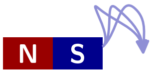
The Magnetic Field

A2 Physics ▪ Topic 20

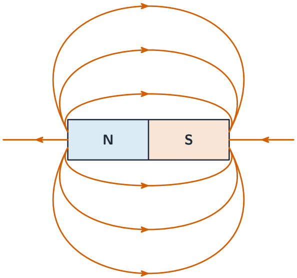
A-Level Physics



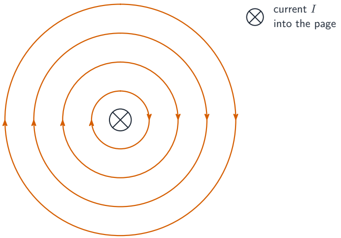
What we will cover

1. Magnetic fields
2. Force on a current: $F = BIL$
3. Force on a charge: $F = BQv$
4. Parallel currents
5. Electromagnetic induction
6. Recap

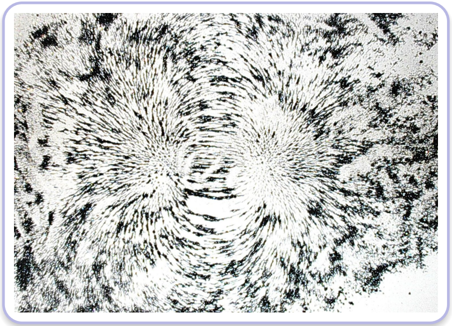
field lines run from **N** to **S** outside the magnet



Fields and field lines

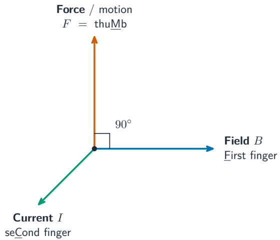


circular field lines (right-hand grip rule)

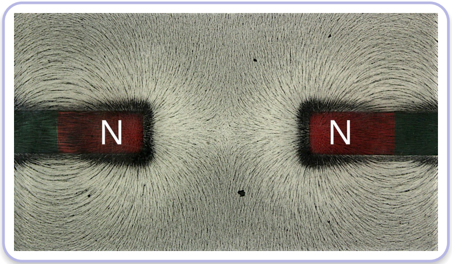


iron filings field

Force on a current-carrying conductor



use the **left** hand; hold the three at right angles



iron filings

Worked example – force on a wire

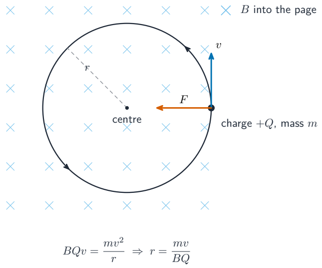
A $5.0\,\mathrm{cm}$ wire carries $3.0\,\mathrm{A}$ at right angles to a $0.20\,\mathrm{T}$ field. Find the force.

$$F = BIL = (0.20)(3.0)(5.0 \times 10^{-2})$$

$$= 3.0 \times 10^{-2}\,\mathrm{N}$$

Only the length inside the field counts, and only the part perpendicular to B. Convert cm to m first.

Force on a moving charge



A charge Q moving at v across a field feels

$$F = BQv\sin\theta$$

Always perpendicular to the velocity, so it curves the path into a circle:

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

> A magnetic force does no work – it changes direction, never speed.

Worked example – a charge in a field

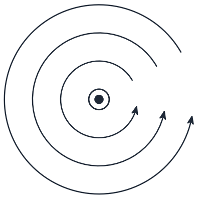
An electron at $2.0 \times 10^{7}\,\mathrm{m\,s^{-1}}$ enters a $1.5\,\mathrm{mT}$ field at $90°$. Find the radius. ($e = 1.6 \times 10^{-19}\,\mathrm{C}$, $m_e = 9.11 \times 10^{-31}\,\mathrm{kg}$)

$$r = \frac{mv}{BQ} = \frac{(9.11 \times 10^{-31})(2.0 \times 10^{7})}{(1.5 \times 10^{-3})(1.6 \times 10^{-19})}$$

$$\approx 7.6 \times 10^{-2}\,\mathrm{m}$$

The **Hall effect** 霍尔效应 uses this sideways force to measure B and to find the sign of the charge carriers.

Force between parallel currents



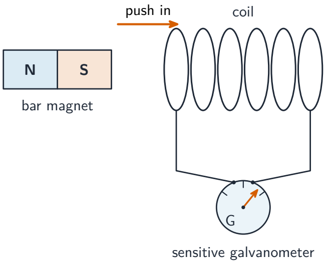
current out of page

Each wire sits in the other's field, so they exert equal and opposite forces:

- same direction currents attract
- opposite currents repel

> This is the physics behind the definition of the **ampere** 安培 – currents that produce a set force per metre.

Faraday and Lenz



A changing flux linkage induces an e.m.f.:

$$\varepsilon = -\frac{d(N\Phi)}{dt}, \qquad \Phi = BA\cos\theta$$

- **Faraday** 法拉第: size = rate of change of flux linkage
- **Lenz** 楞次: the minus sign – it opposes the change

> Lenz's law is energy conservation: push a magnet in and you meet resistance – that work becomes the electrical energy.

Topic 20 – key takeaways

1 On a wire

$F = BIL\sin\theta$ – left-hand rule

2 On a charge

$F = BQv$ – circular path, radius mv/BQ

3 Two wires

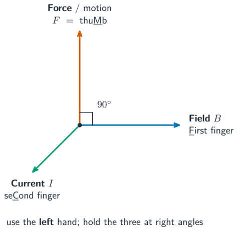
same way attract, opposite repel

4 Induction

$\varepsilon = -d(N\Phi)/dt$ – Faraday and Lenz

Check yourself

1. When is $F = BIL$ a maximum?
2. Why does a magnetic force do no work?
3. Two currents flow the same way – attract or repel?
4. What does the minus sign in Faraday's law mean?



Answers **1.** wire perpendicular to B **2.** force $\perp$ velocity **3.** attract **4.** it opposes the change (Lenz)