Electromagnetic Induction

Class 12 Physics · Chapter 6 · CBSE

Handwritten Notes · Sequence: NCERT + S.L. Arora

How to use these notes: Topics follow the NCERT order. Extra topics from S.L. Arora are added where they fit and marked [S.L. Arora]. Boxed formulas are the ones to remember.

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1. Introduction NCERT 6.1

→ Oersted showed that an **electric current produces a magnetic field**.

→ Faraday (England) and Henry (USA), around 1830, asked the reverse question: can a magnetic field produce a current?

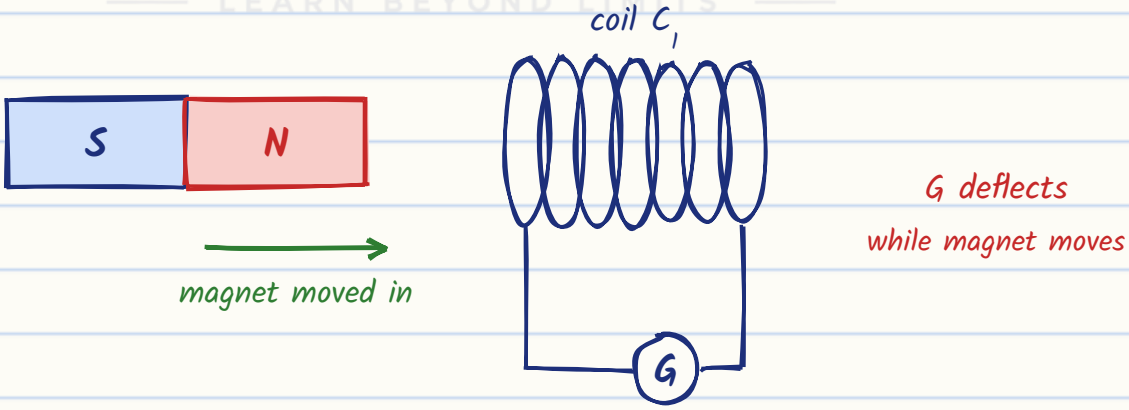
→ Answer: yes — but only when the magnetic field linked with a circuit is **changing**.

> **Electromagnetic induction (EMI):** the phenomenon in which an emf (and hence a current) is induced in a circuit when the magnetic flux linked with it changes.

The emf so produced is the **induced emf**; the current is the **induced current**. Generators, transformers and induction cooktops all work on EMI.

2. Experiments of Faraday & Henry NCERT 6.2

Experiment 1 — magnet and coil



→ Magnet moved **towards** the coil → G deflects.

→ Magnet held **at rest** → no deflection.

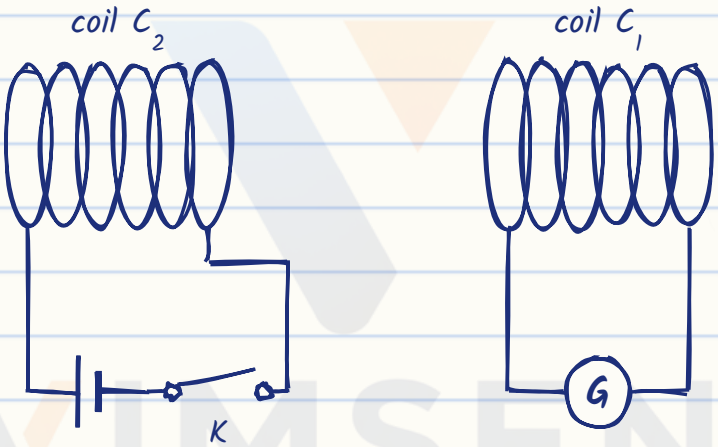
→ Magnet moved **away** → G deflects in the opposite direction.

→ Faster motion → **larger** deflection. S-pole instead of N-pole → deflections reverse.

Experiment 2 — current-carrying coil instead of magnet

Replace the magnet by a coil C_2 carrying a steady current. Relative motion between C_1 and C_2 again produces a current in C_1.

Experiment 3 — no motion at all



press / release K → G deflects momentarily

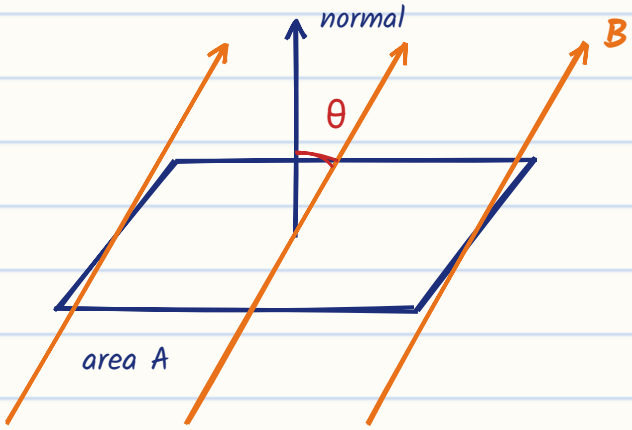
→ Both coils at rest. Pressing or releasing key K gives a **momentary** deflection in G.

→ Steady current in C_2 → no deflection. Putting an iron rod along the common axis increases the deflection.

Conclusion: Relative motion is not essential. What matters is a **change in magnetic flux** linked with the coil.

3. Magnetic Flux NCERT 6.3

Magnetic flux is a measure of the number of magnetic field lines passing through a surface.



$$\Phi = B\,A\cos\theta$$

$$\Phi_B = \mathbf{B}\cdot\mathbf{A} = B\,A\cos\theta$$

θ = angle between **B** and the **normal** to the surface (area vector).

For a non-uniform field: $\Phi_B = \int \mathbf{B}\cdot d\mathbf{A}$.

→ **SI unit:** weber (Wb). 1 Wb = 1 T m^2. Flux is a scalar.

→ $\theta = 0°$ (B along normal): $\Phi = BA$, **maximum**. $\theta = 90°$ (B in the plane): $\Phi = 0$.

→ For a coil of N turns, **flux linkage** = $N\Phi$.

Three ways to change flux: change B, change area A, or change angle θ (rotate the coil).

LEARN BEYOND LIMITS

4. Faraday's Law of Induction NCERT 6.4

First law: Whenever the magnetic flux linked with a circuit changes, an emf is induced in it. It lasts only as long as the flux keeps changing.

Second law: The magnitude of the induced emf equals the rate of change of magnetic flux through the circuit.

$$\varepsilon = -\frac{d\Phi_B}{dt} \qquad \text{for } N \text{ turns: } \varepsilon = -N\frac{d\Phi_B}{dt}$$

The **minus sign** gives the direction of the induced emf (Lenz's law, Topic 5).

Induced current and induced charge [S.L. Arora]

⇒ Coil of resistance R: $I = \varepsilon/R = -(N/R)\, d\Phi/dt$

⇒ Charge through the coil: $q = \int I\, dt = N\,\Delta\Phi / R$

$$q = N\,\Delta\Phi / R$$

Induced charge depends only on the change in flux, **not on how fast** it changes. Induced emf and current do depend on the rate.

Example (NCERT): A square loop of side 10 cm and resistance 0.5 ohm is placed vertically in the east–west plane. A field of 0.10 T acts in the north-east direction (45° to the normal). It is reduced to zero at a steady rate in 0.70 s. Find the induced emf and current.

$\Phi = BA\cos 45° = 0.10 \times 10^{-2} \times 0.707 = 7.07 \times 10^{-4}$ Wb

$\varepsilon = \Phi / t = 7.07 \times 10^{-4} / 0.70 =$ **1.0×10^{-3} V**; $I = \varepsilon/R =$ **2×10^{-3} A**

NCERT Exercise: A long solenoid with 15 turns per cm has a small loop of area 2.0 cm^2 placed inside, normal to its axis. The current changes steadily from 2.0 A to 4.0 A in 0.1 s. Find the induced emf in the loop.

$\Delta B = \mu_0 n \Delta I = 4\pi \times 10^{-7} \times 1500 \times 2 = 3.77 \times 10^{-3}$ T

$\varepsilon = A\,\Delta B / \Delta t = 2 \times 10^{-4} \times 3.77 \times 10^{-3} / 0.1 =$ **7.5×10^{-6} V**

Example (NCERT): A circular coil of radius 10 cm, 500 turns and resistance 2 ohm lies with its plane normal to the horizontal component of earth's field (3.0×10^{-5} T). It is turned through 180° in 0.25 s. Find the emf and current.

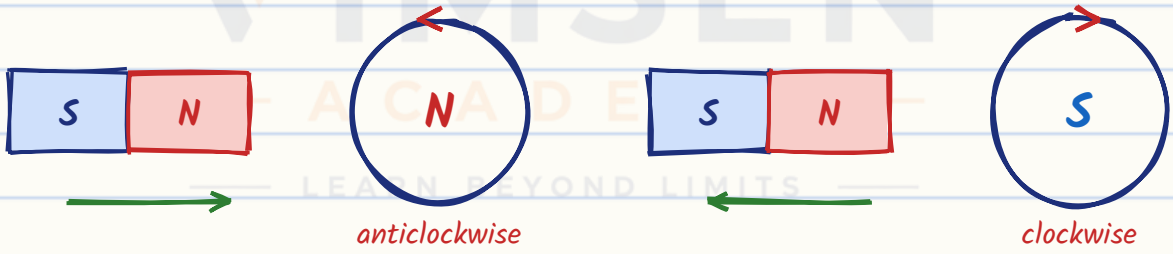
$\Delta\Phi = BA - (-BA) = 2BA$, $A = \pi(0.1)^2 = 3.14 \times 10^{-2}$ m^2

$\varepsilon = N(2BA)/\Delta t = 500 \times 2 \times 3 \times 10^{-5} \times 3.14 \times 10^{-2} / 0.25 = \mathbf{3.8 \times 10^{-3}}$ **V**

$I = \varepsilon/R = 3.8 \times 10^{-3} / 2 = \mathbf{1.9 \times 10^{-3}}$ **A**

5. Lenz's Law & Conservation of Energy NCERT 6.5

Lenz's law: The polarity of the induced emf is such that it tends to produce a current which **opposes the change in magnetic flux** that produced it.



(a) N approaches: face → N (repels) (b) N recedes: face → S (attracts)

→ N-pole approaching: flux through the coil increases → near face becomes **N** to repel the magnet → current **anticlockwise** (seen from the magnet).

→ N-pole receding: flux decreases → near face becomes **S** to attract the magnet back → current **clockwise**.

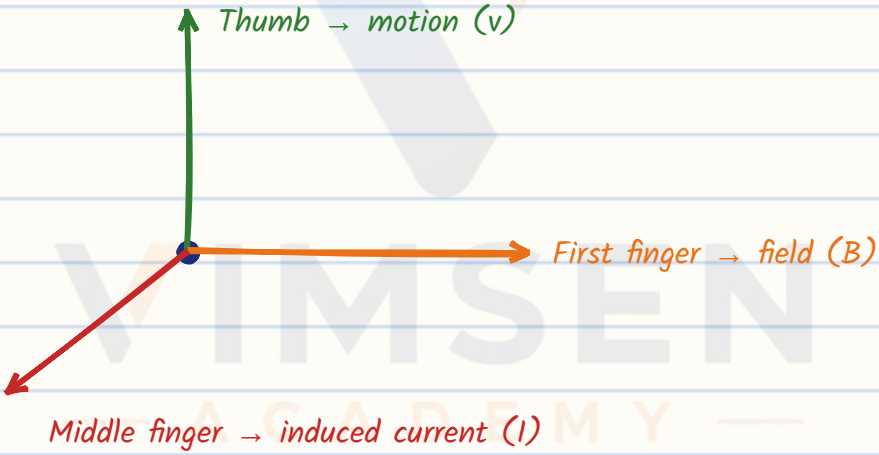
Lenz's law and conservation of energy

⇒ If the induced current **helped** the change, the magnet would speed up by itself and keep producing more current — energy from nothing. Impossible!

⇒ So the induced current always opposes. We must do work against this opposition, and that mechanical work appears as **electrical energy** (then heat).

> **Remember:** Lenz's law is a consequence of the **law of conservation of energy**. It explains the minus sign in $\varepsilon = -d\Phi/dt$.

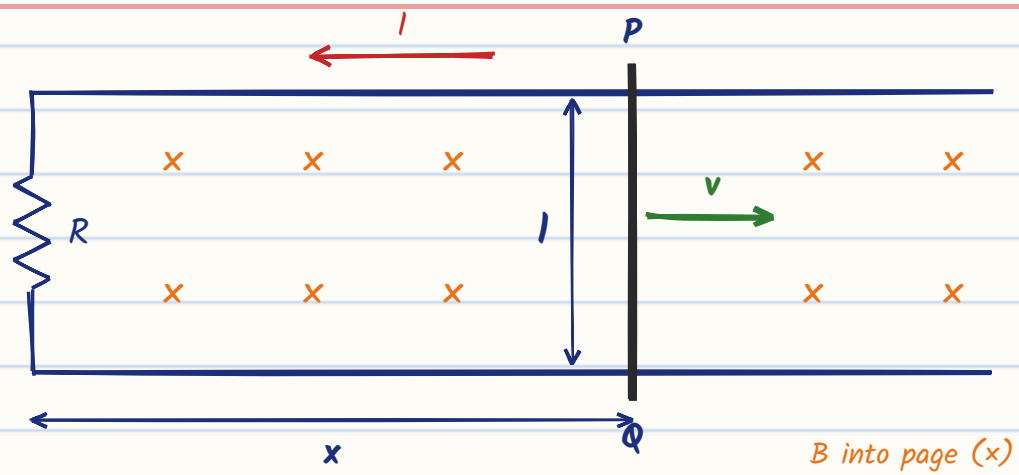
Fleming's right-hand rule [S.L. Arora]



Stretch the thumb, first finger and middle finger of the **right hand** mutually perpendicular. Used for a conductor moving in a field (generator rule).

6. Motional Electromotive Force NCERT 6.6

EMF induced when a conductor moves in a magnetic field. Rod PQ of length l slides with speed v on rails in a uniform field B (into the page).



(a) Using Faraday's law

⇒ Area of loop = l x ⇒ $\Phi_B = B\,l\,x$

⇒ $\varepsilon = -d\Phi_B/dt = -B\,l\,(dx/dt)$

⇒ The rod moves away from R with speed $v = dx/dt$, so $|\varepsilon| = B\,l\,v$

$$\varepsilon = B\,l\,v$$

(b) Using the Lorentz force

⇒ Each free charge q in the rod moves with velocity v in field B: $F = q\,v\,B$, directed along the rod.

⇒ Work done in moving q from Q to P: $W = F\,l = q\,v\,B\,l$

⇒ EMF = work done per unit charge = $W/q = B\,l\,v$ (same answer!)

Energy consideration [S.L. Arora · old NCERT 6.7]

⇒ Current $I = \varepsilon/R = B\,l\,v\,/\,R$

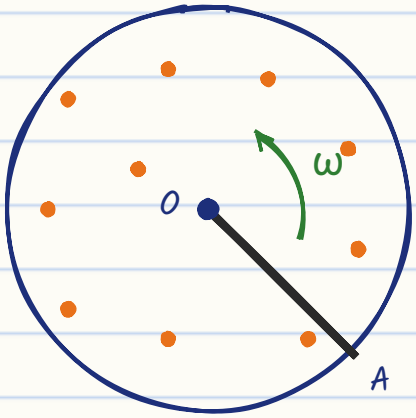
⇒ Force on the rod (opposes motion, Lenz): $F = I\,l\,B = B^2\,l^2\,v\,/\,R$

⇒ Power needed to keep v constant: $P = F\,v = B^2\,l^2\,v^2\,/\,R$

$$P = B^2\,l^2\,v^2\,/\,R = I^2\,R$$

Mechanical power supplied = Joule heat produced. Energy is conserved.

EMF across a rotating rod



B out of page (dots)

$\varepsilon = \frac{1}{2} B \omega l^2$

l = length of rod OA

⇒ A small element dr at distance r moves with speed $v = r\omega$: $d\varepsilon = B(r\omega)\,dr$

⇒ $\varepsilon = \int_0^l B\omega r\,dr = \frac{1}{2} B \omega l^2$

$$\varepsilon = \frac{1}{2} B \omega l^2 = B \pi l^2 \nu \qquad (\nu = \text{rev/s})$$

Example (NCERT): A rod 1 m long rotates at 50 rev/s about one end, in a field B = 1 T parallel to the axis of rotation. Find the emf between its ends.

$\omega = 2\pi \times 50 = 100\pi$ rad/s; $\varepsilon = \frac{1}{2} \times 1 \times 100\pi \times 1^2 =$ **157 V**

Example (NCERT): A wheel with 10 spokes, each 0.5 m long, rotates at 120 rev/min normal to the earth's horizontal field 0.4 G. Find the emf between axle and rim.

$\omega = 4\pi$ rad/s, $B = 0.4 \times 10^{-4}$ T; $\varepsilon = \frac{1}{2} B \omega l^2 =$ **6.28×10^{-5} V**

The spokes are in **parallel**, so the number of spokes does not matter.

NCERT Exercise: A loop 8 cm × 2 cm moves out of a field B = 0.3 T at 1 cm/s. Find the emf when the velocity is normal to (a) the longer side (b) the shorter side.

(a) $\varepsilon = 0.3 \times 0.08 \times 0.01 = \mathbf{2.4 \times 10^{-4}\ V}$, lasting 2 s

(b) $\varepsilon = 0.3 \times 0.02 \times 0.01 = \mathbf{0.6 \times 10^{-4}\ V}$, lasting 8 s

NCERT Exercise: A 1.0 m rod rotates at 400 rad/s about an axis through one end, normal to the rod; the other end touches a metal ring. B = 0.5 T parallel to the axis. Find the emf between centre and ring.

$\varepsilon = \frac{1}{2} B \omega l^2 = \frac{1}{2} \times 0.5 \times 400 \times 1^2 = \mathbf{100\ V}$

NCERT Exercise: A horizontal wire 10 m long, lying east–west, falls at 5.0 m/s at right angles to the earth's horizontal field 0.30×10^{-4} T. Find (a) the emf (b) its direction (c) which end is at higher potential.

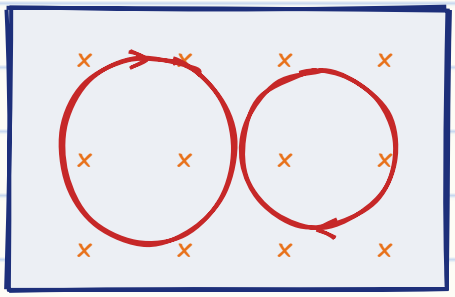
(a) $\varepsilon = B l v = 0.30 \times 10^{-4} \times 10 \times 5 = \mathbf{1.5 \times 10^{-3}\ V}$

(b) By Fleming's right-hand rule: from **west to east** (c) the **east end** is at higher potential.

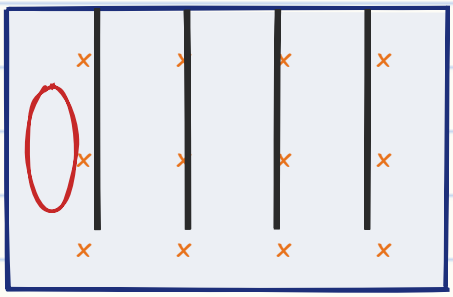
7. Eddy Currents [S.L. Arora · old NCERT 6.8]

Syllabus note: Eddy currents and "Energy consideration" were removed from the current (rationalised) NCERT book. Keep them for concept clarity and competitive exams.

Eddy currents: currents induced in the body of a bulk conductor when the magnetic flux through it changes. They swirl in closed loops like eddies in water (Foucault, 1895).



(a) solid plate: large eddy currents



(b) slotted plate: eddy currents reduced

→ They oppose the change (Lenz's law) and produce heat — energy loss.

→ **Reduced by** using **laminated** cores (thin insulated sheets) or slots — the current path is broken.

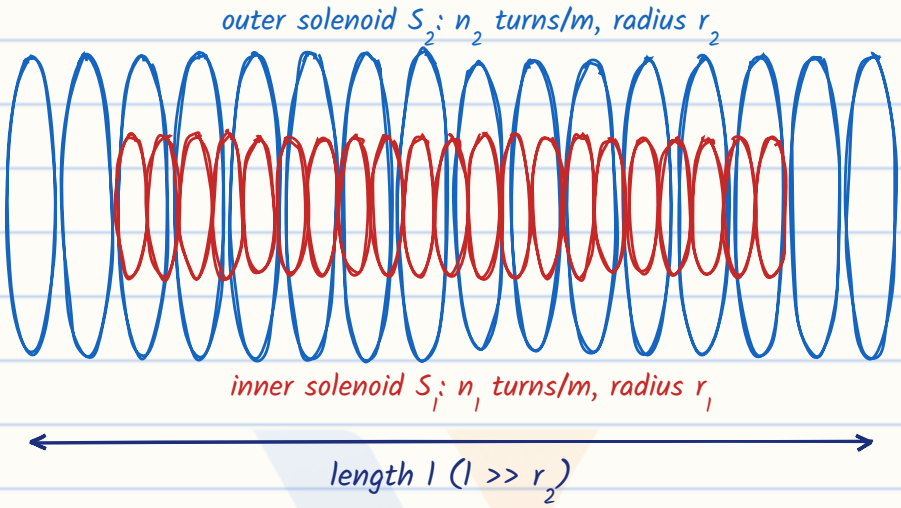
Applications

1. **Magnetic braking** in electric trains.
2. **Electromagnetic damping** in galvanometers (pointer comes to rest quickly).
3. **Induction furnace** — melting metals by heat of eddy currents.
4. **Electric power meters** — rotating metal disc in old energy meters.
5. **Speedometers** — a magnet rotating near an aluminium drum drags it by eddy currents.

8. Inductance: Mutual Inductance NCERT 6.7.1

Flux linked with a coil is proportional to the current producing it: $N\Phi_B \propto I$. The constant of proportionality is called inductance. Unit: henry (H), $1\ H = 1\ Wb\ A^{-1} = 1\ V\ s\ A^{-1}$.

Mutual induction: production of an induced emf in a coil due to a change of current in a **neighbouring** coil.



M of two long coaxial solenoids

⇒ Current I_2 in S_2 gives field inside: $B_2 = \mu_0 n_2 I_2$

⇒ Flux linkage with S_1: $N_1\Phi_1 = (n_1 l)(\pi r_1^2)(\mu_0 n_2 I_2) = M_{12} I_2$

⇒ ⇒ $M_{12} = \mu_0 n_1 n_2 \pi r_1^2 l$. Working the other way gives the same value for M_{21}.

$$M = \mu_0 n_1 n_2 \pi r_1^2 l \qquad (M_{12} = M_{21})$$

With a medium of relative permeability μ_r inside: $M = \mu_r \mu_0 n_1 n_2 \pi r_1^2 l$.

$$\text{Induced emf: } \varepsilon_1 = -M \frac{dI_2}{dt}$$

→ M depends on **geometry** (number of turns, areas, length), **separation and orientation** of the coils, and the **medium**.

→ **Coefficient of coupling** [S.L. Arora]: $M = k\sqrt{(L_1 L_2)}$, $0 \le k \le 1$. Tightly wound coaxial coils: $k \approx 1$.

NCERT Exercise: Two adjacent coils have $M = 1.5$ H. The current in one changes from 0 to 20 A in 0.5 s. Find the change of flux linkage with the other coil.

$\Delta(N\Phi) = M\,\Delta I = 1.5 \times 20 =$ **30 Wb**

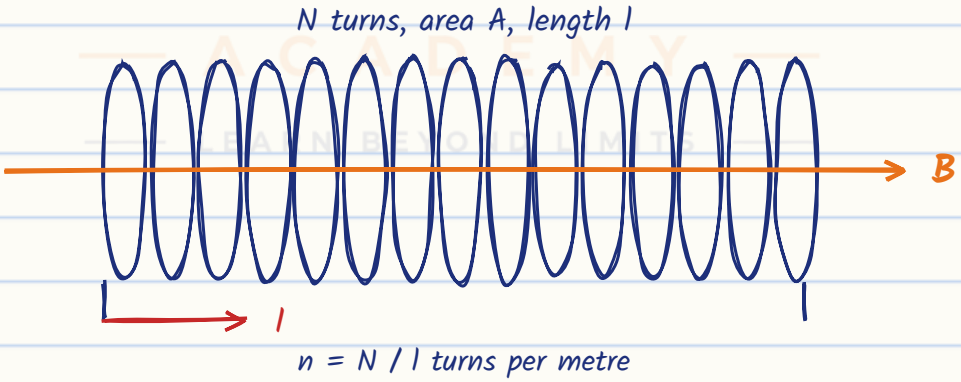
9. Self-Inductance NCERT 6.7.2

Self-induction: production of an induced emf in a coil due to a change of current in the **same** coil.

$$N\Phi_B = L\,I \qquad \varepsilon = -L\,\frac{dI}{dt}$$

L = coefficient of **self-inductance**. The self-induced emf opposes any change of current in the coil — it is called the back emf.

L of a long solenoid



$\Rightarrow B = \mu_0\, n\, I$ inside; total flux linkage $N\Phi_B = (n\,l)(\mu_0\, n\, I)(A)$

$\Rightarrow N\Phi_B = \mu_0\, n^2\, A\, l\, I = L\, I$

$$L = \mu_0\, n^2\, A\, l \qquad \text{(with core: } L = \mu_r\, \mu_0\, n^2\, A\, l\text{)}$$

→ L depends on N^2, area A, length l and the core material (μ_r). It does not depend on the current.

→ A soft-iron core increases L by μ_r times.

Electrical inertia: Inductance opposes a change of current, just as mass opposes a change of velocity. L plays the role of **mass** in electricity.

Example: The current in a coil of $L = 2$ H falls from 5 A to 1 A in 0.2 s. Find the induced emf.

$|\varepsilon| = L\,\Delta I/\Delta t = 2 \times 4 / 0.2 =$ **40 V**

NCERT Exercise: The current in a circuit falls from 5.0 A to 0 in 0.1 s. If the average induced emf is 200 V, estimate the self-inductance.

$L = \varepsilon\,\Delta t / \Delta I = 200 \times 0.1 / 5 =$ **4 H**

Combination of inductors [Reference books]

Coils placed far apart (no mutual inductance) combine like resistors:

$$\text{Series: } L = L_1 + L_2 \qquad \text{Parallel: } 1/L = 1/L_1 + 1/L_2$$

If the coils are coupled (mutual inductance M) and in series: $L = L_1 + L_2 \pm 2M$ (+ when their fluxes aid, − when they oppose).

10. Energy Stored in an Inductor NCERT 6.7.2

⇒ While current grows, the source does work against the back emf: $dW = |\varepsilon|\, I\, dt = L\, I\, dI$

⇒ Total work to raise current from 0 to I: $W = \int_0^I L\, I\, dI$

$$U = \tfrac{1}{2} L I^2$$

This energy is stored in the magnetic field of the inductor (compare with ½ m v^2).

Magnetic energy density

⇒ For a solenoid: $U = \frac{1}{2}(\mu_0 n^2 A l) I^2$ and $B = \mu_0 n I$

⇒ $U = (B^2 / 2\mu_0) \times (A l)$ ⇒ energy per unit volume:

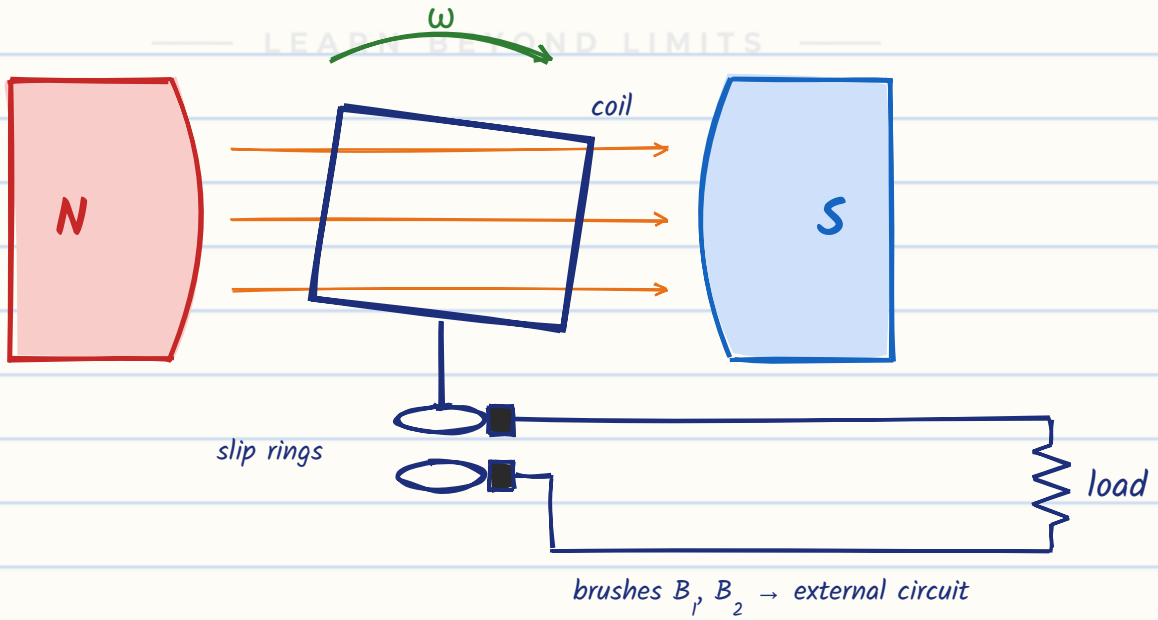
$$u_B = B^2 / 2\mu_0$$

Example: Find the energy stored in a 50 mH inductor carrying 2 A.

$U = \frac{1}{2} \times 50 \times 10^{-3} \times 2^2 = 0.1$ J

11. AC Generator NCERT 6.8

Principle: Electromagnetic induction. When a coil is rotated in a uniform magnetic field, the angle θ — and so the flux through it — changes continuously, inducing an alternating emf. It converts **mechanical energy into electrical energy**.



→ **Armature:** coil of N turns, area A, rotated with angular speed ω.

→ **Field magnets:** poles N and S give a uniform field B.

→ **Slip rings and brushes:** connect the rotating coil to the external circuit.

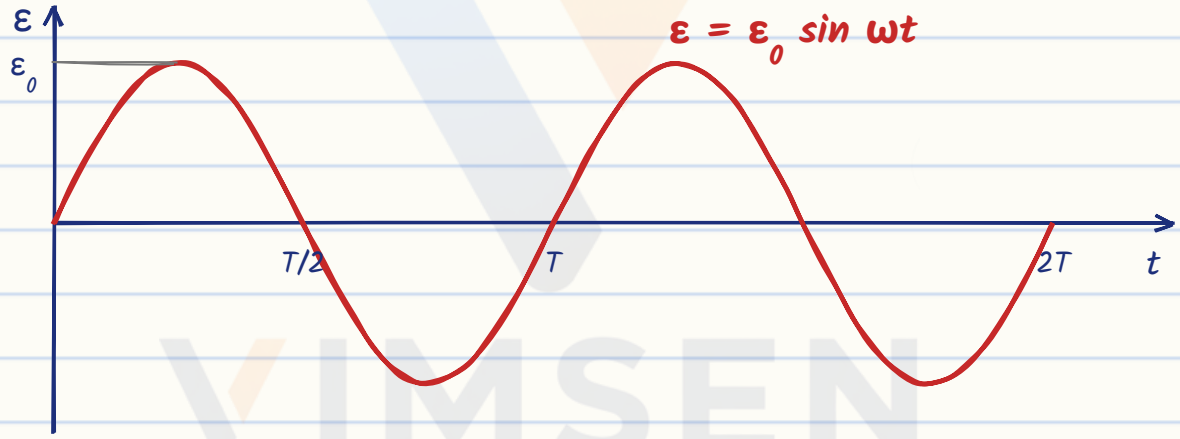
Expression for induced emf

⇒ At time t, angle between B and the normal: $\theta = \omega t$

⇒ Flux: $\Phi_B = B A \cos \omega t$

⇒ $\varepsilon = -N \, d\Phi_B/dt = N B A \omega \sin \omega t$

$$\varepsilon = \varepsilon_0 \sin \omega t, \qquad \varepsilon_0 = N B A \omega$$



→ ε = **maximum** (ε_0) when the plane of the coil is parallel to B (flux = 0, but changing fastest).

→ ε = **zero** when the plane of the coil is perpendicular to B (flux maximum).

→ $\omega = 2\pi\nu$. In India, $\nu = 50$ Hz. Turbines are driven by water (hydro), steam (thermal) or wind.

Example (NCERT): Kamla peddles a stationary bicycle whose pedals turn a 100-turn coil of area 0.10 m^2 at ½ rev/s in a field of 0.01 T perpendicular to the axis. Find the maximum voltage.
$\omega = 2\pi \times 0.5 = \pi$ rad/s; $\varepsilon_0 = N B A \omega = 100 \times 0.01 \times 0.1 \times \pi =$ **0.314 V**

12. Formula Sheet – Quick Revision

Magnetic flux	$\Phi = B\,A\cos\theta$ (Wb)
Faraday's law	$\varepsilon = -N\,d\Phi/dt$
Induced charge	$q = N\,\Delta\Phi / R$
Motional emf	$\varepsilon = B\,l\,v$
Force on rod	$F = B^2l^2v / R$, $P = B^2l^2v^2 / R$
Rotating rod	$\varepsilon = \frac{1}{2}\,B\,\omega\,l^2$
Mutual inductance	$N_1\Phi_1 = M\,I_2$, $\varepsilon_1 = -M\,dI_2/dt$
Coaxial solenoids	$M = \mu_0\,n_1\,n_2\,\pi\,r_1^2\,l$
Coupling	$M = k\sqrt{(L_1L_2)}$
Self-inductance	$N\Phi = L\,I$, $\varepsilon = -L\,dI/dt$
Solenoid	$L = \mu_0\,n^2\,A\,l$
Inductors	Series $L_1 + L_2$, parallel $1/L = 1/L_1 + 1/L_2$
Energy in inductor	$U = \frac{1}{2}\,L\,I^2$, $u_B = B^2/2\mu_0$
AC generator	$\varepsilon = N\,B\,A\,\omega\,\sin\omega t$, $\varepsilon_0 = N\,B\,A\,\omega$
Units	$1\ Wb = 1\ T\ m^2$, $1\ H = 1\ Wb/A = 1\ V\ s/A$

13. Previous Year Questions CBSE Board

How to use: Try each question first, then read the solution. The Concept line tells you the idea the examiner is testing. Paper codes are given so you can check the original papers.

PYQ 1 · CBSE 2025 (55/1/2) · MCQ

The dimensions of self-inductance are: (A) $[ML T^{-2} A^{-2}]$ (B) $[ML^2 T^{-1} A^{-1}]$ (C) $[ML^{-1} T^{-2} A^{-2}]$ (D) $[ML^2 T^{-2} A^{-2}]$

$U = \frac{1}{2} L I^2 \Rightarrow L = 2U / I^2 = [ML^2 T^{-2}] / [A^2] \Rightarrow$ **(D)** $[ML^2 T^{-2} A^{-2}]$

Concept: For dimensions of a new quantity, use the simplest formula it appears in — here the energy stored in an inductor.

PYQ 2 · CBSE 2025 (55/1/3) · MCQ

A rectangular coil of area A is placed in a uniform field B such that the **plane** of the coil makes an angle α with B. The flux linked is: (A) BA sin α (B) BA cos α (C) BA (D) zero

Angle between B and the **normal** = $90° - \alpha \Rightarrow \Phi = BA \cos(90° - \alpha) =$ **BA sin α (A)**

Concept: In $\Phi = BA \cos\theta$, θ is measured from the **normal**, not from the plane. This is the most common trap.

PYQ 3 · CBSE 2025 (55/1/2) · MCQ

A 300-turn coil of diameter 15 mm is held perpendicular to a 30 mT field. The field is reduced uniformly to zero in 20 ms, then raised back to 30 mT in 40 ms. Ratio of the induced emfs e_1/e_2 is: (A) 1/2 (B) 1 (C) 2 (D) 4

$e = N A \Delta B/\Delta t$. Same N, A and ΔB, so $e \propto 1/\Delta t$

$e_1/e_2 = 40/20 =$ **2 (C)** ($e_1 \approx 0.08$ V, $e_2 \approx 0.04$ V)

Concept: Induced emf depends on the **rate** of change of flux. The same change done faster gives a bigger emf.

PYQ 4 · CBSE 2025 (55/7/2) · MCQ

A metal rod 50 cm long is held vertically and moved east at 10 m/s, where the earth's horizontal field is 0.4 G. The emf across its ends is: (A) 0.1 mV (B) 0.2 mV (C) 0.8 mV (D) 1.6 mV

$\varepsilon = B_H l v = 0.4 \times 10^{-4} \times 0.5 \times 10 = 2 \times 10^{-4}$ V = **0.2 mV (B)**

Concept: In $\varepsilon = Blv$, B, l and v must be mutually perpendicular. A vertical rod moving east cuts the horizontal (south–north) field lines, so only B_H counts. 1 G = 10^{-4} T.

PYQ 5 · CBSE 2025 (55/1/2) · Assertion–Reason

Assertion (A): It is difficult to move a magnet into a coil of a large number of turns when the circuit of the coil is closed.

Reason (R): The direction of the induced current in a coil is such that it opposes the cause producing it.

Both A and R are true, and R is the correct explanation of A ⇒ **(A)**

Concept: Lenz's law. A closed coil with many turns carries a larger induced current, which opposes the magnet more strongly. With the circuit open, there is no current and no opposition.

PYQ 6 · CBSE 2025 (55/1/2) · MCQ

An air-filled solenoid of inductance 0.016 H has length 0.81 m and radius 0.02 m. The number of turns is: (A) 2592 (B) 2866 (C) 2976 (D) 3140

$L = \mu_0 N^2 A / l \Rightarrow N^2 = L l / (\mu_0 \pi r^2)$

$N^2 = (0.016 \times 0.81) / (4\pi \times 10^{-7} \times \pi \times 4 \times 10^{-4}) \approx 8.21 \times 10^6 \Rightarrow N \approx$ **2866 (B)**

Concept: $L = \mu_0 n^2 A l$ with $n = N/l$ becomes $L = \mu_0 N^2 A / l$. L grows as N^2.

PYQ 7 · CBSE 2025 (55/7/2)

The current in a solenoid decreases steadily from 6 mA to 2 mA in 50 ms. If an average emf of 0.4 V is induced, find the self-inductance of the solenoid.

$|\varepsilon| = L\,\Delta I/\Delta t \Rightarrow L = \varepsilon\,\Delta t / \Delta I = 0.4 \times 0.05 / (4 \times 10^{-3}) =$ **5 H**

Concept: Self-induced emf depends on the **change** in current (ΔI = 4 mA), not on the current itself. Convert mA and ms to SI first.

PYQ 8 · CBSE 2024 (55/5/3) · MCQ

The mutual inductance of two coils is 50 mH. The current in the first coil is $i = 1.0 \sin(100\pi t + \pi/3)$ A. The peak emf induced in the second coil is: (A) $\pi/5$ V (B) 5π V (C) 0.5π V (D) 0.05π V

$\varepsilon = M\,di/dt = 0.05 \times 1.0 \times 100\pi \cos(100\pi t + \pi/3)$

Peak emf $= 0.05 \times 100\pi =$ **5π V (B)**

Concept: Mutual emf follows di/dt, not i. It is maximum when the current passes through zero, where it changes fastest.

LEARN BEYOND LIMITS

PYQ 9 · CBSE 2024 (55/5/3)

(i) State Lenz's law and justify it on the basis of conservation of energy. (ii) A metal rod of length 2 m rotates at 60 rev/s about an axis through its centre, perpendicular to its length, in a field of 2 T perpendicular to the plane of rotation. Find the emf between the centre and one end.

(i) See Topic 5: the induced current opposes the change in flux. If it helped, energy would be created from nothing.

(ii) Each half of the rod is $l = 1$ m long; $\omega = 2\pi \times 60 = 120\pi$ rad/s

$\varepsilon = \frac{1}{2} B \omega l^2 = \frac{1}{2} \times 2 \times 120\pi \times l^2 = 120\pi \approx$ **377 V**

Concept: Use the **half-length** (centre to end), not the full 2 m. Both ends are at the same potential, so the emf between the two ends is zero.

PYQ 10 · CBSE 2025 (55/7/2)

Two concentric circular coils of radii r_1 and r_2 ($r_2 \gg r_1$) are placed coaxially with their centres coinciding. If a current I is passed through the outer coil, obtain the expression for the mutual inductance.

Field at the centre of the outer coil: $B_2 = \mu_0 I / 2r_2$

Since $r_1 \ll r_2$, this field is uniform over the small coil: $\Phi_1 = B_2 \pi r_1^2 = \mu_0 I \pi r_1^2 / 2r_2$

$M = \Phi_1 / I =$ **$\mu_0 \pi r_1^2 / 2r_2$** (for N_1, N_2 turns, multiply by N_1N_2)

Concept: Always pass current through the **bigger** coil — its field is easy to find and nearly uniform over the small coil.

PYQ 11 · CBSE 2025 (55/1/2)

Two long coaxial solenoids S_1 and S_2 of equal length l have radii $r_1 < r_2$ and n_1, n_2 turns per unit length. Derive the mutual inductance M_{12} and show that $M_{21} = M_{12}$.

Current I_2 in S_2: $B_2 = \mu_0 n_2 I_2$. Flux linkage with $S_1 = (n_1 l)(\pi r_1^2)(\mu_0 n_2 I_2) \Rightarrow M_{12} = \mu_0 n_1 n_2 \pi r_1^2 l$

Current I_1 in S_1: field $\mu_0 n_1 I_1$ exists only inside S_1 (area πr_1^2). Flux linkage with $S_2 = (n_2 l)(\pi r_1^2)(\mu_0 n_1 I_1) \Rightarrow M_{21} = \mu_0 n_1 n_2 \pi r_1^2 l$

$\therefore M_{12} = M_{21} = \mu_0 n_1 n_2 \pi r_1^2 l$

Concept: Both use the area of the **inner** solenoid, because that is the only region where both coils share flux.