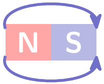
Magnetism & Electromagnetism

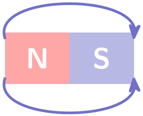
AP Physics 2 ▪ Unit 12

AP Physics 2



What we will cover

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



1 Magnetic fields

Magnetic fields

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

- unlike **poles** 磁极 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

2 Moving charges

Force on a moving charge

A field pushes a charge only when it moves:

Magnetic force

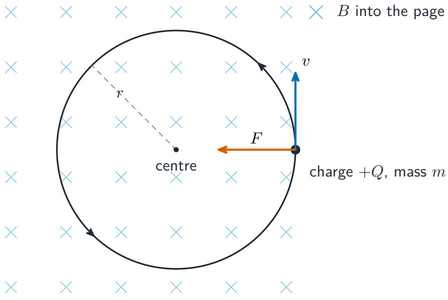
$$F = qvB\sin\theta$$

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

Perpendicular entry ⇒ a circle: $qvB = \frac{mv^2}{r}$, 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 force: $qvB = \dfrac{mv^2}{r}$
- $r = \dfrac{mv}{qB} = \dfrac{(1.67 \times 10^{-27})(2.0 \times 10^{5})}{(1.6 \times 10^{-19})(0.50)}$
- $= 4.2 \times 10^{-3}$ 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.

3

Wires

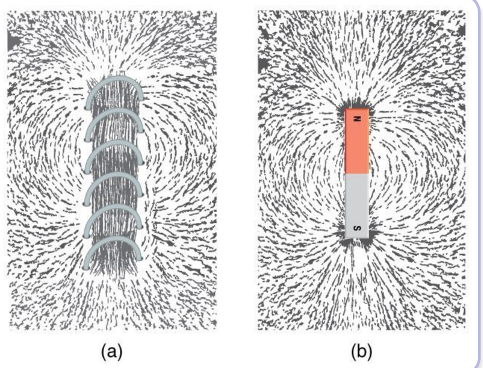
Current-carrying wires

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

Field and force

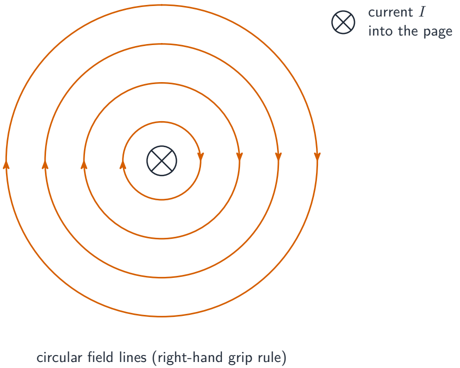
$$B = \frac{\mu_0 I}{2\pi r}, \qquad F = BI\ell \sin\theta$$

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



Currents produce magnetic fields

Magnetism and Current-Carrying Wires



Concentric circular field lines surround a straight current-carrying wire

4 Induction

Electromagnetic induction

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

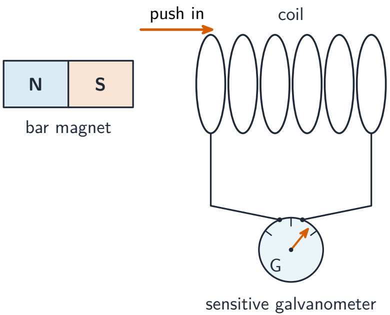
Flux and Faraday's law

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

Lenz's law 楞次定律 (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

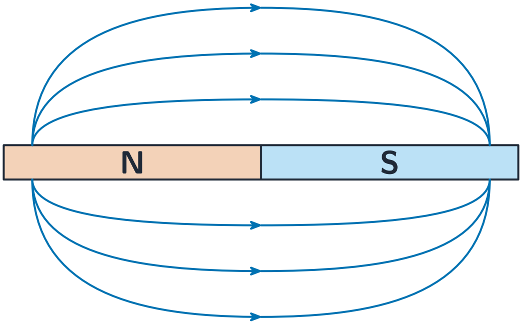
Worked example – an average induced emf

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

- $\varepsilon = -N\frac{\Delta\Phi}{\Delta t}$, with $N = 1$
- $= -\frac{0.008 - 0.020}{0.030} = \frac{0.012}{0.030}$
- $= 0.40$ V

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 铁磁性	iron, nickel, cobalt – domains align *with* the field, strongly, and can stay aligned as a permanent magnet
paramagnetic 顺磁性	a weak alignment with the field, lost as soon as the field is removed
diamagnetic 抗磁性	present in all materials – a usually weak alignment *opposite* to the field
permeability 磁导率	the measure of the response; free space has the constant $\mu_0 = 4\pi \times 10^{-7}$ 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).

5 Recap

Unit 12 – key takeaways

1 Fields

lines N→S in closed loops; no monopoles

2 Moving charge

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

3 Wires

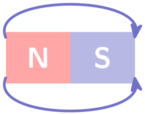
$F = BI\ell\sin\theta$; parallel same-direction currents attract

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)