Electromagnetic Induction

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NEET: 1-2 Qs (~4-8 marks) | Boards: 6-8 marks

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A changing magnetic flux makes electricity. Faraday gives the size of the induced emf, Lenz gives its direction, and inductance measures a coil's resistance to changing current.

1. Magnetic Flux

Flux counts the field lines threading a surface; it is the quantity that must CHANGE to induce emf.

$\Phi = B \cdot A \cdot \cos\theta$
θ measured from the NORMAL (area vector)

$\Phi_{link} = N \cdot \Phi$
linkage for N turns

Unit: weber, 1 Wb = 1 T·m²
scalar quantity

- Flux is MAX when B ⊥ surface ($\theta = 0°$, $\cos\theta = 1$) and ZERO when B lies in the plane ($\theta = 90°$).

MUST KNOW θ is from the normal: 'field 30° to the PLANE' means θ = 60°, so use cos60°. Classic trap.

MUST KNOW Flux changes 3 ways: change B, change A, or rotate to change θ.

2. Faraday's & Lenz's Laws

Induced emf = rate of change of flux linkage; the minus sign IS Lenz's law (direction).

$\varepsilon = -d\Phi/dt$ (Faraday)
single turn

$\varepsilon = -N\, d\Phi/dt$
N turns

$q = N \cdot \Delta\Phi / R$
induced charge (time-independent)

MUST KNOW Lenz's law = conservation of energy: induced current opposes the change that caused it.

- Magnet pushed toward coil is REPELLED; pulled away is ATTRACTED. The coil always resists you.

MUST KNOW Induced CHARGE depends only on total ΔΦ and R, not on speed; faster motion raises emf/current, not charge.

3. Motional EMF

A conductor moving through a field becomes a tiny battery as free charges feel qv×B.

$\varepsilon = B \cdot l \cdot v$ (motional)
v, B, rod mutually ⊥

$I = Blv / R$
rod on closed rails

$F = B^2 l^2 v / R$
retarding force ∝ v

$P = B^2 l^2 v^2 / R = \varepsilon^2/R$
power = work done to push

$\varepsilon = \frac{1}{2} \cdot B \cdot \omega \cdot l^2$
rod rotating about one end

MUST KNOW Only the velocity component ⊥ to BOTH B and rod counts; v ∥ B gives ZERO emf.

- Retarding force ∝ v, but dissipated power ∝ v² — don't mix them up.

MUST KNOW Rotating rod/spoke: $\frac{1}{2}B\omega l^2$ (note the ½ and l^2, not l). Spokes in parallel give same emf as one.

4. Eddy Currents

Swirling induced currents inside a SOLID conductor; same Faraday-Lenz laws, always damp motion and make heat.

Heat loss ∝ I^2R
dissipated in the metal body

Lamination ⇒ higher R ⇒ less loss
thin insulated sheets

- Useful: electromagnetic braking, induction furnace/cooktop, dead-beat galvanometers.

MUST KNOW Transformer/motor cores are LAMINATED to raise eddy-path resistance and cut I^2R loss; flux is unchanged.

- Magnet falls slowly down a copper pipe; a slotted plate swings longer than a solid one (loops broken).

5. Self-Inductance

A coil's 'electrical inertia' — it opposes changes in its OWN current via a back-emf.

$\varepsilon = -L\,dI/dt$ (self)
back-emf

$N\cdot\Phi = L\cdot I$
defining relation

$L = \mu_0 n^2 Al$ (solenoid)
$= \mu_0 N^2A/l$, $n = N/l$

$U = \frac{1}{2}LI^2$
energy stored in field

MUST KNOW L depends ONLY on geometry and core, NEVER on the current; unit henry (H).

MUST KNOW $L \propto N^2$, so doubling the turns QUADRUPLES L. An iron core (μ_r) multiplies L by μ_r.

- Energy $\frac{1}{2}LI^2$ is the magnetic twin of $\frac{1}{2}CV^2$ for a capacitor.

6. Mutual Inductance, Energy & AC Generator

A changing current in one coil induces emf in a neighbour; the principle behind the transformer and AC generator.

$\varepsilon_2 = -M\,dI_1/dt$
M = mutual inductance, unit H

$N_2\Phi_2 = M\cdot I_1$
defining relation

$M = k\cdot\sqrt{L_1L_2}$, $0 \le k \le 1$
$k = 1 \Rightarrow$ perfect coupling

$M = \mu_0 N_1N_2A/l$
coaxial solenoids

$\varepsilon = NBA\omega\cdot\sin(\omega t)$
AC generator, peak $\varepsilon_0 = NBA\omega$

MUST KNOW M is SYMMETRIC: $M_{12} = M_{21}$; depends only on geometry/medium, not on current.

- Only a CHANGING primary current induces emf; steady DC gives zero secondary emf. Transformer = mutual induction.
- AC generator converts mechanical rotation into emf by continuously changing θ (flux), output is sinusoidal.

Self vs Mutual Inductance

	Self (L)	Mutual (M)
Cause	Coil's own changing current	Neighbour's changing current
emf	$\varepsilon = -L\,dI/dt$	$\varepsilon_2 = -M\,dI_1/dt$
Depends on	Own geometry + core	Both coils' geometry, separation, core
Unit	henry (H)	henry (H)
Link	—	$M = k\sqrt{L_1L_2}$, $k \le 1$

Magnet & Coil (Lenz)

Action	Near face of coil	Force
N-pole approaches	Becomes N	Repels magnet
N-pole withdrawn	Becomes S	Attracts magnet

Mnemonic - Direction of induced current (the minus sign in Faraday's law)
Lenz = 'Lazy/oppose' — the induced current is always a spoilsport that fights the change.

Common traps

- θ in $\Phi = BA\cos\theta$ is from the NORMAL, not the plane. 'Field 30° to the plane' ⇒ θ = 60°.
- emf needs a CHANGING flux ($d\Phi/dt$), not flux itself — a large steady flux induces nothing.
- Induced charge $q = N\Delta\Phi/R$ is time-independent; only emf and current depend on how fast it changes.
- $L \propto N^2$ (not N): doubling turns gives 4× L. And $M = k\sqrt{L_1L_2}$, never kL_1L_2.
- The minus sign in $\varepsilon = -d\Phi/dt$ IS Lenz's law — magnitude is Faraday, direction is Lenz.

Most asked in NEET » Flux & angle-from-normal | Induced charge $q = N\Delta\Phi/R$ | Φ as a function of t → $\varepsilon = d\Phi/dt$ | Shrinking/rotating loop emf | Rotating rod/spoke $\frac{1}{2}B\omega l^2$ | Solenoid $L \propto N^2$, energy $\frac{1}{2}LI^2$ | $M = k\sqrt{L_1L_2}$ & symmetry | Lamination / eddy-current uses

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