ELECTROMAGNETIC INDUCTION & ALTERNATING CURRENT

1. State and explain Faraday's law of EMI:

This law states that the magnitude of the induced emf is directly proportional to the rate of change of magnetic flux.

If e is the induced emf when the magnetic flux changed by $d\Phi$ in a time interval dt then from Faraday's law

$$\text{i.e.} \quad \mathbf{e = -\frac{d\Phi}{dt}}$$

2. What are eddy currents? Write any two applications of eddy currents.

The current induced in metal plate when placed in changing magnetic field is called 'eddy currents'.

Eddy currents are used in Speedometer, induction furnace, electric breaks etc.

3. Derive an expression for Energy stored in an Inductor

Let dw be the work done in establishing a current I in the coil in time dt.

Then

$$dw = -\, e\, I\, dt$$

$$dw = +\, L \times \frac{dI}{dt} \times I \times dt \qquad (\text{since } e = -\,L\frac{dI}{dt})$$

$$dw = +\, L \times I\, dI$$

Total work done in establishing the current I is given by

$$\int dw = \int_o^I I\, dI = L\int_o^I I dI = L\left[\frac{I^2}{2}\right]_O^I = \frac{1}{2} L\, I^2$$

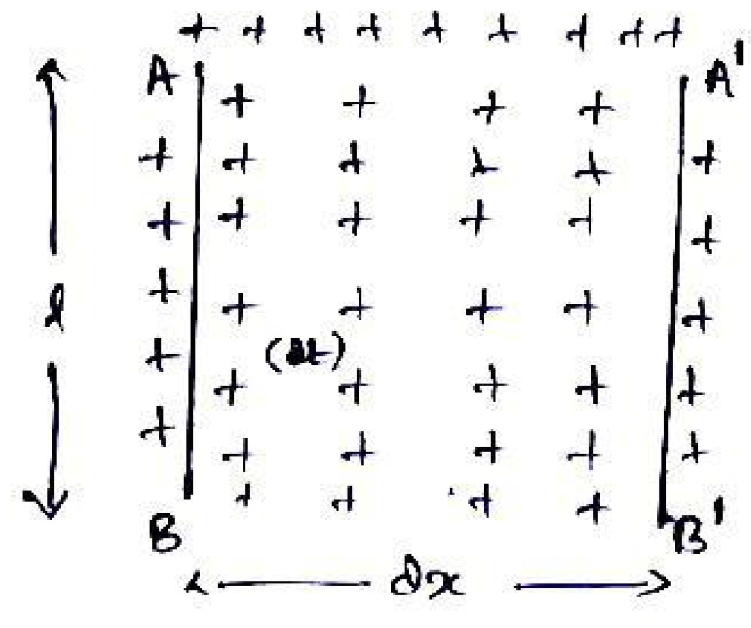
$$W = \frac{1}{2} L\, I^2$$

By definition, W = U

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

4. Obtain an Expression for motional e.m.f induced in a conductor (rod) moving in a magnetic field:

Let us consider a conductor AB of length l is placed in a uniform magnetic field B perpendicular to the direction of field. Let the conductor moves to the position A^1B^1 through a distance 'dx' in time 'dt'.



Change in magnetic flux linking the conductor in time dt is given by

$$d\Phi = B \,.\, l \,.\, dx \qquad\qquad l \times dx = \text{area } ABB^1A^1$$

Rate of change of magnetic flux is given by

$$\frac{d\Phi}{dt} = B\ l \,.\, \frac{dx}{dt}$$

$$\frac{d\Phi}{dt} = B\,l\,v \qquad \because \frac{dx}{dt} = v \text{ (velocity)}$$

By Faraday's second law

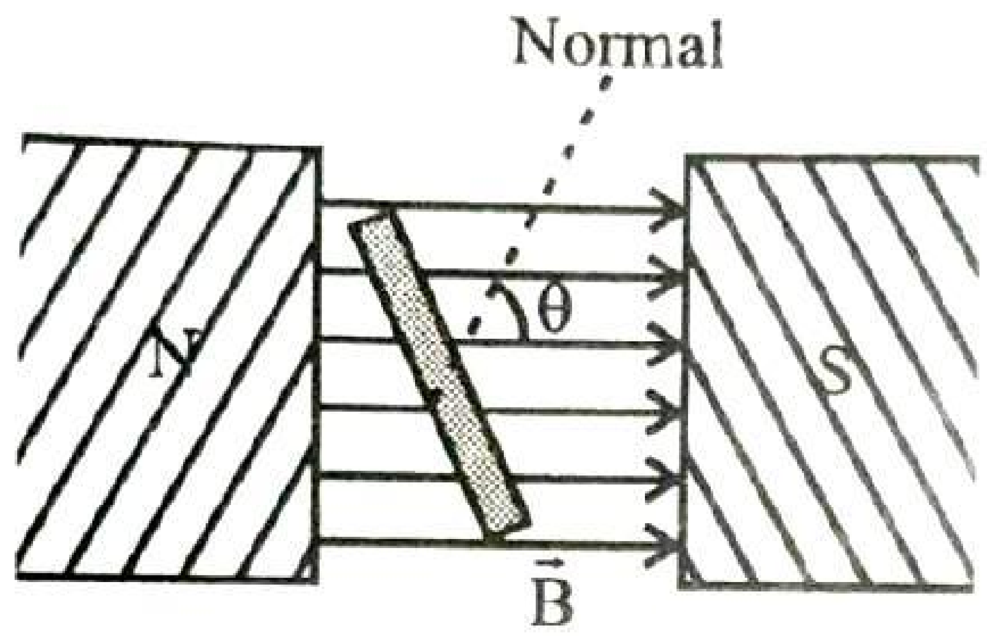
$$e = -\frac{d\Phi}{dt}$$

$$\boxed{e = -B\,l\,v}$$

This is the expression for motional emf.

5. What is AC generator? Derive an expression for the instantaneous emf in AC generator.

Ans: It is a device used for converting mechanical energy in to electric energy.



Let us consider a rectangular coil of 'n' turns of area A is rotating ***in a uniform magnetic field of strength B with constant angular velocity*** 'w' ($w = 2\pi f$) magnetic flux linking round the coil at any instant of time is given by, $\Phi = n A B \cos\theta$

Where 'θ' is the angle made by the normal to the plain of coil with the field direction

and $\theta = w t$, $\therefore$ $\Phi = n A B \cos wt$

As the coil rotates with uniform angular velocity 'w' normal to the magnetic field, magnetic flux linking round the coil changes therefore according to Faraday's law , an emf is induced in the coil. This emf is given by,

$$e = -d\Phi / dt$$

$$e = -d(n A B \cos wt) / dt$$

$$e = -n A B \frac{d}{dt}(\cos wt)$$

$$e = -n A B(-w \sin wt)$$

$$\mathbf{e = n A B w \sin wt}$$

Emf is maximum when $\sin wt = 1$. This emf is called as peak value of emf or maximum value of emf. It is denoted by 'e_0'

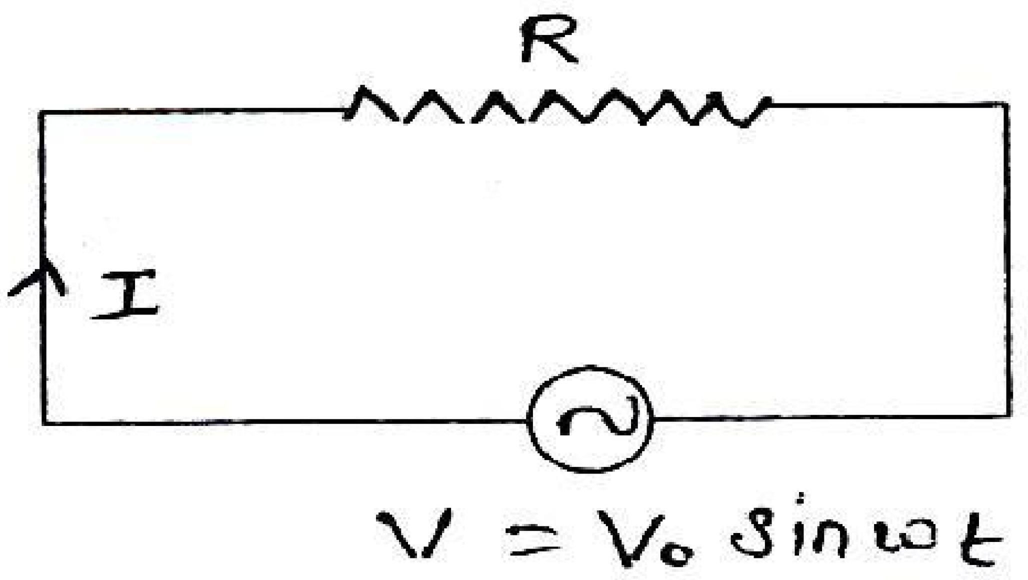
$$e_0 = n A B w \qquad \text{when, } \sin wt = \pm 1$$

$$\therefore \boxed{V = V_0 \sin wt} \qquad (e = V, \quad e_o = V_0)$$

This is the expression for alternating emf (voltage).

AC Circuits:

6) Expression for Current in an AC circuit containing pure resistance only :



Let us consider an AC circuit in which a pure resistance R connected in series with a source of alternating voltage.

Let $V = V_0 \sin \omega t$ ----------(1) is the applied AC voltage

Where, V_0 is the peak value of voltage and w is the angular velocity. $w = 2\pi f$

Due to the applied AC voltage, A current flows in the circuit this current is given by,

$$I = V / R = \frac{V_0}{R} (\sin \omega t) \quad \text{---------(2)}$$

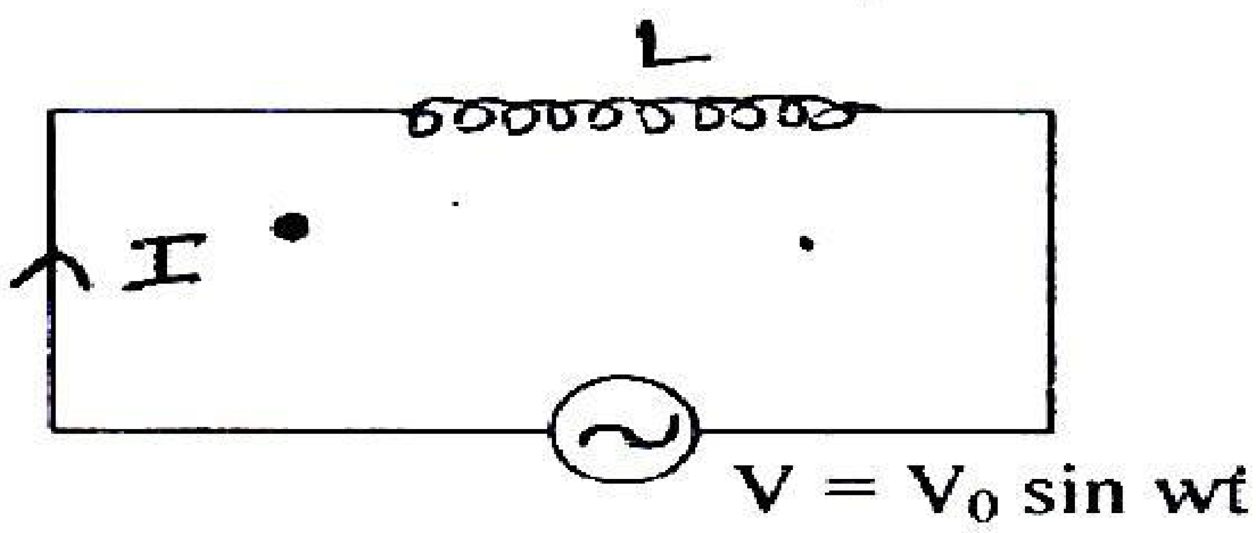
Current is maximum when $\sin wt = \pm 1$, that current is called 'peak value of current and is denoted as I_0 .

$$\therefore\ I_0 = V_0 / R$$

(2) becomes , $\mathbf{I = I_0 \sin \omega t}$ - ------------(3)

This is the expression for current in pure resistance circuit.

7) Expression for Current in an AC circuit containing pure inductance:



Let, $V = V_0 \sin wt$ ------------ (1) is the applied alternating voltage.

And $V^1 = - L . \frac{dI}{dt}$

Applying KVL for the circuit , we get

$$V + V^1 = 0 \qquad (\because R = 0 ,\ IR = 0)$$

$$V = L . \frac{dI}{dt}$$

$$V_0 \sin \omega t = L . \frac{dI}{dt}$$

$$dI = \frac{V_0}{L} \sin \omega t . dt$$

Integrating we get,

$$\int dI = \int (V_0 / L) \sin \omega t . dt$$

$$I = \frac{V_0}{L} \int \sin \omega t . dt$$

$$I = \frac{V_0}{L} [- \cos \omega t / w]$$

$$I = \frac{V_0}{\omega L} \cdot \sin(\omega t - \pi/2) \qquad -\cos \omega t = \sin(\omega t - \pi/2)$$

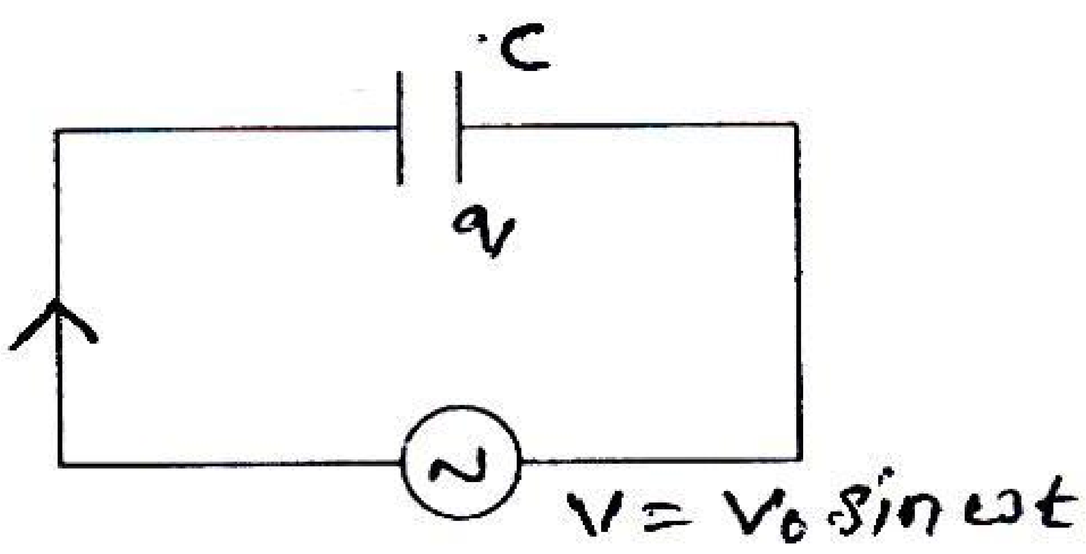
Current is maximum when $\sin(wt - \pi/2) = \pm 1$,
that current is called as 'peak value of current and it is denoted as I_0.

$$I_0 = V_0 / \omega L \qquad \text{when } \sin(wt - \pi/2) = \pm 1$$

$$\mathbf{I = I_0 \sin(\omega t - \pi/2)} \quad \text{-------------(2)}$$

This is the expression for current in inductance circuit.

8) An AC circuit consisting of pure capacitance:



Let $V = V_0 \sin \omega t$ ----------(1)

∴ Alternating current flows in the circuit, thus current in the circuit given by,

$$I = dq / dt \qquad \text{But, } q = CV$$

$$I = d(CV) / dt$$

$$I = C \cdot \frac{d}{dt}(V_0 \sin \omega t)$$

$$I = C V_0 \frac{d}{dt}(\sin \omega t)$$

$$I = C V_0 \omega \cos \omega t$$

$$I = \frac{V_0}{(1/\omega C)} \cdot \sin(\omega t + \pi/2) \qquad \because \cos wt = \sin(\omega t + \pi/2)$$

Current is maximum when $\sin(\omega t + \pi/2) = \pm 1$, this current is called as peak value of current and is denoted as I_0.

$$I_0 = \frac{V_0}{(1/\omega C)} \qquad \text{when } \sin(\omega t + \pi/2) = \pm 1$$

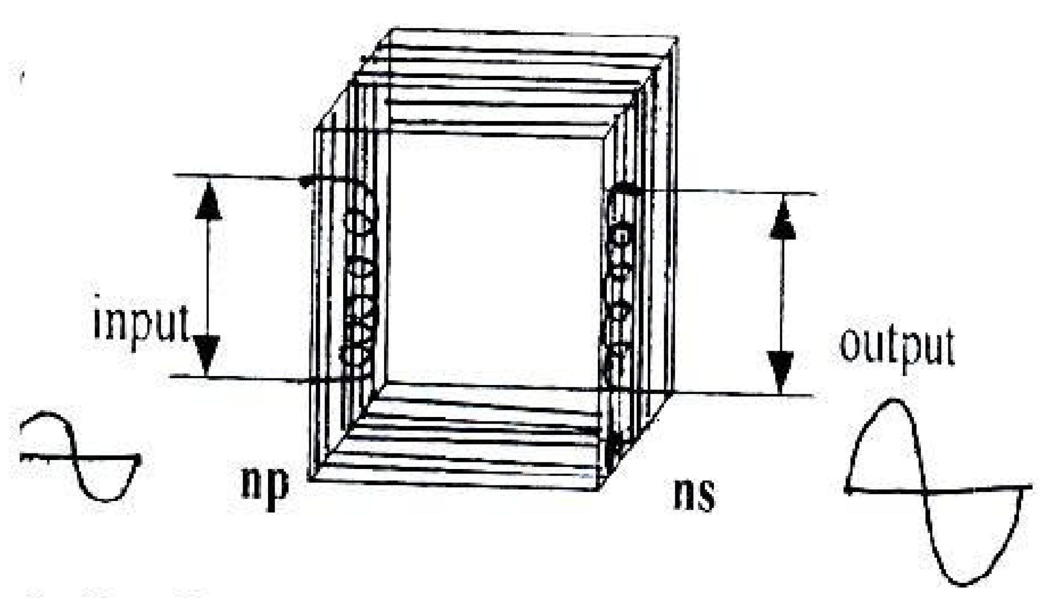
$$\boxed{\mathbf{I = I_0 \sin(\omega t + \pi/2)}} \quad \text{------------ (2)}$$

This is the expression for alternating current in a capacitor circuit.
From (1) and (2), it is found that 'in capacitor circuit current leads the voltage by 90^0 or $\pi/2$ '.

9. What is a Transformer? Explain the working of a Transformer.

TRANSFORMER: Transformer is a device used to step up or step down alternating voltages.
Principle: It works on the principle of mutual induction.

Working:



As input is alternating, at every alteration magnetic flux linking round the secondary changes. Therefore an emf of the same nature is induced in the secondary. The magnitude of output voltage depends on number of turns in primary and secondary coils.

Let V_p and V_s are the input and output voltages. n_p and n_s be the number of turns in primary and secondary.

Then it can be shown that

$$V_s / V_p = n_s / n_p = T$$

Where, T is a constant of the transformer called as turns ratio.

10 . Mention any three Sources of Energy losses in Transformer:

Energy losses in transformer are

1) Magnetic flux leakage loss
2) Eddy current loss
3) Resistance of winding loss
4) Hysteresis loss