T} = 1\,\text{N}\,\text{A}^{-1}\,\text{m}^{-1} = 1\,\text{Wb}\,\text{m}^{-2}$ (magnetic flux density)

TRAP If a charge moves **parallel** to $\vec{B}$, the force is **zero** ($\sin 0 = 0$). This is a very common MCQ trap.

NOTE The magnetic force on a charge is always $\perp$ to $\vec{v}$, so it does NO work and cannot change the particle's speed or KE. It only changes direction.

FROM THE PHOTON QUESTION BANK

θ is measured between the current/velocity and $\vec{B}$ — a charge or wire *along* $\vec{B}$ feels zero force. Convert mN/cm to SI before substituting.

§3 — Circular Motion in a Magnetic Field

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Circular Path ($\vec{v} \perp \vec{B}$)

Setting magnetic force = centripetal force: $qvB = \dfrac{mv^2}{r}$

Radius: $r = \dfrac{mv}{qB} = \dfrac{p}{qB}$

Period: $T = \dfrac{2\pi m}{qB}$ (independent of speed!)

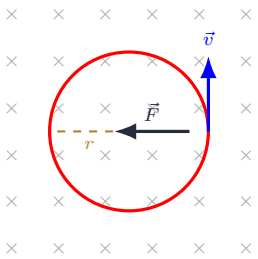
Charge-to-mass ratio: $q/m = v/(rB)$

TRICK $r \propto mv$ (momentum). Heavier/faster ⇒ larger radius. Larger q or B ⇒ smaller radius. Period depends only on m, q, B — not on speed.

TRICK **Two ways the path is a circle at constant speed:** the force $qv \times B$ is always $\perp$ to v (so it only turns, giving a circle); and $\perp$ force does no work (so speed stays fixed).

FROM THE PHOTON QUESTION BANK

Set $qvB = mv^2/r \Rightarrow r = mv/qB$; get v from $qV = \frac{1}{2}mv^2$ if the charge was accelerated first. The curvature direction gives the sign of the charge.



§4 — Velocity Selector & Thomson's Experiment

D.3 AHL

Velocity Selector

Perpendicular $\vec{E}$ and $\vec{B}$ fields. For no deflection: $qE = qvB$

Selected speed: $v = \dfrac{E}{B}$ (independent of q and m!)

Only particles with this exact speed pass through undeflected.

Thomson's Experiment

1. Use velocity selector to find $v = E/B$
2. Turn off E; electron follows circular path radius r in B alone
3. $e/m_e = v/(rB) = E/(rB^2)$

Result: $e/m_e = 1.76 \times 10^{11}$ C kg^{-1}

TRICK In the velocity selector, q cancels. A proton and electron with the same speed are both undeflected. Different particles, same speed ⇒ same result.

TRICK **Two ways to see $v = E/B$:** force balance $qE = qvB$ selects one speed; and the q divides out, so the selected speed is independent of charge and mass.

FROM THE PHOTON QUESTION BANK

Show F_E and F_B oppose for the undeflected beam, then $v = E/B$ (independent of q, m). Feed into $e/m_e = v/(rB) = E/(rB^2)$.

§5 — Magnetic Fields from Currents

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B Field Formulae

Long straight wire: $B = \dfrac{\mu_0 I}{2\pi r}$

Solenoid (inside): $B = \mu_0 n I = \mu_0 \dfrac{N}{L} I$

$\mu_0 = 4\pi \times 10^{-7}$ T m A^{-1}
Direction: **Right-hand grip rule**

- Straight wire: thumb = current, fingers curl in direction of $\vec{B}$
- Solenoid: fingers curl with current, thumb = N pole (field direction)

§6 — Parallel Wires & the Ampere

D.3 AHL

Force Between Parallel Wires

Force per unit length: $\dfrac{F}{L} = \dfrac{\mu_0 I_1 I_2}{2\pi r}$

- Same direction currents $\Rightarrow$ **attract**
- Opposite direction currents $\Rightarrow$ **repel**

Definition of the Ampere

One ampere: two infinite parallel wires, 1 m apart, force $= 2 \times 10^{-7}$ N m^{-1}.
Check: $F/L = \mu_0 \times 1 \times 1/(2\pi \times 1) = 2 \times 10^{-7}$ N m^{-1} ✓

TRAP "Same direction attract" seems counterintuitive. Remember: two wires with current in the same direction create fields that push them together (use FLHR on wire 2 sitting in the field of wire 1).

D.3 Motion in EM Fields

Student Self-Check Table — IB Physics HL

Ref	Topic	Formulas	Tricks	Confidence
§1	Charged particles in E fields	☐	☐	☐☐☐☐☐
§2	Magnetic force (wires & charges)	☐	☐	☐☐☐☐☐
§3	Circular motion in B field	☐	☐	☐☐☐☐☐
§4	Velocity selector & Thomson	☐	☐	☐☐☐☐☐
§5	B fields from currents	☐	☐	☐☐☐☐☐
§6	Parallel wires & the ampere	☐	☐	☐☐☐☐☐

Confidence: fill each box for 1–5 (1 = need help, 5 = exam-ready)

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