

CUET · PHYSICS · CLASS XII · CODE 322

# Electromagnetic Induction

CUET unit: Electromagnetic Induction

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## Snapshot

- Establishes that a time-varying magnetic flux through a circuit induces an emf — the foundational link between electricity and magnetism discovered by Faraday and Henry around 1830.
- Develops the quantitative laws: magnetic flux  $\Phi_B = \mathbf{B} \cdot \mathbf{A} = BA \cos \theta$ , Faraday's law  $\varepsilon = -d\Phi_B/dt$  (or  $-N d\Phi_B/dt$  for an N-turn coil), and Lenz's law for the sign (rooted in energy conservation).
- Introduces motional emf  $\varepsilon = Blv$  from a moving conductor and shows it can be derived independently from the Lorentz force on free charges.
- Defines inductance (self and mutual) as the geometric/material constant relating flux linkage to current, with worked formulas for long solenoids and coaxial solenoid pairs.
- The AC generator applies these ideas:  $\varepsilon = NBA\omega \sin \omega t$ .

## Detailed Notes

### 2.1 Core concepts

- Oersted, Ampere and others established that moving charges produce magnetic fields; the converse — that a changing magnetic field can drive currents in a closed coil — was demonstrated independently by Faraday (England) and Henry (USA) around 1830 (NCERT §6.1, p. 154).
- Experiment 6.1: a galvanometer connected to a coil deflects when a bar magnet is moved towards or away from the coil; deflection reverses if the pole is reversed, is larger for faster motion, and is zero when the magnet is stationary — it is the relative motion between magnet and coil that matters (NCERT §6.2, p. 155).
- Experiment 6.2: replacing the bar magnet with a second current-carrying coil C2 reproduces the effect; moving C2 relative to C1 induces a current in C1, again driven by relative motion (NCERT §6.2, p. 155-156).
- Experiment 6.3: two stationary coils — pressing the tapping key in coil C2 produces a momentary deflection in C1; holding the key down gives no deflection; releasing it gives a momentary deflection in the opposite direction. Inserting an iron rod dramatically increases the effect, showing that change of flux (not motion per se) is the cause (NCERT §6.2, p. 156).

- Magnetic flux through a plane of area  $A$  in a uniform field  $B$  is  $\Phi_B = B \cdot A = BA \cos \theta$ ; for non-uniform fields and curved surfaces,  $\Phi_B = \sum B_i \cdot dA_i$ ; SI unit is the weber ( $\text{Wb} = \text{T} \cdot \text{m}^2$ ); flux is a scalar (NCERT §6.3, p. 156-157).
- Faraday's law: the magnitude of induced emf equals the time rate of change of magnetic flux,  $\varepsilon = -d\Phi_B/dt$ ; for a closely wound coil of  $N$  turns,  $\varepsilon = -N d\Phi_B/dt$ ; the negative sign encodes direction (Lenz) (NCERT §6.4, p. 157-158).
- Flux can be changed by varying  $B$ , by changing area  $A$  (stretching/shrinking the coil), or by changing  $\theta$  (rotating the coil) — all produce induced emf (NCERT §6.4, p. 158).
- Lenz's law (Heinrich Friedrich Lenz, 1834): the polarity of induced emf is such that the induced current opposes the change in flux that produced it. If the opposite were true, a small push on a magnet would create runaway acceleration — a perpetual motion machine — violating conservation of energy; therefore work done by the agent moving the magnet appears as Joule heat in the induced current (NCERT §6.5, p. 160).
- Motional emf: for a rod of length  $l$  moving with velocity  $v$  perpendicular to a uniform field  $B$  (and to its own length),  $\Phi_B = Blx$ , so  $\varepsilon = -d\Phi_B/dt = Blv$ . The same expression follows from the Lorentz force  $qvB$  on each free charge — work  $qvBl$  per charge gives emf  $Blv$  (NCERT §6.6, p. 162-163).
- For a stationary conductor in a time-varying  $B$ , the force on charges is purely  $qE$  (since  $v = 0$ ), so a time-varying magnetic field must generate an electric field — this induced electric field is different in nature from the electrostatic field produced by static charges (NCERT §6.6, p. 163).
- For a rod of length  $R$  rotating with angular speed  $\omega$  about one end in a field  $B$  parallel to the axis, the motional emf between centre and tip is  $\varepsilon = B\omega R^2/2$  (NCERT §6.6, Example 6.6, p. 163-164).
- Inductance: in any geometry-fixed coil, flux linkage  $N\Phi_B \propto I$ ; the constant of proportionality is the inductance. It depends only on geometry and intrinsic material properties; SI unit is the henry (H), dimensions  $[\text{M L}^2 \text{T}^{-2} \text{A}^{-2}]$  (NCERT §6.7, p. 165).
- Mutual inductance  $M$  for two long coaxial solenoids (inner radius  $r_1$ , turns/length  $n_1$ ; outer turns/length  $n_2$ ; common length  $l$ ):  $M = \mu_0 n_1 n_2 \pi r_1^2 l$ . In a medium of relative permeability  $\mu_r$ ,  $M = \mu_r \mu_0 n_1 n_2 \pi r_1^2 l$ .  $M_{12} = M_{21} = M$  is general, even when only one direction is easy to compute (NCERT §6.7.1, p. 165-167).
- Mutual-induction emf:  $\varepsilon_1 = -M di_2/dt$  — a changing current in one coil induces emf in a neighbouring coil (NCERT §6.7.1, p. 167).
- Self-inductance: when current in a single coil changes,  $N\Phi_B = LI$ , and  $\varepsilon = -L di/dt$ ; the self-induced emf is also called the back emf because it opposes any change (increase or decrease) of current (NCERT §6.7.2, p. 168).
- Self-inductance of a long solenoid (cross-section  $A$ , length  $l$ ,  $n$  turns per unit length):  $L = \mu_0 n^2 A l$  (air core);  $L = \mu_r \mu_0 n^2 A l$  (core of relative permeability  $\mu_r$ ) (NCERT §6.7.2, p. 168).

- Work done against the back emf in establishing a current  $I$  is stored as magnetic energy  $W = \frac{1}{2} L I^2$ ;  $L$  plays the role of inertia (mass-analogue) for current; magnetic energy density  $u_B = B^2/(2\mu_0)$  (NCERT §6.7.2, p. 168-170).
- For two simultaneously-current-carrying nearby coils, flux in coil 1 is  $N_1\Phi_1 = M_{11}I_1 + M_{12}I_2 = L_1I_1 + M_{12}I_2$ , so  $\epsilon_1 = -L_1 dI_1/dt - M_{12} dI_2/dt$  (NCERT §6.7.2, p. 169).
- AC generator (credited to Nicola Tesla in its developed form): an armature coil of  $N$  turns and area  $A$  is rotated with constant angular speed  $\omega$  in a uniform field  $B$ . With  $\theta = \omega t$ ,  $\Phi_B = BA \cos \omega t$ , so  $\epsilon = NBA\omega \sin \omega t = \epsilon_0 \sin \omega t$  with  $\epsilon_0 = NBA\omega$ ; commercial frequency is 50 Hz in India, 60 Hz in the USA (NCERT §6.8, p. 170-172).
- Energy stored in an inductor is analogous to kinetic energy of a moving mass:  $W = \frac{1}{2}LI^2$  mirrors  $K = \frac{1}{2}mv^2$ , with  $L$  taking the role of inertia and  $I$  that of velocity. This analogy underpins the conservation arguments used for LC oscillations in the next chapter (NCERT §6.7.2, p. 168-170).
- Magnetic energy density:  $u_B = B^2/(2\mu_0)$  for an air-cored region; this is the magnetic counterpart of the electric energy density  $u_E = \frac{1}{2} \epsilon_0 E^2$  that students met in Chapter 2, and integrating it over the solenoid volume reproduces  $\frac{1}{2}LI^2$  (NCERT §6.7.2, p. 170).
- The induced electric field generated by a time-varying  $B$  is non-conservative — its line integral around a closed loop equals  $-d\Phi_B/dt$ , not zero. Hence one cannot define a single-valued potential for an induced field; this is the conceptual fork from electrostatics (NCERT §6.6, p. 163).
- For a stationary loop and a time-varying field, the flux change drives the emf via the induced  $E$ -field; for a moving loop in a static field, the flux change is geometric and the emf is the motional  $Blv$  computed via the Lorentz force. Both pictures give identical numerical answers, illustrating the elegance of Faraday's law (NCERT §6.6, p. 162-163).

## 2.2 Definitions to memorise

Term	Definition	Page
Electromagnetic induction	The phenomenon in which electric current (emf) is generated in a circuit by a changing magnetic flux through it.	154
Magnetic flux ( $\Phi_B$ )	$\Phi_B = B \cdot A = BA \cos \theta$ for a uniform field over a plane area $A$ ; SI unit weber (Wb) = $T \cdot m^2$ ; a scalar quantity.	156-157
Faraday's law of induction	The induced emf equals the (negative) time rate of change of magnetic flux: $\epsilon = -d\Phi_B/dt$ ; for $N$ turns, $\epsilon = -N d\Phi_B/dt$ .	157-158
Lenz's law	The polarity of the induced emf is such that the induced current opposes the change in magnetic flux that produced it.	160
Motional emf		162

Term	Definition	Page
	The emf $Bvl$ induced across a rod of length $l$ moving with velocity $v$ perpendicular to a uniform magnetic field $B$ .	
Mutual inductance (M)	Constant of proportionality between flux linkage in one coil and the current in a neighbouring coil: $N_1 \Phi_1 = M I_2$ ; $\epsilon_1 = -M \frac{dI_2}{dt}$ .	165-167
Self-inductance (L)	Constant of proportionality between flux linkage and current in the same coil: $N\Phi_B = LI$ ; $\epsilon = -L \frac{dI}{dt}$ .	168
Henry (H)	SI unit of inductance; 1 H gives 1 V of emf for a current changing at $1 \text{ A s}^{-1}$ .	165
Back emf	The self-induced emf in a coil, so called because it opposes the change in current that produces it.	168
AC generator	A device that converts mechanical energy into electrical energy by rotating a coil in a uniform magnetic field, producing $\epsilon = NBA\omega \sin \omega t$ .	170-172
Weber (Wb)	SI unit of magnetic flux; $1 \text{ Wb} = 1 \text{ T}\cdot\text{m}^2$ .	157
Flux linkage	Product $N\Phi_B$ of number of turns and flux through one turn.	157, 165
Induced current	Current flowing in a closed circuit as a result of induced emf.	154
Induced electric field	Non-conservative electric field set up by a time-varying magnetic field; drives the induced current.	163
Magnetic energy density	$u_B = B^2/(2\mu_0)$ ; energy per unit volume stored in a magnetic field.	170
Energy stored in inductor	$W = \frac{1}{2} L I^2$ .	168-170
Coaxial solenoids	Two long solenoids on the same axis, used to compute mutual inductance.	166
Lenz–energy argument	Statement that the negative sign in $\epsilon = -d\Phi/dt$ is enforced by energy conservation.	160
Frequency of AC generator	$\nu = \omega/(2\pi)$ ; 50 Hz in India, 60 Hz in the USA.	172

### 2.3 Diagrams / processes to remember

- Figure 6.1: bar magnet pushed towards a coil C1 connected to galvanometer G — galvanometer pointer deflects only while the magnet moves (NCERT p. 155).
- Figure 6.2: coil C2 carrying steady current, moved relative to coil C1 — galvanometer in C1 deflects (NCERT p. 156).
- Figure 6.3: two stationary coils C1 and C2; tapping key K in C2 — momentary deflection in C1 on press and again (opposite direction) on release (NCERT p. 156).

- Figure 6.4: a plane area  $A$  in a uniform magnetic field  $B$ , used to define  $\Phi_B = B \cdot A$  (NCERT p. 157).
- Figure 6.5: non-uniform field over a curved/divided surface, with area-element vectors  $dA_i$  — basis for  $\Phi_B = \sum B_i \cdot dA_i$  (NCERT p. 157).
- Figure 6.6 (a, b): induced-current direction illustrations for Lenz's law with bar magnet approaching/receding from a coil (NCERT p. 160).
- Figure 6.7 / Figure 6.8: planar loops of various shapes moving into/out of a field region — used to argue when induced emf is constant (rectangular) vs varying (circular) (NCERT p. 161-162).
- Figure 6.10: rectangular conductor PQRS with movable arm PQ — geometric setup for motional emf  $Blv$  (NCERT p. 162).
- Figure 6.11: rotating rod hinged at the centre of a metallic ring — setup for  $\varepsilon = B\omega R^2/2$  (NCERT p. 164).
- Figure 6.12: two long coaxial solenoids of common length  $l$  — geometry from which  $M = \mu_0 n_1 n_2 \pi r^2 l$  is derived (NCERT p. 166).
- Figure 6.13 / 6.14: schematic of an AC generator and the resulting sinusoidal emf vs time (NCERT p. 170-172).

## 2.4 Common confusions / NTA trap points

- "Strong magnet near a stationary coil" — students often expect current. NCERT Example 6.5(a) is explicit: however strong the magnet, no flux change  $\Rightarrow$  no induced current (NCERT p. 162).
- Confusing changing electric flux with changing magnetic flux — Example 6.5(b) hammers home that a loop moving through a static electric field between capacitor plates does NOT have an induced current; only changing magnetic flux induces emf in this chapter (NCERT p. 162).
- "Number of spokes matters" trap — for a rotating wheel, all spokes are emf sources in parallel, so their number does not affect the emf between axle and rim (NCERT Example 6.7, p. 165).
- Misremembering the area-vector angle — flux is  $BA \cos \theta$ , where  $\theta$  is the angle between  $B$  and the area-vector normal, not between  $B$  and the plane of the coil. NCERT Example 6.2 sets up a  $45^\circ$  case to test exactly this (NCERT p. 158-159).
- For the rotating rod, the right formula is  $\varepsilon = B\omega R^2/2$  (not  $B\omega R^2$  and not  $B\omega R$ ), traceable to integrating  $d\varepsilon = B\omega r dr$  from 0 to  $R$  (NCERT p. 164).
- For the long solenoid,  $L = \mu_0 n^2 A l$  (where  $n$  is turns per unit length and  $A$  is cross-section), often confused with formulas using  $N$  (total turns) — be careful which the question gives (NCERT p. 168).
- Lenz's law is not an independent postulate that overrides Faraday's law — it is the physical content of the negative sign and is enforced by conservation of energy (NCERT p. 160).

- Forgetting the factor of N for multi-turn coils:  $\varepsilon = -N d\Phi/dt$  — neglecting N gives an emf low by exactly the number of turns. Likewise self-inductance L scales as  $n^2$ , not n.
- Sign of motional emf direction: students get the magnitude  $Blv$  right but confuse polarity. Use Lenz: the induced current must oppose the change in flux through the circuit; the resulting magnetic force on the rod is opposite to  $v$  (a drag force consistent with energy conservation).
- $M = M_{12} = M_{21}$  even when the two coils have very different sizes; the reciprocity follows from energy conservation, even though direct calculation in one direction may be hard.
- Wrong direction of induced E-field: the induced E-field circles the changing flux, with sense given by the right-hand rule applied to  $-dB/dt$  (not  $dB/dt$ ).
- Misapplying  $\varepsilon = Blv$  when  $v$  is parallel to  $l$ : the formula requires  $v$  perpendicular to both  $l$  and  $B$ . If the rod slides along its own length, no emf is induced.

## 2.5 Key formulas table

Quantity	Symbol / Formula	NCERT reference
Magnetic flux	$\Phi_B = B \cdot A = BA \cos \theta$	§6.3, Eq. 6.1, p. 156
Flux linkage	$N\Phi_B$	§6.4, p. 157
Faraday's law (single loop)	$\varepsilon = -d\Phi_B/dt$	§6.4, Eq. 6.3, p. 158
Faraday's law (N turns)	$\varepsilon = -N d\Phi_B/dt$	§6.4, Eq. 6.4, p. 158
Motional emf	$\varepsilon = Blv$	§6.6, Eq. 6.5, p. 162
Rotating rod emf	$\varepsilon = B\omega R^2/2$	§6.6, Ex. 6.6, p. 164
Mutual inductance (coaxial solenoids)	$M = \mu_0 n_1 n_2 \pi r_1^2 l$	§6.7.1, Eq. 6.9, p. 166
Mutual-induction emf	$\varepsilon_1 = -M dl_2/dt$	§6.7.1, p. 167
Self-inductance (definition)	$N\Phi_B = LI$	§6.7.2, p. 168
Self-inductance of solenoid	$L = \mu_0 n^2 A l$	§6.7.2, Eq. 6.15, p. 168
Back emf	$\varepsilon = -L dl/dt$	§6.7.2, Eq. 6.14, p. 168
Energy stored in inductor	$W = \frac{1}{2} L I^2$	§6.7.2, p. 170
Magnetic energy density	$u_B = B^2/(2\mu_0)$	§6.7.2, p. 170
AC generator emf	$\varepsilon = NBA\omega \sin \omega t = \varepsilon_0 \sin \omega t$	§6.8, Eq. 6.19, p. 171
Peak emf (AC gen.)	$\varepsilon_0 = NBA\omega$	§6.8, p. 171
Coupled coils total emf (coil 1)	$\varepsilon_1 = -L_1 dl_1/dt - M dl_2/dt$	§6.7.2, p. 169
Reciprocity	$M_{12} = M_{21} = M$	§6.7.1, p. 167
SI unit of flux	weber $Wb = T \cdot m^2 = V \cdot s$	§6.3, p. 157
SI unit of inductance	henry $H = V \cdot s \cdot A^{-1} = Wb \cdot A^{-1}$	§6.7, p. 165

Quantity	Symbol / Formula	NCERT reference
Indian / USA mains frequency	50 Hz / 60 Hz	§6.8, p. 172

## Practice MCQs

## PYQ Alignment

Electromagnetic Induction is a high-yield CUET (UG) chapter — typically 2–4 MCQs per year across CUET 2023-25 papers, with a steady mix of (i) direct formula recall ( $\Phi_B = BA \cos \theta$ ,  $\varepsilon = -d\Phi_B/dt$ ,  $Blv$ ,  $B\omega R^2/2$ ,  $L = \mu_0 n^2 Al$ ,  $M = \mu_0 n_1 n_2 \pi r_1^2 l$ ) and (ii) plug-and-chug numericals lifted almost verbatim from NCERT Examples 6.2–6.7 and Exercises 6.3, 6.5, 6.7, 6.8. Conceptual items on Lenz's law direction-finding and on the "strong magnet  $\neq$  induced current" trap (Example 6.5) also recur.

### CUET 2025 — Actual PYQs from this chapter

**Q.23 (CUET 2025)** A coil connected to galvanometer. When north pole of magnet moves toward coil, deflection occurs. Which statements are correct? (A) Indicates electric current in coil (B) Deflection smaller when magnet pushed faster (C) Repulsion occurs (D) If magnet stationary, no current Choose correct option.

- (options not in extracted source — see official paper) **Tests:** Electromagnetic induction — qualitative observations (Faraday/Lenz) **Answer:** Not in extracted key

**Q.24 (CUET 2025)** Rectangular conductor moves in magnetic field  $B$  with velocity  $v$ . Magnetic flux and induced emf expressions are: (Options given in diagram question)

- (options not in extracted source — see official paper) **Tests:** Motional EMF in a rectangular conductor —  $\varepsilon = Bvl$  **Answer:** Not in extracted key

**Q.25 (CUET 2025)** Average emf induced when current changes 5 A  $\rightarrow$  2 A in 0.4 s: (A) self-inductance 0.266 mH (B) 0.10 mH Choose correct statement.

- (options not in extracted source — see official paper) **Tests:** Self-induced EMF from  $di/dt$  and self-inductance **Answer:** Not in extracted key

**Q.27 (CUET 2025)** A 12 V battery connected to 10 mH coil. Switch opened in 1 ms. Average induced emf:

- A) 10 V B) 20 V C) 200 V D) 12 V **Tests:** Average induced EMF on opening a switch —  $\varepsilon = -L \Delta i/\Delta t$  **Answer:** Not in extracted key

**Q.29 (CUET 2025)** Which statement is NOT correct for electromagnetic induction?

- A) emf proportional to rate of change of flux B) emf equals total change of flux C) emf increases with number of turns D) induced current opposes change in flux **Tests:**

Faraday's law —  $\varepsilon$  proportional to RATE of change of flux (not total change) **Answer:**  
Not in extracted key

### CUET 2024 — Actual PYQs from this chapter

**Q.13 (CUET 2024)** Flux change 15 Wb when current changes  $0 \rightarrow 10$  A in 0.25 s. Mutual inductance:

- A) 120 H B) 12 H C) 1.5 H D) 0.75 H **Tests:** Mutual inductance from flux change and current change **Answer:** Not in extracted key

**Q.14 (CUET 2024)** Direction of induced current in two changing loops (figure case):

- A) Clockwise in both B) Anticlockwise in both C) Clockwise in (a), anticlockwise in (b)  
D) Anticlockwise in (a), clockwise in (b) **Tests:** Lenz's law — direction of induced current in changing-flux loops **Answer:** Not in extracted key

**Q.42 (CUET 2024)** A conducting ring of radius  $r$  is placed in a changing magnetic field perpendicular to the plane. If rate of change of magnetic field is  $x$ , electric field induced is:

- A)  $\pi r x$  B)  $\pi r x / 2$  C)  $2 \pi r x$  D)  $4 r / x$  **Tests:** Induced electric field from changing  $B$  ( $E = 2 \pi r \frac{dB}{dt}$ ) **Answer:** Not in extracted key

### CUET 2023 — Actual PYQs from this chapter

**Q.18 (CUET 2023)** Which of the following is not an application of eddy currents?

- A) Transformers B) Speedometers C) Magnetic brakes D) Induction furnace **Tests:** Applications of eddy currents (transformer is NOT an eddy-current application) **Answer:** Not in extracted key

**Q.20 (CUET 2023)** A square loop of copper is pulled through a region of uniform magnetic field. Rank the pulling forces required in different regions.

- A)  $F_A = F_B = F_C = F_D$  B)  $F_C > F_B > F_D > F_A$  C)  $F_C > F_D > F_B > F_A$  D)  $F_D > F_B > F_A = F_C$  **Tests:** Motional EMF / force on a loop entering-leaving a magnetic field **Answer:** Not in extracted key