

Magnetism & Electromagnetism

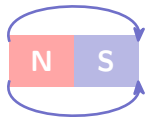
AP Physics 2 ■ Unit 12

AP Physics 2



What we will cover

- 1 Magnetic fields
- 2 Force on a moving charge
- 3 Current-carrying wires
- 4 Electromagnetic induction





Magnetic fields

A **magnetic field** $\vec{B}$ is made by **magnets** or **moving** charges (a still charge makes none).

- unlike **poles** attract; like poles repel
- lines run $N \rightarrow S$ outside, in closed loops

Cut a magnet in half $\Rightarrow$ two magnets – there is **no magnetic monopole**.



Magnets produce field patterns in space



Force on a moving charge

A field pushes a charge only when it moves:

Magnetic force

$$F = qvB \sin \theta$$

Perpendicular to *both* $\vec{v}$ and $\vec{B}$ (right-hand rule). Zero if $v \parallel B$.

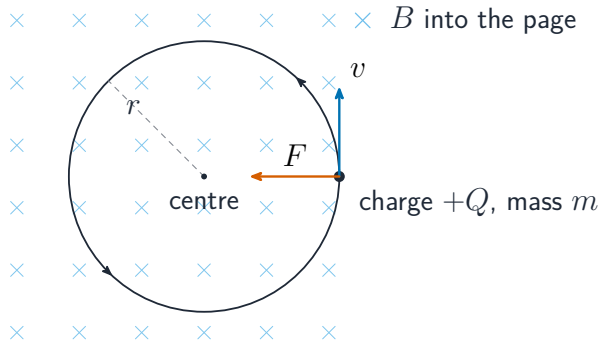
Perpendicular entry $\Rightarrow$ a circle:

$$qvB = \frac{mv^2}{r}, \text{ so } r = \frac{mv}{qB}.$$



Moving charges feel magnetic forces

Magnetism and Moving Charges



$$BQv = \frac{mv^2}{r} \Rightarrow r = \frac{mv}{BQ}$$

A charged particle moving across a magnetic field follows a circular path

Worked example – a proton circling in a magnetic field

A proton ($q = 1.6 \times 10^{-19}$ C, $m = 1.67 \times 10^{-27}$ kg) enters a 0.50 T field at 2.0×10^5 m/s, perpendicular to it. Find r .

- the magnetic force supplies the centripetal

$$\text{force: } qvB = \frac{mv^2}{r}$$

- $r = \frac{mv}{qB} = \frac{(1.67 \times 10^{-27})(2.0 \times 10^5)}{(1.6 \times 10^{-19})(0.50)}$

- $= 4.2 \times 10^{-3}$ m

The period $T = 2\pi m/(qB)$ contains **no v** : faster particles ride bigger circles in the same time. That is what a cyclotron exploits.



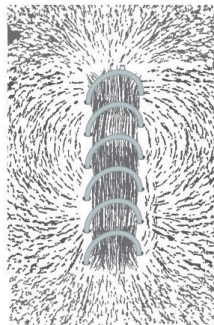
Current-carrying wires

A current makes its own field (circles around the wire), and a field pushes on a current:

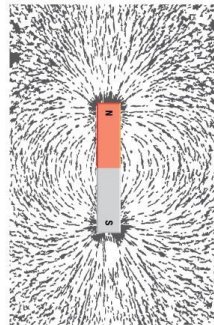
Field and force

$$B = \frac{\mu_0 I}{2\pi r}, \quad F = B\ell \sin \theta$$

Two parallel wires: **same** direction attract, opposite repel. (The opposite of charges!)



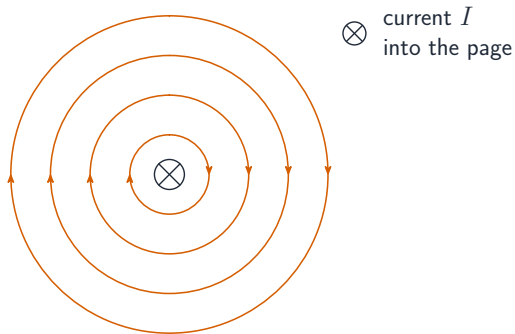
(a)



(b)

Currents produce magnetic fields

Magnetism and Current-Carrying Wires



circular field lines (right-hand grip rule)

Concentric circular field lines surround a straight current-carrying wire



Electromagnetic induction

A **changing** magnetic **flux** through a loop induces a voltage:

Flux and Faraday's law

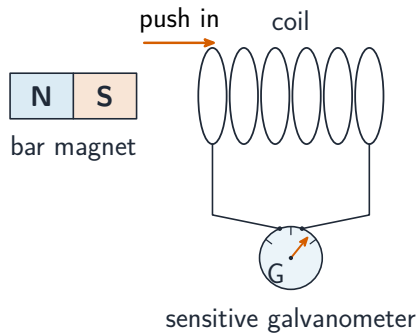
$$\Phi = BA \cos \theta, \quad \varepsilon = -\frac{\Delta \Phi}{\Delta t}$$

Lenz's law (the minus sign):
the induced current **opposes the change** – energy conservation.



Induction moves energy between coils

Electromagnetic Induction and Faraday's Law



Moving a magnet into a coil induces an e.m.f. that drives a current

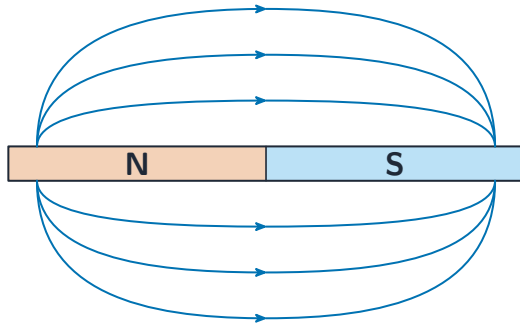
Worked example – an average induced emf

The flux through a single loop drops from 0.020 Wb to 0.008 Wb in 0.030 s. Find the average emf.

$$\begin{aligned} \blacksquare \quad \varepsilon &= -N \frac{\Delta \Phi}{\Delta t}, \text{ with } N = 1 \\ \blacksquare \quad &= - \frac{0.008 - 0.020}{0.030} = \frac{0.012}{0.030} \\ \blacksquare \quad &= 0.40 \text{ V} \end{aligned}$$

The minus sign is **Lenz's law**: the induced current opposes the change that caused it. Quote the magnitude, then say which way the current flows and why.

Magnetic Fields, continued



Field lines run from N to S outside a bar magnet, closer where the field is stronger

How three kinds of material answer a magnetic field

ferromagnetic

iron, nickel, cobalt – domains align *with* the field, strongly, and can *stay* aligned as a permanent magnet

paramagnetic

a *weak* alignment with the field, lost as soon as the field is removed

diamagnetic

present in *all* materials – a usually weak alignment *opposite* to the field

permeability

the measure of the response; free space has the constant $\mu_0 = 4\pi \times 10^{-7} \text{ T m/A}$

Diamagnetism is universal but weak, so it only shows when nothing stronger is present. The other two are extra effects on top of it.

Exam tips

- The magnetic force $F = qvB \sin \theta$ is **perpendicular** to the velocity, so it changes direction (a circle) but not speed; a stationary charge or one moving **along** the field feels no force.
- Use $F = BIL$ for the force on a current-carrying wire (the motor effect).
- A current **creates** a magnetic field (circles around a wire; a solenoid acts like a bar magnet).
- **Induction** needs a **changing** flux $\Phi = BA$ – a stationary magnet in a coil induces nothing.
- **Faraday**: $\varepsilon = \Delta\Phi/\Delta t$ (times N turns); **Lenz**: the induced current opposes the change (energy conservation).



Unit 12 – key takeaways

1

Fields

lines $N \rightarrow S$ in closed loops; no monopoles

2

Moving charge

$F = qvB \sin \theta$, $\perp$ to v and B ;
circle $r = mv/qB$

3

Wires

$F = BIl \sin \theta$; parallel same-direction currents attract

4

Induction

changing flux $\Rightarrow$ emf; Lenz opposes the change

Check yourself

- 1 Does a stationary charge feel a magnetic force?
- 2 A charge moves parallel to B – what is the force?
- 3 Two wires carry current the same way – attract or repel?
- 4 What must change to induce an emf in a loop?



Answers 1. no 2. zero 3. attract 4. the flux (B , A , or θ)