Class 12 Physics

📘 Chapter 6 – Electromagnetic Induction

Notes By - The Conclusion Daily

6.1 Introduction

- **Electromagnetic Induction (EMI)** is the phenomenon of **producing current or emf by changing magnetic flux**.
- Discovered by **Michael Faraday** (1831).
- **Key idea:** A changing magnetic field induces an emf in a conductor.

6.2 Magnetic Flux (Φ)

- Magnetic flux through a surface area A:

$$\phi = BA\cos\theta$$

where
B = magnetic field strength
A = area of the loop
θ = angle between $\vec{B}$ and normal to the surface

- Unit: **Weber (Wb)**
  1 Wb = 1 T·m²

Flux change is necessary for induction.

6.3 Faraday's Laws of Electromagnetic Induction

1️⃣ **First Law:**
Whenever magnetic flux linked with a circuit changes, an **emf is induced** in it.

2️⃣ **Second Law:**
Magnitude of induced emf is directly proportional to the **rate of change of magnetic flux**.

$$\varepsilon = -\frac{d\phi}{dt}$$

(The negative sign shows direction — explained by Lenz's Law.)

6.4 Lenz's Law

- The induced emf produces a current which **opposes the change in magnetic flux**.

$$\varepsilon = -\frac{d\phi}{dt}$$

- Explains **conservation of energy**: induced current always resists the cause producing it.

Example:
When a magnet approaches a coil, the induced current opposes motion (repels the magnet).

6.5 Motional Electromotive Force (emf)

If a conductor of length l moves with velocity vvv perpendicular to a magnetic field BBB:

$$\varepsilon = Blv$$

Derivation:

- Force on charge q: $F = qvB$
- Work done per unit charge = $emf = Blv$
- Direction given by **right-hand rule**.

Power generated:

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

6.6 Induced emf in a Rotating Coil

For a coil of N turns rotating with angular speed ω in uniform B-field:

$$\Phi = B\, A\, \cos(\omega\, t)$$
$$\varepsilon = -\frac{d\phi}{dt} = N\, B\, A\, \omega\, \sin(\omega\, t)$$

- **Maximum emf:** $\varepsilon_0 = N\, B\, A\, \omega$
- **Instantaneous emf:** $\varepsilon = \varepsilon_0 \sin(\omega t)$

This is the **principle of AC generators**.

6.7 Eddy Currents

- When a bulk conductor (like metal plate) moves through a magnetic field, **circular currents** are induced within it.
- Called **Eddy currents**.
- They oppose motion (Lenz's law).

Applications:

- Electromagnetic braking in trains
- Induction cookers
- Energy meters
- Magnetic damping (galvanometers)

Disadvantage: Energy loss as heat (eddy current loss).

6.8 Self Induction

- When current in a coil changes, flux through the same coil changes, inducing emf in itself.

$$\varepsilon = -L\frac{dI}{dt}$$

where L = **self inductance** (Henry).

Flux linkage:

$$\phi = LI$$

Unit: Henry (H)
1 H = 1 Wb/A

Physical meaning:
A coil has self-inductance 1 H if 1 A/s change in current induces 1 V emf.

6.9 Mutual Induction

- When current in one coil changes, emf is induced in **another nearby coil**.

$$\varepsilon_2 = -M\frac{dI_1}{dt}$$

where M = mutual inductance.

Unit: Henry (H)

Applications:

- Transformer
- Induction coils

6.10 Energy Stored in Inductor

- Energy stored in magnetic field of an inductor carrying current I:

$$U = \frac{1}{2}LI^2$$

Magnetic energy density:

$$u = \frac{1}{2}\frac{B^2}{\mu}$$

6.11 AC Generator (Alternator)

Principle:
Based on **electromagnetic induction** – rotation of a coil in a magnetic field induces an emf.

Construction:

- Rectangular coil (N turns, area A)
- Rotates in uniform B-field
- Slip rings and brushes connect coils to external circuits.

Working:

$$\varepsilon = NBA\,\omega\sin(\omega t)$$

Output: Alternating emf (changes direction periodically).

Frequency:

$$f = \frac{\omega}{2\pi}$$

6.12 Key Formula Summary

Concept	Formula	Description

Magnetic flux	$\Phi = B\,A\,\cos\theta$	Amount of magnetic field through area
Induced emf	$\varepsilon = -\frac{d\Phi}{dt}$	Faraday’s law
Motional emf	$\varepsilon = B\,l\,v$	Conductor moving in field
Rotating coil	$\varepsilon = N\,B\,A\,\omega\,\sin(\omega\,t)$	AC generation
Self induction	$\varepsilon = -L\frac{dI}{dt}$	emf in same coil
Mutual induction	$\varepsilon_2 = -M\frac{dI_1}{dt}$	emf in another coil
Stored energy	$U = \frac{1}{2}LI^2$	Magnetic energy
Energy density	$u = \frac{1}{2}\frac{B^2}{\mu}$	Energy per unit volume

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6.13 Quick Recap

- **Faraday’s Law:** emf ∝ rate of flux change.
- **Lenz’s Law:** opposes cause producing emf.
- **Self & Mutual Induction:** emf due to changing current.
- **Eddy currents:** induced circulating currents in conductors.
- **AC generator:** practical application of EMI.
- Energy stored in the inductor = $U = \frac{1}{2}LI^2$