

Magnetic Fields
A2 Physics ■ Topic 20

A-Level Physics



Magnetic Fields

What we will cover

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

1 Magnetic fields

Magnetic Fields

└ Magnetic fields

A field that acts on moving charge

A **magnetic field** 磁场 is a region where a moving charge (or a **current** 电流) feels a **force** 力.

moving charges

usually a current in a wire

permanent magnets

tiny atomic currents
inside the material

Magnetic Fields

└ Magnetic fields

Field-line rules

- **field lines** 场线 run **N to S** outside a magnet (S to N inside – closed loops)
- lines never cross
- closer lines $\Rightarrow$ a stronger field



Magnetic Fields

└ Magnetic fields

Four patterns you must recognise

bar magnet

curved N $\rightarrow$ S outside; strongest near the poles

straight wire

circles; **right-hand grip** 右手定则: thumb = current, fingers = field

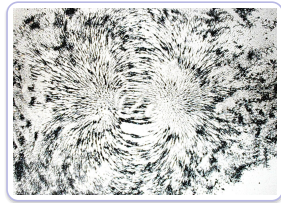
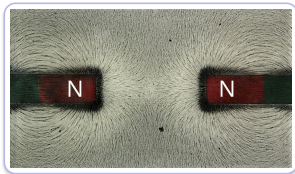
flat coil

field through the centre is at right angles; acts like a small bar magnet

solenoid

nearly **uniform** inside along the axis; outside falls off fast

The same patterns, in iron filings



Filings line up along the field, crowding where it is strongest.

An iron core multiplies the field

An **iron core** 铁芯 inside a solenoid greatly **increases** the field: the iron's atomic magnets line up and add to it. That is why **electromagnets** 电磁铁 and **transformers** 变压器 have iron cores.

2 Force on a current

Force on a current-carrying wire

$$F = BIL \sin \theta$$

θ is the angle between the wire and the field. Largest when the wire is at right angles ($F = BIL$); zero when the wire is along the field. This also **defines** the **magnetic flux density** 磁通密度 B :

$$B = \frac{F}{IL} \quad (\text{wire} \perp \text{field}), \quad [B] = \text{T} = \text{N A}^{-1} \text{m}^{-1}$$

Fleming's left-hand rule

Use the **left** hand. Three fingers at right angles:

- **F**irst finger – **F**ield
- **se**Cond finger – **C**urrent
- **thumb** – **th**rust (force)

$$L = 0.20 \text{ m}, I = 3.0 \text{ A}, B = 0.50 \text{ T}, \theta = 90^\circ$$

$$F = BIL = 0.50 \times 3.0 \times 0.20 = 0.30 \text{ N}$$

3 Force on a charge

Force on a moving charge

$$F = BQv \sin \theta$$

Same left-hand rule – the second finger is the motion of a **positive** charge (reverse it for a negative one). Largest when $v \perp B$; zero when v is along B .

The force is always perpendicular to the velocity, so it does **no work** – it changes direction, never speed.

Circular path in a uniform field

$$BQv = mv^2/r \text{ gives}$$

$$r = \frac{mv}{BQ}, \quad T = \frac{2\pi m}{BQ}$$

T does **not** depend on speed – a faster particle goes in a bigger circle but takes the same time per turn. A component of v along B is unchanged, so the path is a **helix** 螺旋.

Proton: $m = 1.7 \times 10^{-27} \text{ kg}$, $v = 2.0 \times 10^6 \text{ m s}^{-1}$, $B = 0.50 \text{ T}$

$$r = \frac{mv}{BQ} \approx 0.043 \text{ m}$$

Hall effect – a voltage across a current

A slab carrying I , in a field B at right angles, develops a **Hall voltage** 霍尔电压. Charges feel BQv_d , pile up, and make an electric field that opposes further build-up.

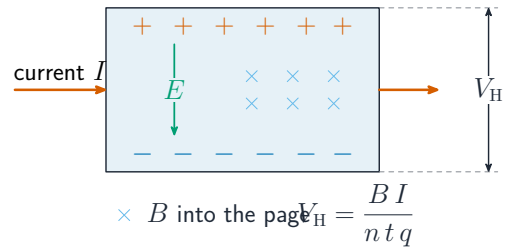
At steady state $E = Bv_d$:

$$V_H = \frac{BI}{ntq}$$

A **Hall probe** 霍尔探头 measures B : known current through a thin semiconductor, read V_H . Largest when the slab is at right angles to B .

Inside the Hall probe

Charges are pushed sideways until the electric field they build up balances the magnetic force – so V_H measures B .

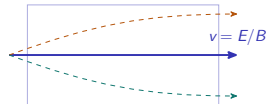


Velocity selector – only one speed gets through

Crossed E and B fields. The electric force qE and magnetic force qvB oppose. Net force is zero only when

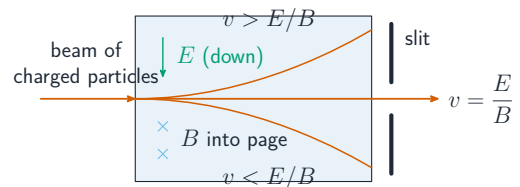
$$v = \frac{E}{B}$$

Particles at that speed go straight; faster or slower ones are deflected.



The selector, drawn

Only a charge with $v = E/B$ passes straight through: for it the electric and magnetic forces cancel exactly, whatever its charge or mass.



goes straight when $qE = qvB$, i.e. $v = E/B$

4 Parallel currents

Magnetic Fields
└ Parallel currents

Two wires, each in the other's field

Using Fleming's left-hand rule:

same direction
currents attract

opposite directions
currents repel

This is the physics behind the SI definition of the **ampere** 安培.

5 Electromagnetic induction

Magnetic Fields
└ Electromagnetic induction

Flux and flux linkage

Magnetic flux 磁通量 through a flat area A :

$$\Phi = BA \cos \theta$$

Unit: **weber** 韦伯, $\text{Wb} = \text{T m}^2$. For a **coil** 线圈 of N turns the **flux linkage** 磁链 is $N\Phi$. Flux changes if you change B , change A (a rod sliding on rails), or change orientation (a coil turning – the a.c. generator).

Magnetic Fields
└ Electromagnetic induction

Faraday and Lenz

Faraday 法拉第: the induced e.m.f. equals the rate of change of flux linkage

$$|\varepsilon| = N \frac{d\Phi}{dt}$$

Lenz 楞次: the induced e.m.f. **opposes the change** that makes it – conservation of energy. Combined:

$$\varepsilon = - \frac{d(N\Phi)}{dt}$$

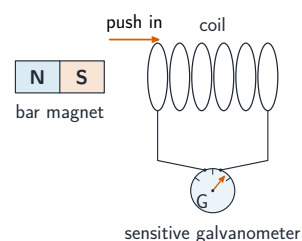
$N = 200$, $A = 0.010 \text{ m}^2$, B falls from 0.50 T to 0 in 0.20 s

$$\Delta(N\Phi) = NBA = 1.0 \text{ Wb}$$

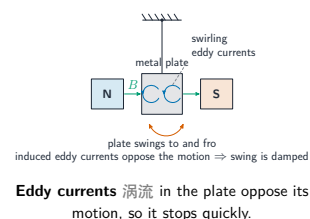
$$|\varepsilon| = \frac{1.0}{0.20} = 5.0 \text{ V}$$

Magnetic Fields
└ Electromagnetic induction

Seeing induction happen



Faster motion, bigger deflection; reverse the motion, reverse the needle.



Eddy currents 涡流 in the plate oppose its motion, so it stops quickly.

What makes the induced e.m.f. larger

From $\varepsilon = N d\Phi/dt$ with $\Phi = BA$, four things raise it:

more turns N stronger B larger area A faster change

It is the **rate of change** of flux linkage that matters, not the flux itself.

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Recap

Topic 20 – key takeaways

1 On a wire

$F = BIL \sin \theta$ – left-hand rule

2 On a charge

$r = mv/BQ$; Hall $V_H = BI/ntq$

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 $T = 2\pi m/BQ$ not depend on speed?
- 3 In a velocity selector, $v = ?$
- 4 What does the minus sign in Faraday's law mean?

Answers 1. wire $\perp B$ 2. faster $\Rightarrow$ bigger r , same time per turn 3. E/B 4. the induced e.m.f. opposes the change (Lenz)