Topic D.4

ELECTROMAGNETIC INDUCTION

Every Formula, Trick & Trap on a Page
& IB-Style Quick Reference

Topics Covered	**Exam Relevance**
Magnetic flux $\Phi = BA\cos\theta$	HL only — P1 & P2
Faraday's & Lenz's laws	$\varepsilon = -N\Delta\Phi/\Delta t$
The AC generator	$\varepsilon_0 = NBA\omega$
RMS values & AC power	$I_{\text{rms}} = I_0/\sqrt{2}$
Self-induction	Back-EMF & the I–t curve

The Big Picture — How D.4 Fits Together

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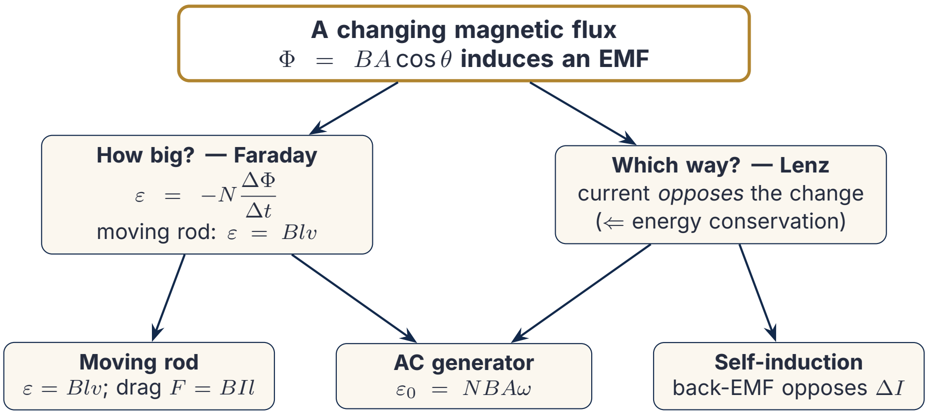

Everything in this chapter hangs off one idea: change the flux, get an EMF. Faraday gives its **size**, *Lenz gives its* **direction**; *the rest are applications.*

§1 — Induced EMF & Magnetic Flux

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EMF in a moving wire: $\varepsilon = Blv$

Rectangular coil (N turns) entering/leaving field: $\varepsilon = BvlN$

Magnetic flux: $\Phi = BA\cos\theta$

Flux density from flux: $B = \dfrac{\Phi}{A}$

Unit: 1 Wb $= 1$ T $\cdot$ m^2

NOTE θ is the angle between $\boldsymbol{B}$ and the **normal** to the surface, not between $\boldsymbol{B}$ and the surface.

TRICK If a question says "field makes angle α with the surface," then $\theta = 90° - \alpha$ and $\Phi = BA\sin\alpha$.

TRAP When a field **reverses direction**, $\Delta B = 2B$, so $\Delta\Phi = 2BA$, not BA.

TRICK **Motional EMF, two ways:** $\varepsilon = Blv$ (force on the charges, $F = qvB$) $= \dfrac{d\Phi}{dt}$ (flux swept, $\Phi = Blx$). Same answer — use whichever the question makes easier.

§2 — Faraday's Law & Lenz's Law

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Faraday's law: $\varepsilon = -N\dfrac{\Delta\Phi}{\Delta t}$

Flux linkage: $\Lambda = N\Phi$ [unit: Wb]

Lenz's Law — Quick Reference

- Induced current opposes the **change** in flux (not the flux itself)
- Based on **conservation of energy**
- Approaching magnet $\rightarrow$ coil repels; retreating magnet $\rightarrow$ coil attracts
- Use right-hand rule to find current direction from required induced B

TRICK For rotating coils: always compute Φ_i and Φ_f separately, then $\Delta\Phi = \Phi_f - \Phi_i$. Do not assume $\Delta\Phi = BA$.

TRAP ε is maximum when $\Phi = 0$ (flux changing fastest). $\varepsilon = 0$ when Φ is at a maximum or minimum (flux momentarily constant).

TRICK **Current direction, two checks:** $\boldsymbol{F} = q\boldsymbol{v} \times \boldsymbol{B}$ on the charges *and* Lenz's law must give the *same* direction. Use one to confirm the other and catch sign slips.

FROM THE PHOTON QUESTION BANK

Direction questions dominate: state that the induced current opposes the **change** in flux, then name it with the right-hand grip rule. Convert a flux-time (or area-time) graph to an emf-time graph via the **gradient**; the area under an emf-time graph is the total change in flux linkage.

§3 — AC Generator

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Sinusoidal EMF: $\varepsilon = \varepsilon_0 \sin(\omega t), \quad \varepsilon_0 = NBA\omega$

Angular velocity: $\omega = 2\pi f = \dfrac{2\pi}{T}$

Effect of Doubling Rotation Speed

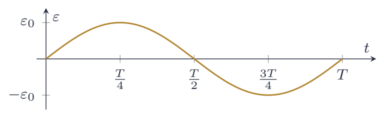
Quantity	Original	Doubled speed
Frequency f	f	$2f$
Period T	T	$T/2$
Peak EMF ε_0	$NBA\omega$	$2NBA\omega$

Both amplitude **and** frequency increase — the graph is "taller and narrower."

TRICK On a generator graph, at $t = 0$ if $\varepsilon = \varepsilon_0$ (max), the coil plane is **parallel** to B (normal $\perp B$, $\Phi = 0$).

FROM THE PHOTON QUESTION BANK

Expect "redraw the graph after doubling/halving ω": both amplitude and frequency scale with ω (taller *and* narrower). The emf is maximum where the flux is changing fastest — coil plane parallel to $\boldsymbol{B}$.



§4 — RMS Values & AC Power

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RMS current: $I_{\text{rms}} = \dfrac{I_0}{\sqrt{2}} \approx 0.707\, I_0$

RMS voltage: $V_{\text{rms}} = \dfrac{V_0}{\sqrt{2}} \approx 0.707\, V_0$

Average power: $\bar{P} = \frac{1}{2} I_0 V_0 = I_{\text{rms}} V_{\text{rms}} = I_{\text{rms}}^2 R = \dfrac{V_{\text{rms}}^2}{R}$

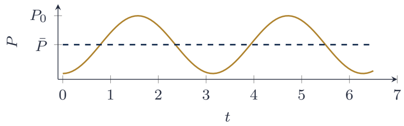
Peak power: $P_0 = I_0 V_0 = 2\bar{P}$

TRAP Peak vs RMS — read which the question asks for. Convert with $V_{\text{rms}} = V_0/\sqrt{2}$ (and $I_{\text{rms}} = I_0/\sqrt{2}$); average power always uses **RMS** values, or equivalently $\bar{P} = \frac{1}{2} V_0 I_0$.

NOTE The power graph $P = I_0 V_0 \sin^2(\omega t)$ has **twice** the frequency of the V-t graph and is always ≥ 0.

FROM THE PHOTON QUESTION BANK

Average power always uses **rms** values ($\bar{P} = V_{\text{rms}} I_{\text{rms}} = \frac{1}{2} V_0 I_0$). In transformer problems apply the turns ratio *first*, then convert peak↔rms; check efficiency with $P = VI$ in vs out.



§5 — Self-Induction

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Instantaneous current (inductor + resistor): $I_{\text{inst}} = \dfrac{V_{\text{ext}} - \varepsilon_{\text{back}}}{R}$

Key Facts — Self-Induction

- Back EMF opposes the **change** in current (Lenz's law)
- At switch-on: back EMF $= V_{\text{ext}}$, $I = 0$
- Steady state: back EMF $= 0$, $I = V_{\text{ext}}/R$
- Current follows exponential growth curve
- Application: spark plugs — sudden current break $\to$ large $dI/dt \to$ huge back EMF

TRICK In IB exams, self-induction questions ask you to **explain** the shape of the I–t graph. Always mention: (1) back EMF opposes change, (2) as I increases, dI/dt decreases, (3) back EMF decreases, (4) current approaches V/R asymptotically.