

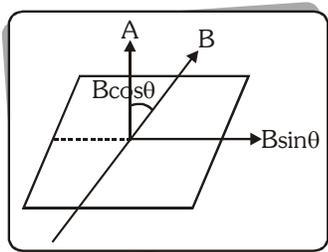
### FARADAY'S LAW

Rate of change of magnetic flux is proportional to induced emf  $e = \frac{d\phi}{dt}$

#### MAGNETIC FLUX ( $\phi$ )

Number of magnetic line of forces passing through a area perpendicular is known as magnetic flux.

$$\text{Magnetic flux } (\phi) = N\vec{B} \cdot \vec{A} = NBA \cos \theta$$



$$emf = \frac{-d\phi}{dt} = \frac{-d(\vec{B} \cdot \vec{A})}{dt}$$

B changes

$$emf = -A \frac{dB}{dt}$$

Avg emf

$$= \frac{A(B_1 - B_2)}{t}$$

A changes

$$emf = -B \frac{dA}{dt}$$

Avg emf

$$= \frac{B(A_1 - A_2)}{t}$$

$\theta$  changes

$$emf = -NBA\omega \sin \omega t$$

(where  $\theta = \omega t$ )

Avg emf

$$= \frac{NBA(\cos \theta_1 - \cos \theta_2)}{t}$$

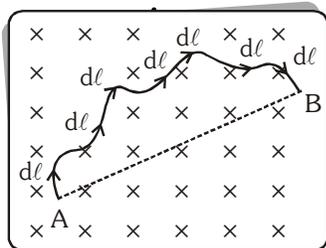
### Lenz Law

Direction of induced current is such that it always try to oppose the course of change.

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

Lenz Law      Faraday Law

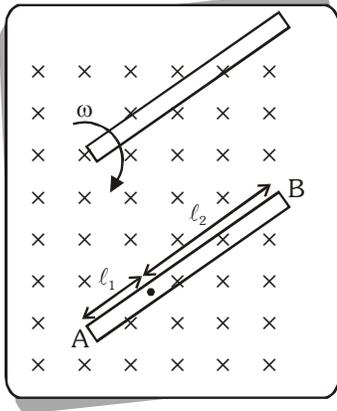
### Motional EMF



$$e = \vec{B} \int (\vec{dl} \times \vec{v}), \quad e = \vec{B} \cdot (\vec{L}_{BA} \times \vec{v})$$

Rod is rotating with angular velocity

$$e = \frac{B\omega l^2}{2} \quad v_B - v_A = \frac{B\omega(l_2^2 - l_1^2)}{2}$$

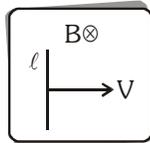


**Case-II :** If angle between area vector and magnetic field changes

$$\phi = \vec{B} \cdot \vec{A} \cos \theta$$

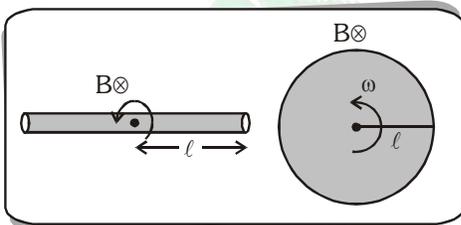
$$e = \frac{d\phi}{dt} = BA\omega \sin \omega t$$

- When a rod moves perpendicular to its length and perpendicular to magnetic field then induces emf in rod =  $B\ell v$  ( $\vec{v} \perp \vec{l} \perp \vec{B}$ )



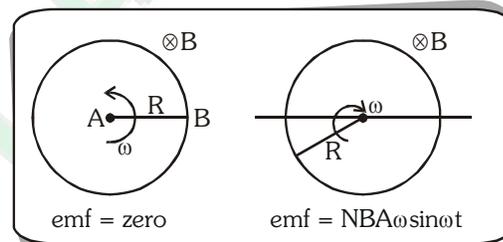
- When a conducting disc or conducting rod is rotated about its axis  $\perp$  to magnetic field then emf induced between its centre and periphery is given

$$\text{by } emf = \frac{B\omega l^2}{2}$$



When a loop of area A is rotated about its diameter in uniform magnetic field B then maximum induced emf =  $NBA\omega$

**Note :**



## Self induction

Phenomena of inducing emf due to change in its

$$\text{own current } \phi = Li \quad emf = -\frac{Ldi}{dt}$$

## Self inductance (L) for solenoid

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

N = number of turns; n = number of turns/length

## Combination of inductors

$$\text{Series } L = L_1 + L_2 \quad \text{Parallel } \frac{1}{L} = \frac{1}{L_1} + \frac{1}{L_2}$$

**Energy stored in inductor :**

$$U = \frac{1}{2} Li^2 = \frac{\phi^2}{2L} = \frac{\phi i}{2}$$

**Mutual induction :**

Phenomena of including emf in a coil due to change in current in another coil is known as mutual induction.

$$\phi = Mi \quad \text{emf} = -M \frac{di}{dt}$$

Mutual inductance between 2 solenoids

$$M = \frac{\mu_0 N_1 N_2 A}{\ell}$$

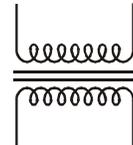
**Relation between self inductance and mutual inductance.**

Real

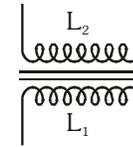
Ideal

$$M = k\sqrt{L_1 L_2}$$

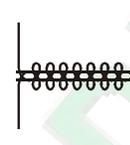
k = coupling factor



$0 < k < 1$

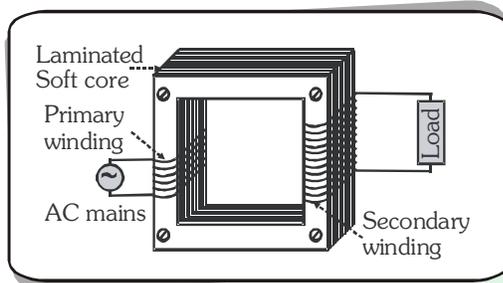


$$M = \sqrt{L_1 L_2} \quad (k = 1)$$



$k = 1$

## TRANSFORMER



Works only for AC

Principle : Mutual induction

For ideal transformer

(1) Power loss = 0  $\Rightarrow$  efficiency = 100%

(2) Flux loss = 0

But practically  $P_{out} < P_{in} \therefore$  efficiency < 100%

$$\frac{V_s}{V_p} = \frac{N_s}{N_p} = \frac{i_p}{i_s} = \text{turnratio}$$

$$\eta(\text{efficiency}) = \frac{i_s^2 R}{V_p i_p} \times 100$$

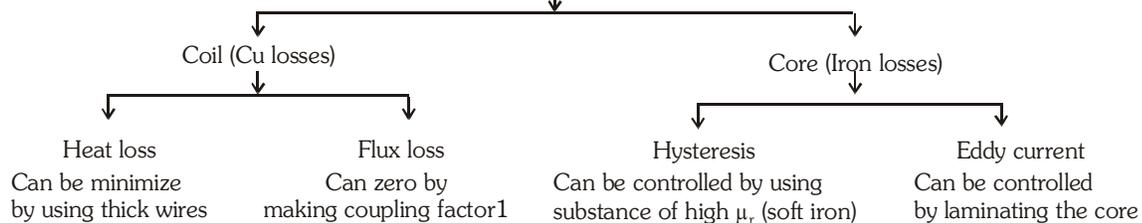
**Types of transformer**

Step up  
 $V_s > V_p$   
 $N_s > N_p$   
 $i_p > i_s$

Step down  
 $V_p > V_s$   
 $N_p > N_s$   
 $i_s > i_p$

Transmissions are done at high voltage and low current by using step up transformer.

**Losses in transformers**

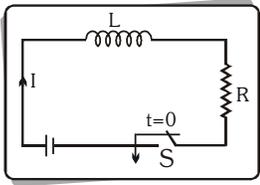


**Induced electric field :**

Produced due to change in magnetic field and is non-conservative in nature

$$\oint \vec{E} \cdot d\vec{\ell} = -\frac{d\phi_B}{dt}$$

## Growth of a Current in an L - R Circuit



$$I = \frac{E}{R} (1 - e^{-Rt/L}) \quad [\text{If initial current} = 0]$$

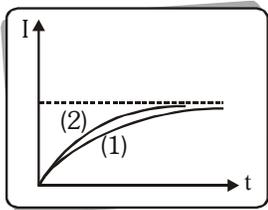
$$I = I_0 (1 - e^{-t/\tau})$$

$$\tau = \frac{L}{R} = \text{time constant of the circuit.}$$

$$I_0 = \frac{E}{R}$$

(i) L behaves as open circuit at  $t = 0$  [as if  $I = 0$ ]

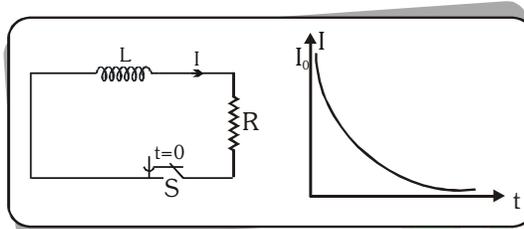
(ii) L behaves as short circuit at  $t = \infty$  always.



Curve (1)  $\rightarrow \frac{L}{R}$  Large Curve (2)  $\rightarrow \frac{L}{R}$  Small

## Decay of Current

Initial current through the inductor =  $I_0$ ; Current at any instant  $i = I_0 e^{-Rt/L}$



### KEY POINTS

- An emf is induced in a closed loop where magnetic flux is varied. The induced electric field is not conservative field because for induced electric field, the line integral  $\oint \vec{E} \cdot d\vec{\ell}$  around a closed path is non-zero.
- Acceleration of a magnet falling through a long solenoid decrease because the induced current produced in a circuit always flows in such direction that it opposes the change or the cause that produces it.
- The mutual inductance of two coils is doubled if the self inductance of the primary and secondary coil is doubled because mutual inductance  $M \propto \sqrt{L_1 L_2}$ .