IB DP PHYSICS · THEME D FIELDS · D.4 (HL ONLY) · ~6 MIN READ

D.4 Induction

Magnetic flux and flux linkage, Faraday's law, the emf in a moving conductor, Lenz's law and conservation of energy, and the sinusoidal emf from a coil rotating in a magnetic field.

Magnetic flux | Faraday's law | ε = BvL | Lenz's law | AC generators | Effect of rotation speed

RS by Riyaz Sir
mentorriyaz.in

No tag = **SL and HL** HL ONLY HL students only DATA BOOKLET given in the exam

M1 A1 how marks are awarded highlight = comes up again and again Test yourself at the end

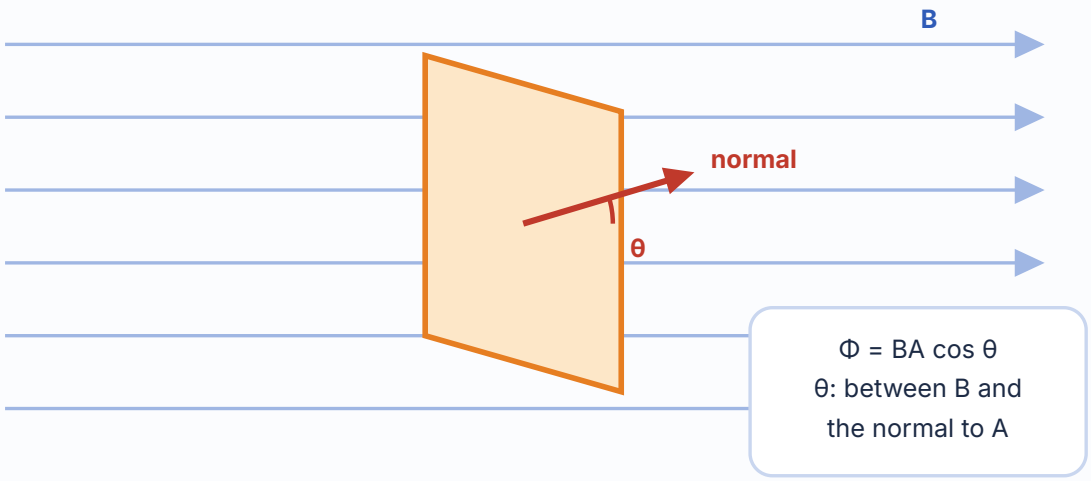
IN 30 SECONDS

- **D.4 is HL only. Magnetic flux** Φ = BA cos θ measures how much field passes through an area.
- **Faraday's law:** a changing flux linkage induces an emf, ε = −NΔΦ/Δt. A rod of length L moving at v through a field B has **ε = BvL**.
- **Lenz's law:** the induced current always flows to oppose the change that causes it. That minus sign is energy conservation.
- A coil rotating in a uniform field gives a **sinusoidal emf**. Spinning it faster raises both the peak emf and the frequency.

BY THE END YOU CAN

- Calculate magnetic flux and flux linkage. HL
- Use Faraday's law to calculate induced emf. HL
- Use ε = BvL for a conductor moving through a field. HL
- Apply Lenz's law to find the direction of induced currents, and explain it with energy. HL
- Describe and explain the emf from a rotating coil, and the effect of changing the rotation frequency. HL

1 Magnetic flux HL



Only the component of B along the normal passes through the loop.

$$\Phi = BA\cos\theta$$ DATA BOOKLET

flux in webers (Wb = T m^2); θ between B and the normal to the area

- **Flux linkage** = NΦ for a coil of N turns.

WORKED EXAMPLE

A coil of area 0.050 m^2 sits in a 0.40 T field, its normal at 60° to the field. Find the flux.

1. Φ = BA cos θ = 0.40 × 0.050 × cos 60° M1
2. **= 0.010 Wb** A1

COMMON MISTAKE

Using the angle between B and the plane of the coil. In Φ = BA cos θ, θ is measured from the **normal**. Flux is greatest when the field is perpendicular to the plane of the coil.

2 Faraday's law HL

$$\varepsilon = -N\frac{\Delta\Phi}{\Delta t}$$ DATA BOOKLET

induced emf equals the rate of change of flux linkage

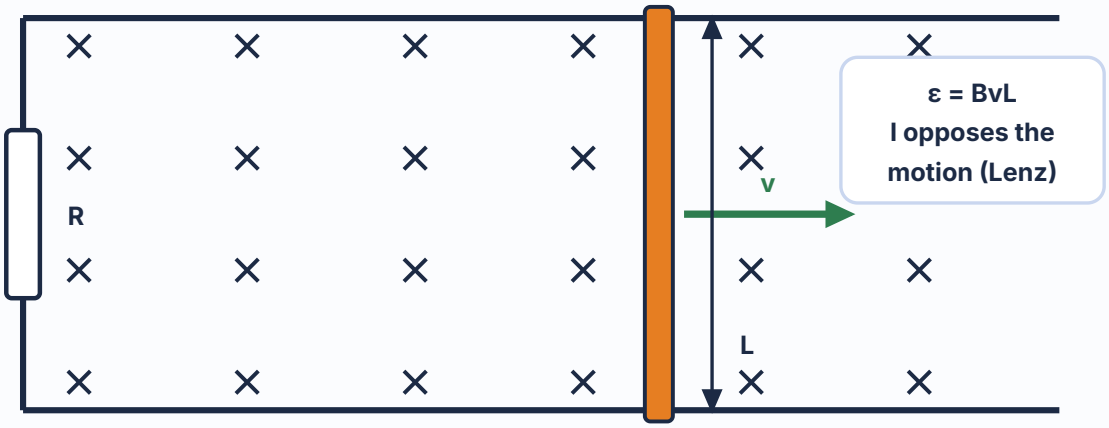
- **Ways to change the flux:** move a magnet or coil, change the current in a nearby coil, change the area, or rotate the coil.

WORKED EXAMPLE

A 200-turn coil's flux falls from 0.010 Wb to zero in 0.20 s. Find the average emf.

1. ε = NΔΦ/Δt = 200 × 0.010/0.20 M1
2. **= 10 V** A1

A conductor moving through a field



As the rod moves, the area of the circuit grows, so the flux through it grows.

$\varepsilon = BvL$ **DATA BOOKLET**

emf across a rod moving perpendicular to B

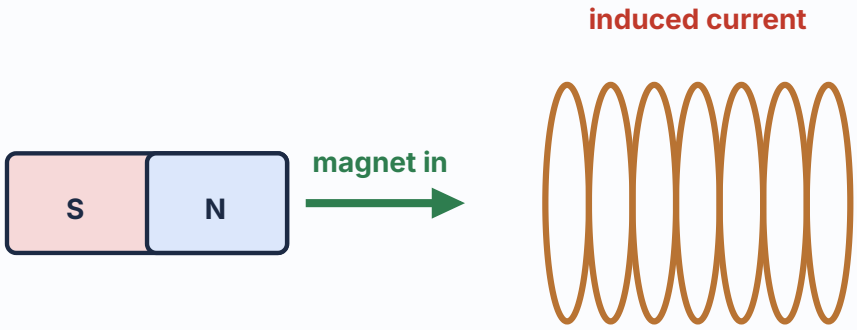
WORKED EXAMPLE

A 0.50 m rod slides at 4.0 m s^{-1} along rails in a 0.20 T field, completing a circuit of resistance 2.0 Ω. Find the emf, the current, the force needed to keep it moving and the power.

1. $\varepsilon = BvL = 0.20 \times 4.0 \times 0.50 =$ **0.40 V** A1
2. $I = \varepsilon/R =$ **0.20 A** A1
3. $F = BIL = 0.20 \times 0.20 \times 0.50 =$ **0.020 N** M1
4. **$P = Fv = 0.080$ W $= I^2R$ ✓: mechanical work becomes electrical energy** R1

3 Lenz's law HL

Lenz's law — the direction of an induced current is such that its magnetic effect opposes the change producing it.



coil face nearest the magnet becomes N:
it repels the approaching N pole

Push a north pole in and the coil makes a north pole to push back. Pull it out and the coil makes a south pole to pull it back.

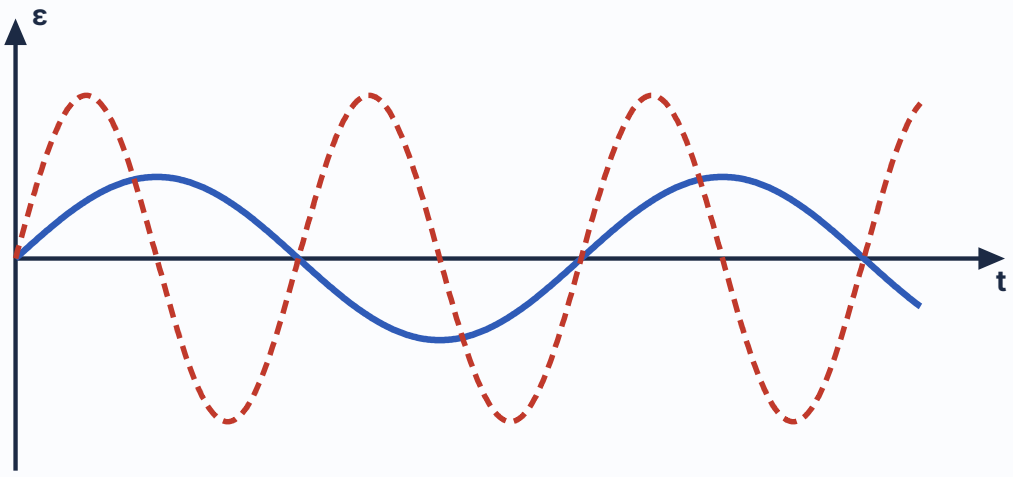
- **Why it must be so:** if the induced current helped the change, the magnet would speed up by itself and energy would be created from nothing. Lenz's law is conservation of energy: you must do work to induce a current.
- **Eddy currents** in solid metal also oppose motion: used in induction braking and cooking; reduced in transformers by laminating the core.

EXAM TIP

For direction questions, say what change happens (flux increasing or decreasing), what the induced field must do (oppose it), then use the right-hand grip rule to get the current.

4 The AC generator HL

- A coil of N turns and area A rotating at angular speed ω in a field B has flux linkage NBA cos ωt. The emf (its rate of change) is **sinusoidal**: maximum when the plane of the coil is **parallel** to B (flux zero but changing fastest), zero when it is perpendicular.



Blue: coil at f. Red dashed: rotated at 2f. Peak emf AND frequency both double.

Doubling the rotation frequency halves the period and doubles the peak emf.

- **Peak emf** ε_0 = NBAω. Increase it with more turns, a stronger field, a bigger coil or faster rotation.

WORKED EXAMPLE

A generator's peak emf is 12 V at 50 Hz. What is its peak emf and frequency at 100 Hz?

1. $\varepsilon_0 \propto \omega$, so peak emf = **24 V** A1
2. **frequency = 100 Hz** A1

COMMON MISTAKE

Saying the emf is greatest when the flux is greatest. emf depends on the **rate of change** of flux, which is greatest when the flux itself passes through zero.

LINKING QUESTION

Induction is how almost all electricity is generated: in power stations (fission E.4, fossil fuels A.3) a turbine turns a generator. The B.5 ideas of emf and internal resistance apply to its output.

IDEA FOR YOUR IA / EXPLORATION

Drop a magnet through a coil connected to a data logger and investigate how the peak emf depends on the drop height (speed), or on the number of turns.

Test yourself — cover the answers first

QUICK CHECK

1. What is the unit of magnetic flux?
2. State Faraday's law.
3. Which conservation law does Lenz's law follow from?
4. A magnet is held still inside a coil. Is there an emf?
5. When is the emf of a rotating coil greatest?
6. A rod moves twice as fast through the same field. What happens to ε?

EXAM-STYLE

7. A square coil of 50 turns, side 4.0 cm, is pulled out of a 0.30 T field in 0.10 s. Find the average emf.
8. An aircraft with a 40 m wingspan flies horizontally at 250 m s^{-1} where the vertical component of the Earth's field is 4.0 × 10^{-5} T. Find the emf between the wingtips.

Show answers

1. weber (Wb = T m^2)
2. the induced emf equals the rate of change of flux linkage
3. conservation of energy
4. no: the flux is not changing
5. when the plane of the coil is parallel to the field
6. it doubles
7. $\Delta\Phi = BA = 0.30 \times 0.040^2 = 4.8 \times 10^{-4}$ Wb
   $\varepsilon = N\Delta\Phi/\Delta t = 50 \times 4.8 \times 10^{-4}/0.10$
   = **0.24 V**
8. $\varepsilon = BvL = 4.0 \times 10^{-5} \times 250 \times 40$
   = **0.40 V**

Stuck on a question?

Send it to me on WhatsApp. I read every message.

Want regular help? Send this to your parent →

Share with a friend

Ask Riyaz Sir