Thinking Pathways Education

EM INDUCTION STUDY GUIDE ⚡

Secondary 4 Pure Physics | Singapore O-Level

This study guide summarises the key ideas and exam skills for electromagnetic induction, including A.C. generators and transformers. You'll learn what causes an induced e.m.f., how to predict current direction, and how to apply transformer relationships confidently. Use it to revise concepts, practise explanations, and check common exam traps.

ELECTROMAGNETIC INDUCTION FUNDAMENTALS

What is Electromagnetic Induction?

Electromagnetic induction is the production of an induced e.m.f. when there is a change in magnetic field (magnetic flux) through a conductor/coil.

Key point: If the circuit is complete, induced e.m.f. causes induced current to flow.

Conditions for inducing an e.m.f.

- Magnet moves into or out of a coil/solenoid
- Coil/solenoid moves relative to a magnet
- A conductor cuts magnetic field lines (moves across the field)
- Magnetic field strength through the coil changes (e.g. electromagnet switched on/off, changing current in nearby coil)

Important note: No change in magnetic field through the conductor/coil = no induced e.m.f. (and hence no induced current).

FARADAY'S AND LENZ'S LAWS

Faraday’s Law

Law: The magnitude of the induced e.m.f. is proportional to the rate of change of magnetic flux linkage through the circuit.

Factors that increase induced e.m.f.

- Move the magnet/coil faster (greater rate of change)
- Use a stronger magnet / stronger magnetic field
- Increase the number of turns in the coil (greater flux linkage)

Lenz’s Law

Law: The induced current flows in a direction such that its magnetic effect opposes the change that produced it (it opposes the change in flux).

Practical application (magnet and solenoid)

- **Magnet moving into** the solenoid: induced current produces a magnetic field that **opposes the approach** (near end becomes the same pole as the approaching pole, causing repulsion).
- **Magnet moving out of** the solenoid: induced current produces a magnetic field that **opposes the separation** (near end becomes the opposite pole, causing attraction).

FACTORS AFFECTING INDUCED E.M.F.

Action	Effect on Induced E.M.F.
Move magnet faster	Increases induced e.m.f. (greater rate of change of flux)

Use stronger magnet	Increases induced e.m.f. (stronger field, larger flux change)
Increase number of turns	Increases induced e.m.f. (greater flux linkage)
Reverse direction of motion	Reverses the direction of induced e.m.f./current (magnitude depends on speed/field/turns)

FLEMING'S RIGHT-HAND RULE

Purpose: To determine the direction of the **induced current** when a conductor moves in a magnetic field (generator effect).

1. First finger: magnetic **Field** direction (from **N** to **S**)
2. Thumb: **Motion** of the conductor (or force on it)
3. Second finger: induced **Current** direction (conventional current)

Note: Use this rule specifically for a **moving conductor cutting magnetic field lines** (electromagnetic induction / generator situations).

GALVANOMETER READINGS

A galvanometer detects the presence and direction of a small current. A deflection means an **induced current** is flowing; the direction of deflection shows the **direction of current** (which depends on the direction of change of magnetic flux).

Case 1: Magnet moving into solenoid

Galvanometer deflects (induced e.m.f. and induced current are produced).

Case 2: Magnet stationary

No deflection because there is **no change in magnetic flux** through the solenoid, so **no induced e.m.f.** is produced. (This is a very common exam explanation.)

Case 3: Magnet moving out of solenoid

Galvanometer deflects in the **opposite direction** compared to Case 1 because the change in flux is reversed, so the induced current reverses.

Exam answer templates
Moving in/out: "There is a change in magnetic flux through the coil, so an induced e.m.f. is produced. Since the circuit is complete, an induced current flows, so the galvanometer deflects."
Stationary: "No change in magnetic flux through the coil, so no induced e.m.f. and no induced current; galvanometer shows no deflection."
Opposite direction: "The change in flux is reversed, so the induced e.m.f./current reverses; galvanometer deflects in the opposite direction."

Simple A.C. Generator

Definition: An A.C. generator converts **mechanical energy** into **electrical energy** by electromagnetic induction.

Main parts

- Rectangular coil (armature)
- Magnetic field (between N and S poles)
- Slip rings (two separate rings connected to the coil ends)
- Carbon brushes (make contact with slip rings)
- External circuit/load

Principle of operation: When the coil rotates in a magnetic field, its sides cut magnetic field lines. The magnetic flux linkage through the coil changes continuously, so an induced e.m.f. is produced across the coil ends (Faraday's Law). If the circuit is complete, an induced current flows.

Role of slip rings: Slip rings allow the rotating coil to stay connected to the external circuit while rotating, without reversing the connections every half-turn (unlike a split-ring commutator).

Why the output is alternating (A.C.): After every half-turn, each side of the coil reverses its direction of motion relative to the magnetic field, so the induced e.m.f. reverses direction. This produces an alternating voltage and current.

Factors affecting output voltage

- Rotate the coil faster (greater rate of change of flux)
- Use a stronger magnetic field
- Increase the number of turns in the coil
- Increase the area of the coil (more flux linkage)

TRANSFORMERS

Definition: A transformer is a device that changes the size of an alternating voltage using electromagnetic induction.

Key point: It works **ONLY with A.C.** because a changing current is needed to produce a changing magnetic field (and hence induce an e.m.f. in the secondary coil).

Structure

- Laminated soft iron core
- Primary coil (input)
- Secondary coil (output)

How it works

1. An A.C. supply in the primary coil produces a changing current.
2. This creates a changing magnetic field in the soft iron core.
3. The changing magnetic flux in the core links the secondary coil.
4. An e.m.f. is induced across the secondary coil (and current flows if a load is connected).

Why the core is laminated: To reduce eddy currents (and therefore reduce heating and energy loss).

Type	Turns	Effect
Step-up	$N_s > N_p$	$V_s > V_p$ (voltage increases, current decreases ideally)
Step-down	$N_s < N_p$	$V_s < V_p$ (voltage decreases, current increases ideally)

KEY FORMULAE

Voltage-turns ratio: $V_s/V_p = N_s/N_p$
Ideal transformer power: $V_pI_p = V_sI_s$
Efficiency: $(V_sI_s)/(V_pI_p) \times 100\%$
Power loss in cables: $P = I^2R$

WORKED EXAMPLES

Example 1: Voltage ratio calculation

A transformer has Np = 500 turns and Ns = 2000 turns. The primary voltage is Vp = 12 V. Find Vs.

Working: Vs/Vp = Ns/Np = 2000/500 = 4
Vs = 4 × 12 = 48 V

Final answer: Vs = 48 V

Example 2: Current in an ideal transformer

An ideal transformer steps up 230 V to 460 V. If the primary current is Ip = 2.0 A, find the secondary current Is.

Working: VpIp = VsIs
230 × 2.0 = 460 × Is
Is = 460/460 = 1.0 A

Final answer: Is = 1.0 A

Example 3: Efficiency calculation

A transformer has input power 120 W and output power 102 W. Find its efficiency.

Working: Efficiency = (output/input) × 100% = (102/120) × 100%
= 85%

Final answer: Efficiency = 85%

Example 4: Power loss in cables

Electricity is transmitted through a cable of resistance 0.80 Ω. If the current is 25 A, find the power loss in the cable.

Working: $P = I^2R = 25^2 \times 0.80$
$= 625 \times 0.80 = 500$ W

Final answer: Power loss = 500 W

HIGH-VOLTAGE TRANSMISSION

High voltage is used for transmission to reduce energy loss in cables. For the same power delivered, increasing voltage reduces current, and power loss in cables is $P = I^2R$, so a smaller current greatly reduces heating loss.

Transmission system (typical sequence)

1. Electricity is generated at a power station (A.C.).
2. A step-up transformer increases the voltage to a very high value for transmission.
3. Electricity is transmitted over long distances through cables (lower current, lower I^2R loss).
4. Near consumers, step-down transformers reduce the voltage to safe/useful levels for distribution and use.

Key insight: High voltage → Low current → Small I^2R loss

COMMON EXAM QUESTIONS

- [ ] **Why is there no deflection when the magnet is stationary?** No change in magnetic flux through the coil, so no induced e.m.f. and no induced current.
- [ ] **Why is the deflection opposite when the magnet is removed?** The change in flux is in the opposite direction, so the induced e.m.f./current reverses (Lenz's Law).
- [ ] **Why doesn't a transformer work with D.C.?** D.C. produces a steady magnetic field (after switching on), so there is no continuous change in flux to induce an e.m.f. in the secondary coil.
- [ ] **Why is high voltage used for transmission?** To reduce current for the same power, reducing cable losses since $P = I^2R$.
- [ ] **What increases induced e.m.f.?** Faster motion, stronger magnetic field, more turns (greater rate of change of flux linkage).
- [ ] **Why does induced current oppose the change?** By Lenz's Law, the induced current's magnetic effect opposes the change in flux that produced it.

QUICK SUMMARY TABLE

Topic	Key Idea
Electromagnetic induction	Induced e.m.f. is produced when magnetic flux through a conductor/coil changes.
Complete circuit	Induced e.m.f. causes induced current only if the circuit is closed.
Faraday's Law	Induced e.m.f. $\propto$ rate of change of flux linkage.
Lenz's Law	Induced current opposes the change in flux that produces it.
Fleming's RHR	Gives direction of induced current for a moving conductor in a magnetic field.
Galvanometer	Deflection shows current; no change in flux → no deflection.

A.C. generator	Rotating coil in magnetic field produces alternating e.m.f.
Transformer	Changes A.C. voltage using mutual induction; Vs/Vp = Ns/Np.
Transmission	Use step-up to reduce current and I^2R losses; step-down for safe use.

EXAM TIPS

- When explaining galvanometer readings, always mention **change in magnetic flux** (or "rate of change of flux") and link it to **induced e.m.f.** then **induced current** (if circuit is complete).
- For direction questions, state the law/rule you are using (usually **Lenz's Law** or **Fleming's right-hand rule**) and describe the **change** you are opposing.
- For transformer calculations, write the correct ratio first (Vs/Vp = Ns/Np) and keep units consistent; show substitution clearly.
- For transmission questions, explicitly use **$P = I^2R$** and the chain: higher V → lower I (for same power) → smaller I^2R loss.

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