6. ELECTRO MAGNETIC INDUCTION

Single Page Simple Synopsis

Electromagnetic Induction is the phenomenon where an electric current is generated in a conductor by varying the magnetic field around it. Whenever the magnetic flux linked with a circuit changes, an electromotive force (EMF) is induced, which drives an electric current if the circuit is closed.

Key Concepts

1. **Magnetic Flux(ϕ):** The total number of magnetic field lines passing normally through a given area. **Formula: Magnetic Flux** $\phi = B A\cos\theta$. Here B is the magnetic field, A is the area.
2. **Induced EMF & Current:**
   The voltage and resulting current produced purely due to the changing magnetic flux.
3. **The Core Laws**
   - **Faraday's First Law:**
     Whenever the magnetic flux linked with a coil changes, an EMF is induced in it.
   - **Faraday's Second Law:** The magnitude of the induced EMF is directly proportional to the rate of change of magnetic flux. **Formula:** $e = -\frac{d\phi}{dt}$
   - **Lenz's Law:** The direction of the induced EMF and current always opposes the change in magnetic flux that produced it. **Formula:** $\varepsilon = -N\frac{d\phi_B}{dt}$
     Here, N is the number of turns in the coil and the negative sign represents Lenz's law.
4. **Types of Induction:**
   - **Motional EMF:** Induced EMF generated when a conductor moves in a stationary magnetic field (e.g., a rod moving in a magnetic field).
   - **Self-Induction:** The phenomenon where a changing current in a single coil induces an EMF in that very same coil. The property is called inductance (L).
   - **Mutual Induction:** The phenomenon where a changing current in one coil induces an EMF in a nearby secondary coil. This is the underlying principle of transformers.
5. **Eddy Currents:** These are loops of electrical current induced within bulk conductors by a changing magnetic field. They flow in circles, much like eddies in water, and often result in unwanted heat loss but are useful in applications like magnetic braking and induction furnaces.

Real Life Examples

- **Electrical power generation plants** (hydro electric, wind), **Step-down transformer,** Plugin chargers, Induction cooktops, Electric motors, Swiping Machines, AC generators,...

IMP. IPE POINTS

1. **Experiments of Faraday and Henry** proved that whenever the magnetic flux through a coil changes, an emf is induced in the coil.

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2. **Magnetic flux** is $\phi_B = \vec{B} \cdot \vec{A} = BA \cos\theta$

SI units: Tm^2 (or) Weber

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3. **Faraday's law** of **induction**: $\varepsilon = -N\frac{d\phi_B}{dt}$

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4. a) Induced emf between the ends of a coil,

$$e = -\frac{d\phi}{dt} \text{ (or) } e = -\frac{d}{dt}(BA\cos\theta)$$

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5. Emf can be produced by
i) changing 'B' with time
ii) changing area of coil with time
iii) rotating the coil.

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6. **Lenz's law** states that induced emf always opposes the change of flux through the coil.

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

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7. **Induced emf** in a current carrying conductor moving in perpendicular magnetic field and perpendicular to its length is $\varepsilon = B\,l\,v$

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8. **Eddy currents** are the induced currents in large metal pieces due to changes in the flux.

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9. **Self inductance (L)** of the coil is the induced emf in a coil due to change of current in it at the rate of – 1 A/s

$L = \varepsilon / \left(-\frac{dI}{dt}\right)$. **SI unit:** henry (H).

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10. **Self inductance** of a coil is given by

$L = \mu_0 n^2 A l$

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11. As long as the current in one of the two adjacent coils changes, a current is induced in the other coil. This phenomenon is called **Mutual induction.**

Mutual induced emf $\varepsilon = -M\frac{di}{dt}$

where M is mutual inductance of the coils.

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12. **Mutual inductance** of long coaxial solenoids is given by

$M = \mu_0 n_1 n_2 \pi r_1^2 l$

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13. Energy stored in a coil is $U = \frac{1}{2}LI^2$

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14. AC generator converts **mechanical energy** into **electrical energy.**

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15. The voltage produced by AC generator is

$\varepsilon = \varepsilon_m \sin\omega t$

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16. When conductor is moved in a magnetic field, power due to Joule heating is

$$P = \frac{B^2 l^2 v^2}{R}$$