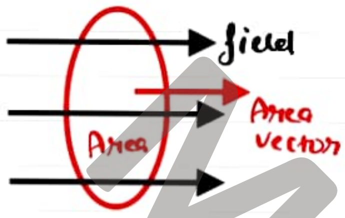
ELECTROMAGNETIC INDUCTION

Electromagnetic Induction

The production of electric current with the help of magnetic field is called electromagnetic Induction.

Magnetic flux

It is the product magnetic field & the Area through which these magnetic field are passing normally. It is denoted by ϕ



$$\boxed{\phi = B \cdot A} \quad \text{or} \quad \boxed{\phi = BA\cos\theta}$$

where θ is angle b/w magnetic field & Area vector.

- magnetic flux is a Scalar Quantity.
- SI unit of magnetic flux is weber

Area vector ⇒ Any vector which is perpendicular to the given area is called as Area vector.

Faraday laws

First law :- whenever there is a change in the magnetic flux linked with a closed coil, an emf is induced in the circuit.

Second law :- The rate of change of magnetic flux is equal to the emf produced in the circuit.

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

Lenz Law

This law states that the direction of induced current is such that it opposes the cause which produce it. (It opposes the change in magnetic flux)

Thus from Lenz law, induced emf is :-

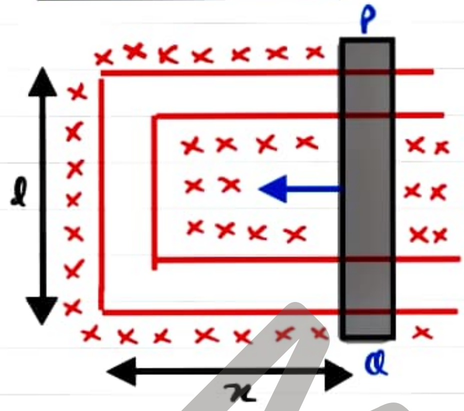
$$\varepsilon = -\frac{d\phi}{dt}$$

If the coil have N turns then

Induced emf , $\boxed{\varepsilon = -N\frac{d\phi}{dt}}$ or $\boxed{\varepsilon = -N\frac{\phi_2 - \phi_1}{t}}$

Note → Lenz law works on the Principle of Conservation of energy.

Motional Emf



As the Rod PQ moves towards left, there is a change in the magnetic flux linked with the coil. So an induced emf set up.

As we know $\phi = BA\cos\theta$

here $\theta = 0°$ so $\phi = BA$

Also here A = Area = length × Breadth = lx

$$\phi = B(lx)$$

Now from Faraday law

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

$$\varepsilon = \frac{d}{dt}(Blx) = Bl\frac{dx}{dt}$$

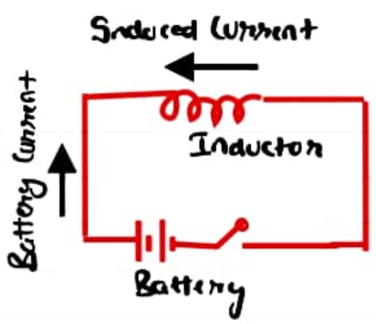
$$\boxed{\varepsilon = Blv}$$ here v = velocity of rod

Now using ohm's law

$$\varepsilon = IR$$

$$Blv = IR$$ Then $$\boxed{I = \frac{Blv}{R}}$$

Self Induction



Self Induction is the phenomenon of production of induced Emf in a coil when a changing current passes through it.

When switch is closed, the current increases through Inductor, due to which a changing magnetic flux produces inside the coil. Hence an induced Emf set up in the coil.

At any time,

flux produced ∝ current

$$\phi \propto I$$

Then $$\boxed{\phi = LI}$$

here L = Coefficient of Self Induction.

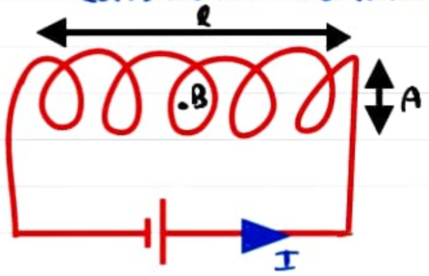
Acc. to Faraday law

$$\varepsilon = -\frac{d\phi}{dt} = -\frac{d}{dt}(LI)$$

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

Coefficient of Self Induction

Consider a Solenoid (Inductor) as shown in figure



here A = Area of loop
l = length of Solenoid
I = current flowing through Solenoid
μ_0 = Permeability of free space
N = Total no. of turn of Solenoid
n = no. of turns per unit length
$n = \frac{N}{l}$ Then $\boxed{N = nl}$ — ①

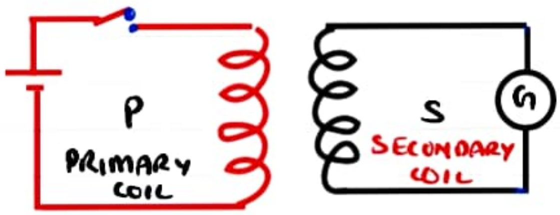
Now we know, magnetic field inside Solenoid is
$B = \mu_0 n I$
Then magnetic flux $\phi = BA$
$\phi = \mu_0 n I A \longrightarrow$ for 1 Turn
For N-turns total flux
$\phi = N \times \mu_0 n I A$
$\phi = nl \times \mu_0 n I A$ ($\because$ from eqn ①)
$\phi = \mu_0 n^2 I A l$
$\phi = (\mu_0 n^2 A l) I$

Comparing above eqn with $\phi = LI$
we get $\boxed{L = \mu_0 n^2 A l}$

or $\boxed{L = \frac{\mu_0 N^2 A l}{l^2}}$ when $n = \frac{N}{l}$

So Self Induction depends upon
1) No. of turns
2) Area
3) Permeability of free space.

Mutual Induction



Mutual Induction is the phenomenon of production of induced emf in one coil due to a change of current in the neighbouring coil.

When key of coil P is closed, the current increases in the coil P upto a maximum value. Due to which a changing magnetic field set up in the coil P which also passes through coil S. As a result, a changing flux develop in the coil S & induced emf is produced in the coil S.

We know

flux lined with coil S $\propto$ current in the P coil

$$\phi \propto I$$

$$\boxed{\phi = MI}$$

where M is called as coefficient of mutual induction

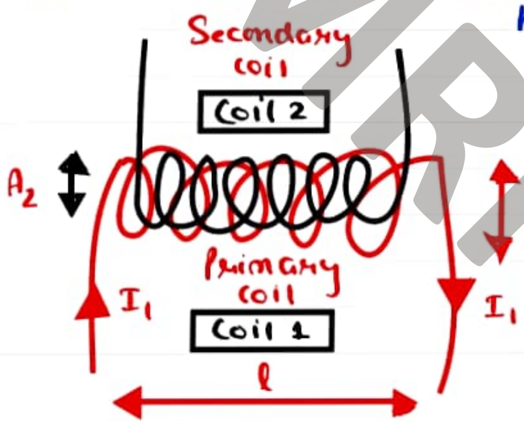
Now

$$\mathcal{E} = -\frac{d\phi}{dt} = -\frac{d}{dt}(MI)$$

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

Coefficient of mutual Induction

Consider two Solenoid (Inductors) as shown in figure



here A_1 = Area of Primary coil

l = length of Both coil

I_1 = current flowing through Primary coil

μ_0 = permeability of free space

N_1 = Total no. of turn of primary coil

n_1 = no. of turns per unit length of Primary coil

$n_1 = \frac{N_1}{l}$ Then $\boxed{N_1 = n_1 l}$

n_2 = no. of turns per unit length of Secondary coil

$n_2 = \frac{N_2}{l}$ Then $\boxed{N_2 = n_2 l}$

Now magnetic field produced in Primary coil is:-

$$B_1 = \mu_0 n_1 I_1$$

This magnetic field also passes through Secondary coil so flux present in Secondary coil is:-

$$\phi_2 = B_1 A_2$$

Then

$$\phi_2 = \mu_0 n_1 I_1 A_2 \longrightarrow \text{flux through 1 turn of Secondary coil (coil-2)}$$

for N_2 turns, flux is:-

$$\phi_2 = N_2(\mu_0 n_1 I_1 A_2)$$

Now using $N_2 = n_2 l$ Then,

$$\phi_2 = n_2 l(\mu_0 n_1 I_1 A_2)$$

$$\phi_2 = (\mu_0 n_1 n_2 l A_2) I_1$$

Comparing it with $\phi = MI$ we get

$$\boxed{M = \mu_0 n_1 n_2 l A_2}$$

or

$$\boxed{M = \frac{\mu_0 N_1 N_2 l A_2}{l^2}}$$

Mutual Inductance depends:-

1) No. of turns
2) Common - Area
3) Relative Separation
4) Relative orientation