Electromagnetic Induction

Magnetic flux linked with a surface:

- It is the number of magnetic lines of force crossing a surface.

- Flux linked with a surface of area A placed in a magnetic field B, $\Phi = \vec{B}.\vec{A} = BA \cos \theta$.

- SI unit of flux is Weber.

Faraday's Laws

First Law – Whenever the amount of magnetic flux linked with a circuit changes, an *emf* is induced in the circuit. The induced *emf* lasts as long as the change in magnetic flux continues.

Second Law – The magnitude of *emf* induced in a circuit is directly proportional to the rate of change of magnetic flux linked with the circuit.

The emf induced in a coil for changing magnetic flux(ϕ_B) linked with it is given by $e = -N \frac{d\Phi_B}{dt}$.

Fleming's Right Hand Rule

The thumb, the first finger and the middle finger of the right hand are stretched such that they are mutually perpendicular to each other. If the first finger is along the direction of the magnetic field and the thumb is along the direction of the motion of the conductor, then the middle finger represents the direction of induced emf or current in the conductor.

Lenz's law

- It states that the direction of induced emf in a circuit is always such to oppose the change in magnetic flux responsible for it.

- It is in accodance with the principle of conservation of the energy.

- It is used to find the polarity of the emf induced in a circuit ,magnetic flux related to which is changing with time.

- The negative sign in the expression of the induced emf($e = -\frac{d\Phi_B}{dt}$) is given by this law.

Motional Electromotive Force
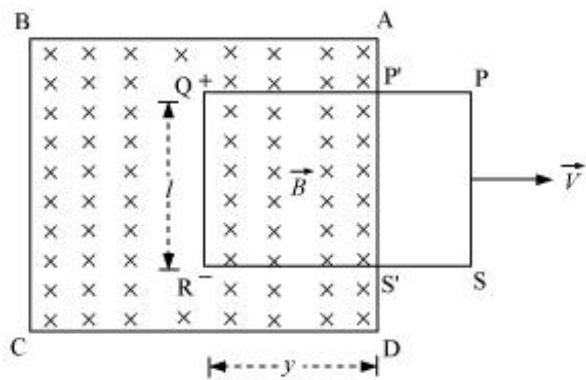
- For a conductor PS of length *l* under the following conditions:

  - moving with the velocity v

  - in a magnetic field of strength B the

- magnetic flux linked with the circuit changes and the emf induced e is given by $e = -Blv$

Energy consideration

- When a conductor is moved in a magnetic field there is conversion of the mechanical enegy into electrical and thermal energy.

- For a rod of the resistance r the current in the circuit is given by $i = \frac{Blv}{r}$.

- The force that opposes the rod to move is given by $F = ilB = \frac{B^2l^2v}{r}$.

- Power required to move the rod in the magnetic field is givenby $P = \frac{B^2l^2v^2}{r}$

- Energy dissipated as heeat is given by $P_J = \frac{B^2l^2v^2}{r}$

- **Eddy currents** $\rightarrow$ Currents induced in a thick conductor when the conductor is placed in a changing magnetic field.

- **Applications of Eddy Currents**
  - **Electromagnetic damping** – Some galvanometers have a fixed core, which is made of non-magnetic metallic materials. When the coil oscillates, the eddy currents generated in the core oppose the motion and bring the coil to rest quickly.

  - **Induction furnace** – In an induction furnace, very high temperature can be produced by producing large eddy currents.

  - **Magnetic braking in trains** – Strong electromagnets are situated above the rails in

some electrically powered trains. When the electromagnets are activated, the eddy currents induced in the rails oppose the motion of the train.

- **Self-induction** – Property of a coil by virtue of which the coil opposes any change in the strength of current flowing through it by inducing an *emf* in itself
- **Self-Inductance of a Long Solenoid of length *l***

$$L = \frac{\mu_0 N^2 A}{l}$$

N is the number of turns in the coil

- **Mutual induction:** It is the phenomenon of production of induced emf in one coil, due to varying current in the neighbouring coil.

Induced emf,

$$E = -M \frac{dI}{dt}$$

Where, *M* is mutual inductance of the coil

- Mutual inductance of two long solenoids:

$$M = \frac{\mu_0 N_p N_s A}{l}$$

Where,
$N_p \rightarrow$ Number of turns in the primary coil
$N_s \rightarrow$ Number of turns in the secondary coil
$A \rightarrow$ Cross-sectional area of the solenoid
$l \rightarrow$ Length of the solenoid

- In an **AC generator**, mechanical energy is converted into electrical energy by virtue of electromagnetic induction. If a coil of *N* turns and area *A* is rotated at *n* revolutions per second in a uniform magnetic field *B*, then the motional emf produced is

$$\varepsilon = NBA(2\pi\nu)\sin(2\pi\nu t)$$

Where, we have assumed that at *t* = 0 s, the coil is perpendicular to the field.