Electromagnetic Induction

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What happen ?

When the charge is static then

Field - electrostatic

When the charge is moving with uniform speed

1. **Magnetic effect of current –**
   On flow of charge magnetic field is generated and follow the Biot–Savart law and Ampere's law.
2. **Heating effect of current –**
   On flow of charge in a wire, it is heated.
3. **Chemical effect of Current –**
   On flow of charge electrolysis happens.

Magnetic field to Electric field ?

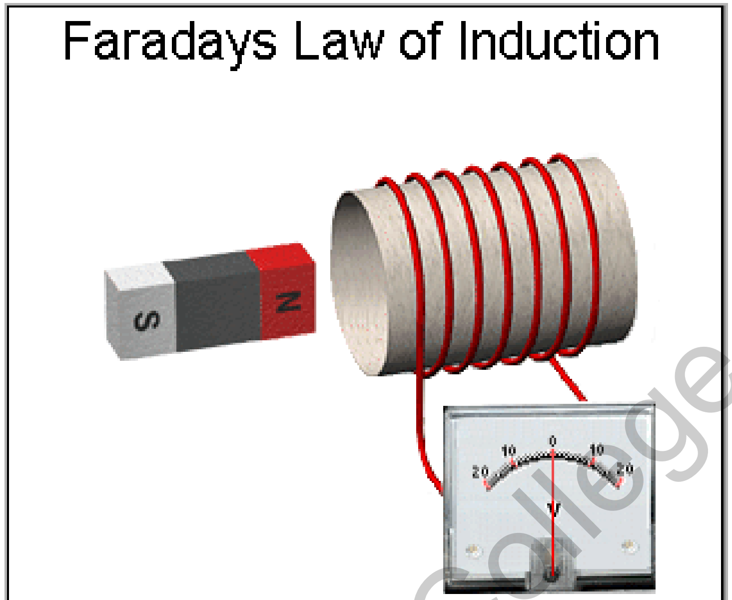
Moving charge
or
Potential difference

→ **Magnetic Field**

? ←

Faradays Observation : 1830's

When there is a relative motion between a coil and magnet then current flows through coil or potential difference is generated.


Faradays Law of Induction
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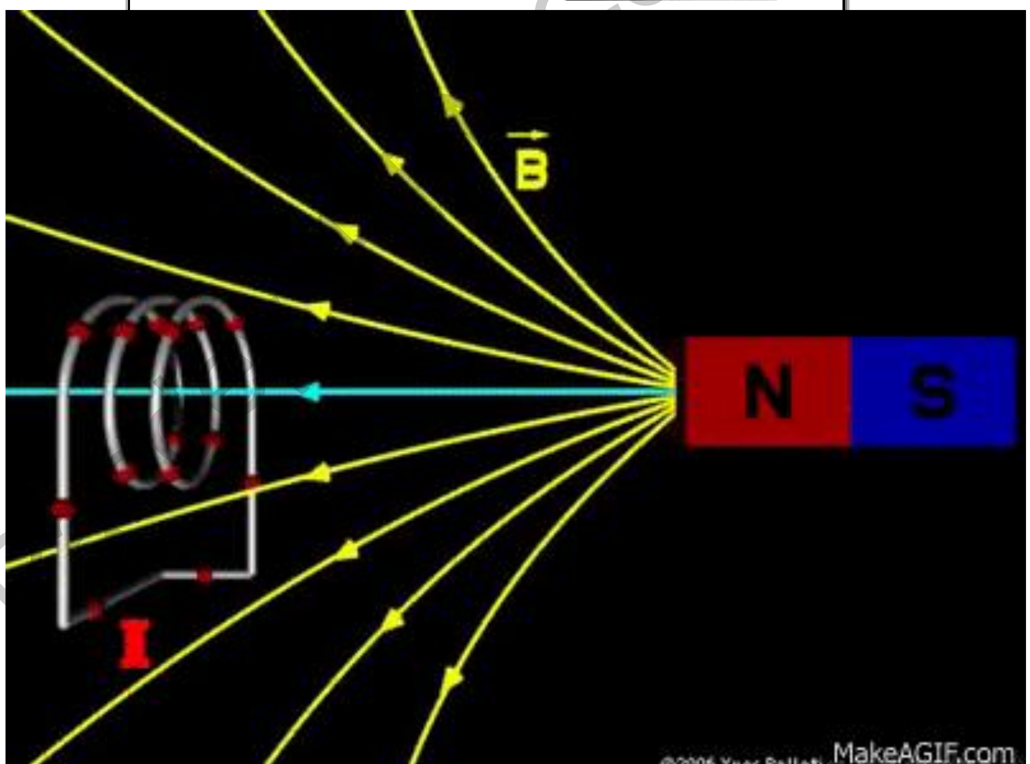
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Faradays Law of EM Induction -1

Electromagnetic or **magnetic induction** is the production of an electromotive force (i.e., voltage) across an electrical conductor in a changing magnetic field. There are two Laws.

1. **First Law:** Whenever a conductor is placed in a varying magnetic field, an electromotive force is induced. If the conductor circuit is closed, a current is induced which is called induced current.
2. **Second Law:** The induced emf in a coil is equal to the rate of change of flux linkage.

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

Direction of Induced Current or voltage : Follows Lenz's Law:

Direction of current is such that it opposes its cause of generation..

Faradays Law of EM Induction -2

$$e = \oint \vec{E}.d\vec{l}$$

$$\phi = \oint \vec{B}.d\vec{s}$$

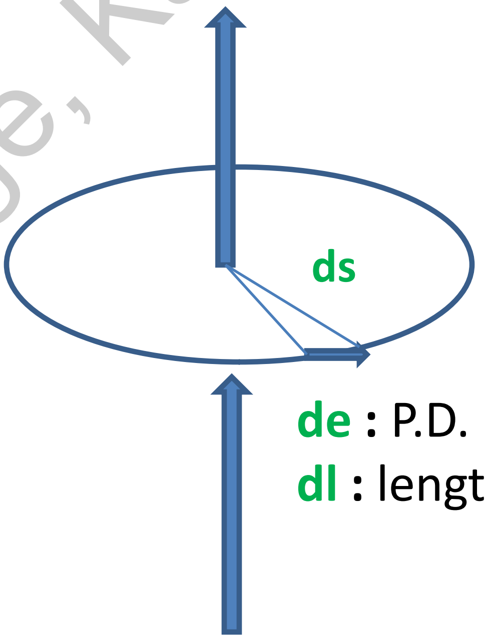
$$\oint \vec{E}.d\vec{l} = -\oint \frac{d\vec{B}}{dt}.d\vec{s}$$

Integral form of Faradays Law

$$\oint \left(\vec{\nabla} \times \vec{E}\right).d\vec{s} = -\oint \frac{d\vec{B}}{dt}.d\vec{s}$$

$$\vec{\nabla} \times \vec{E} = -\frac{d\vec{B}}{dt}$$

Differential form Faradays Law



de : P.D.
dl : length

B : variable

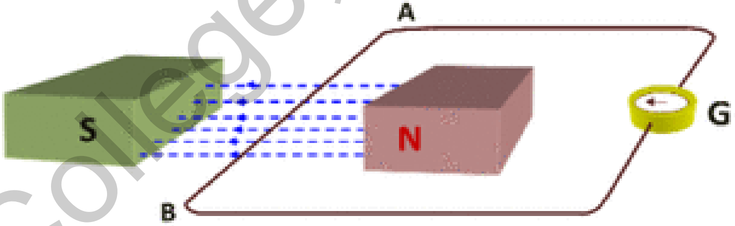
$$\oint \vec{E}.d\vec{l} \neq 0$$

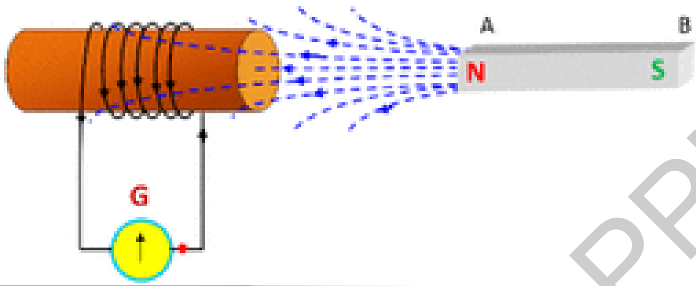
Non-conservative field: E is produced by chaning B

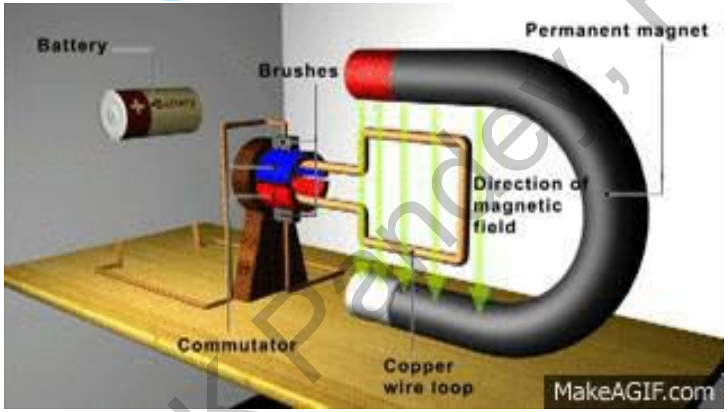
Induced EMF can be developed if

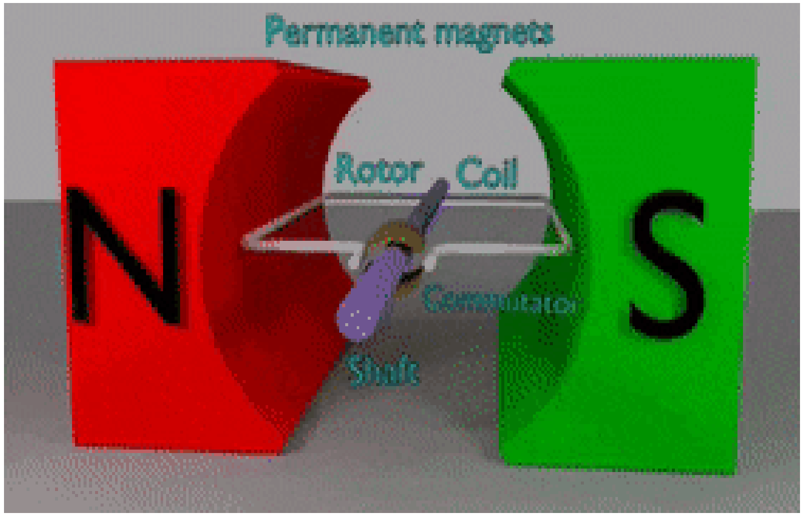
$$\phi = \vec{B} \bullet d\vec{s} = B\, s \cos\theta$$

1. Magnetic field varies
2. Area of coil varies
3. Orientation of coil varies

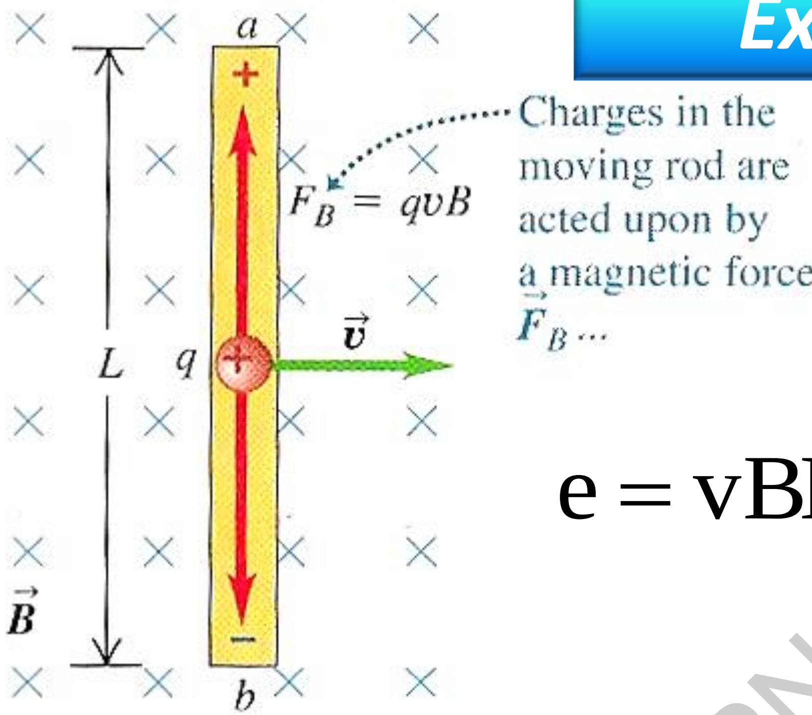




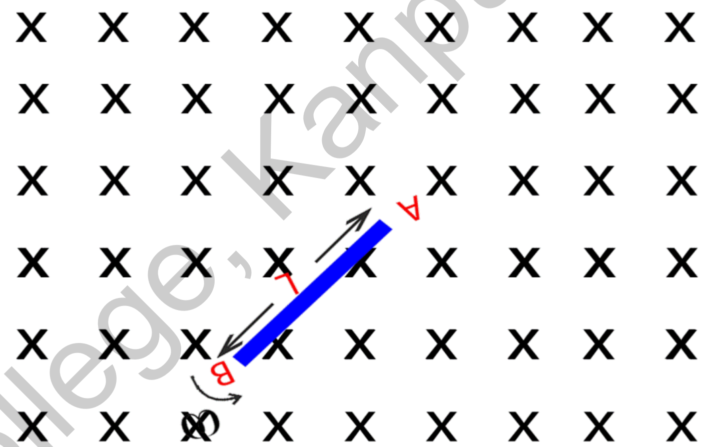




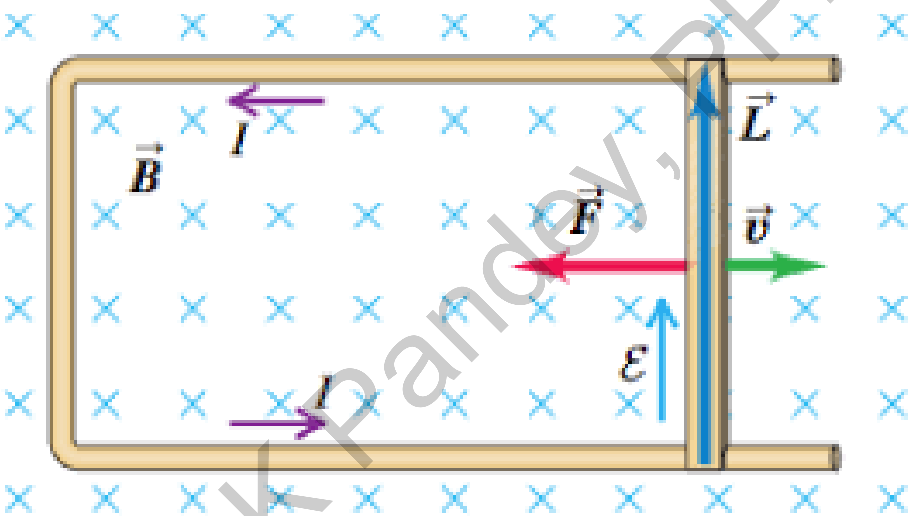
Example

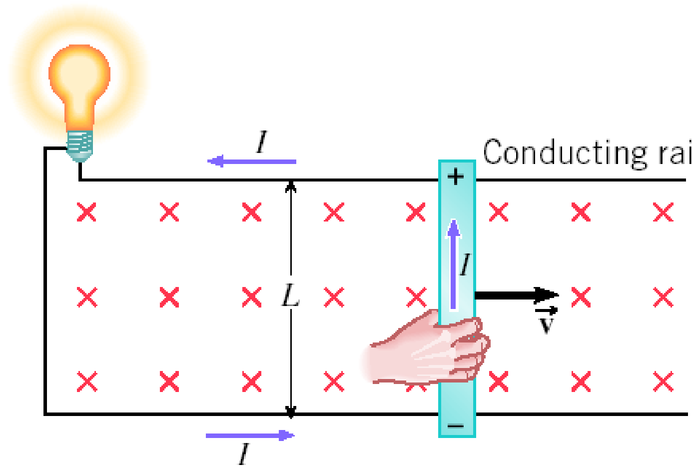


$$e = vBL$$



$$e = \frac{1}{2}\omega BL^2$$

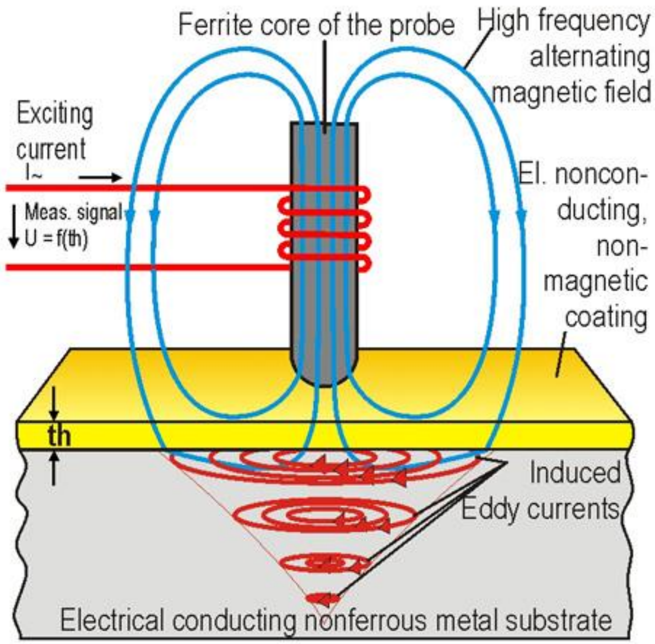


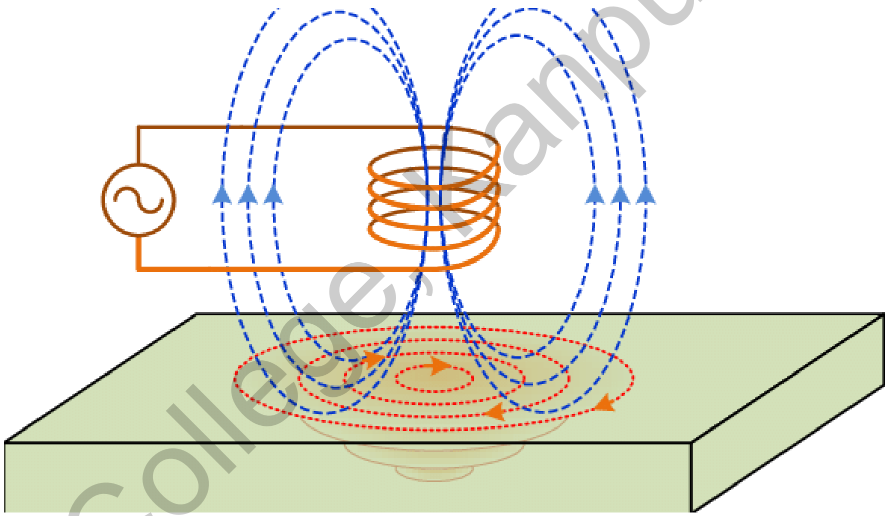


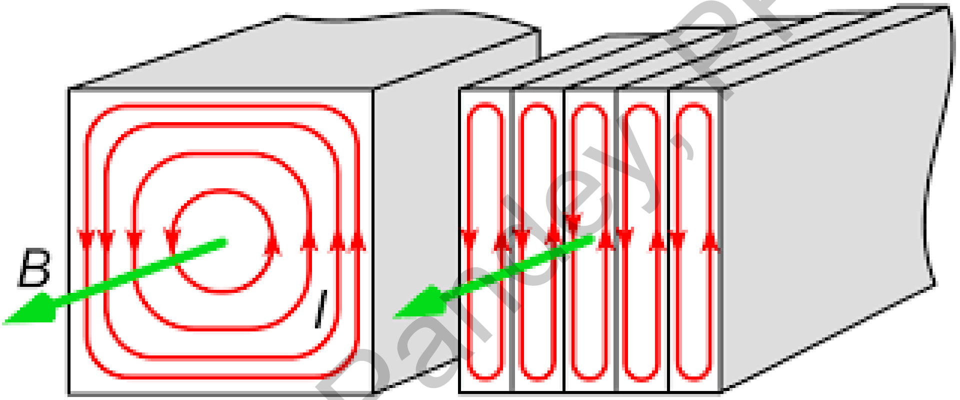
Eddy Current

Eddy currents occur when a solid metallic mass is rotated in a magnetic field, because the outer portion of the metal cuts more magnetic lines of force than the inner portion; hence the induced electromotive force is not uniform; this tends to cause electric currents between the points of greatest and least potential. Eddy currents consume a considerable amount of energy and often cause a harmful rise in temperature.

- **Eddy currents** are loops of electrical current induced within conductors by a changing magnetic field in the conductor according to Faraday's law of induction.
- **Eddy currents flow** in closed loops within conductors, in planes perpendicular to the magnetic field.
- **Eddy currents** can be induced within nearby stationary conductors by a time-varying magnetic field created by an AC electromagnet or transformer, for example, or by relative motion between a magnet and a nearby conductor.
- **Magnitude of Eddy currents** in a given loop is proportional to the strength of the magnetic field, the area of the loop, and the rate of change of flux, and inversely proportional to the resistivity of the material.


Ferrite core of the probe
High frequency alternating magnetic field
Exciting current
I~
Meas. signal
U = f(th)
El. nonconducting, non-magnetic coating
th
Induced Eddy currents
Electrical conducting nonferrous metal substrate

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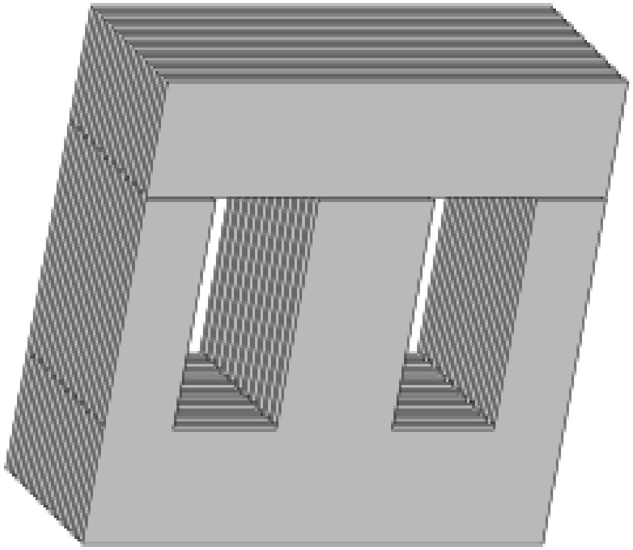
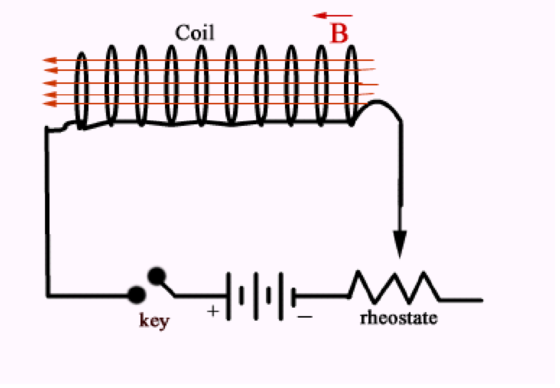
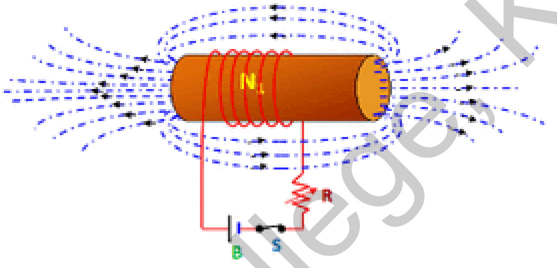
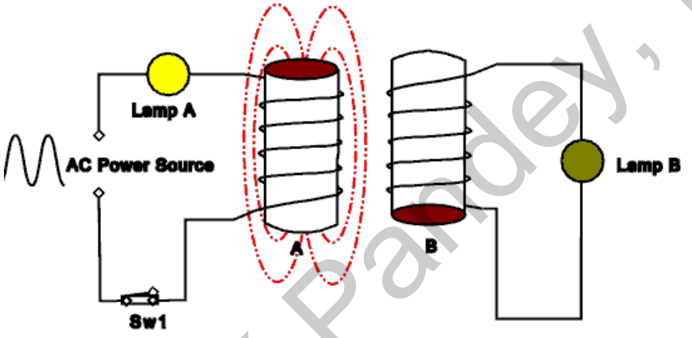


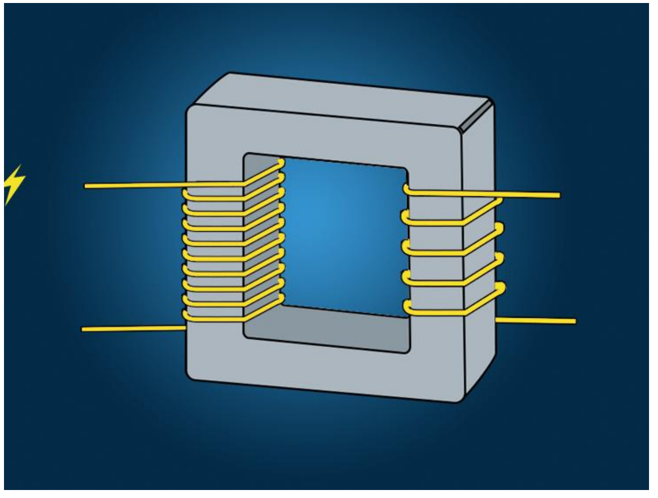
Self Induction





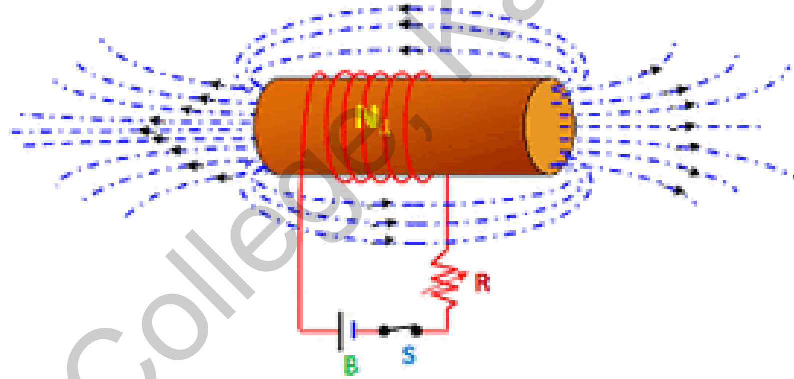
Mutual Induction





Self Induction

The phenomenon of the production of induced emf in a circuit itself due to the change in current through it is called as self induction and the induced emf is called as back emf.



L: measure of ability to oppose the change in current through it

Unit of L

H, mH

$$\phi \propto I$$

$$\phi = LI$$

If I =1 amp

$$L = \phi$$

$$e = -\frac{d\phi}{dt} \Rightarrow e = -L\frac{dI}{dt}$$

If dI/dt =1 amp/sec $\quad L = |e|$

$$w = (p.d.) \times charge = -eIdt$$

$$w = \frac{1}{2}LI^2$$

If I =1 amp $\quad L = 2w$

Self Inductance of solenoid

n : number of turn per unit length

I: current through solenoid

A: area of cross-section *l*

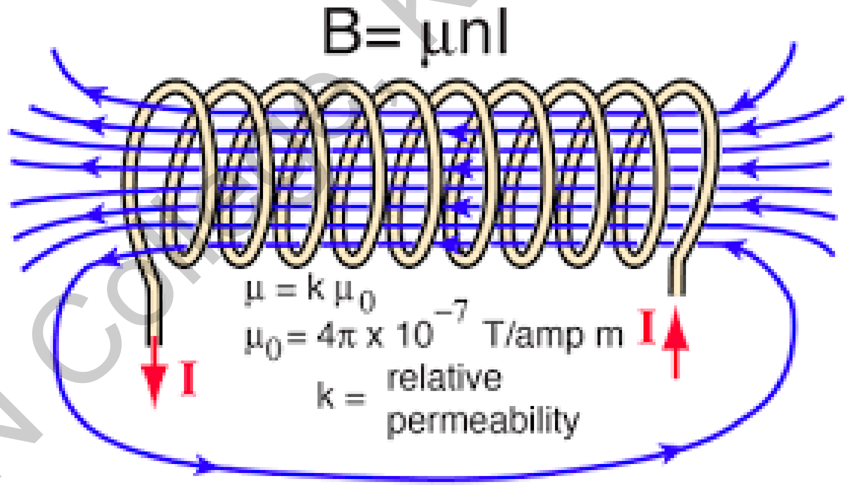
$$B = \mu_0 n I$$

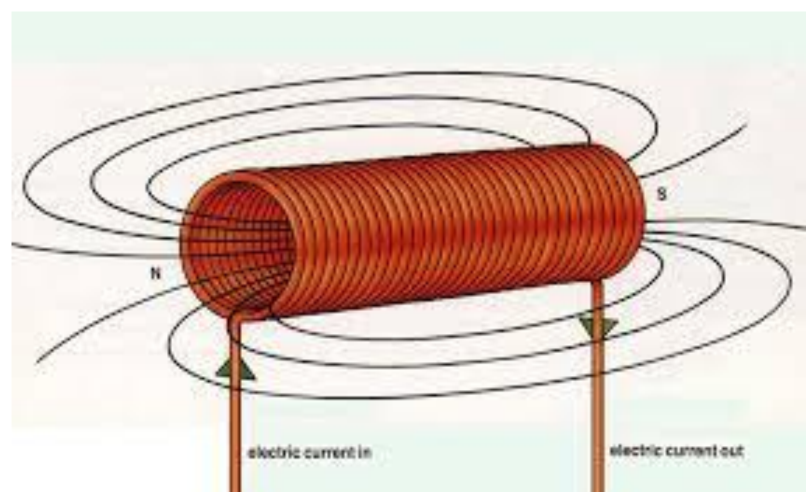
$$\phi = (\mu_0 n I) \times (n l . A)$$

$$\phi = \mu_0 n^2 A l\, I$$

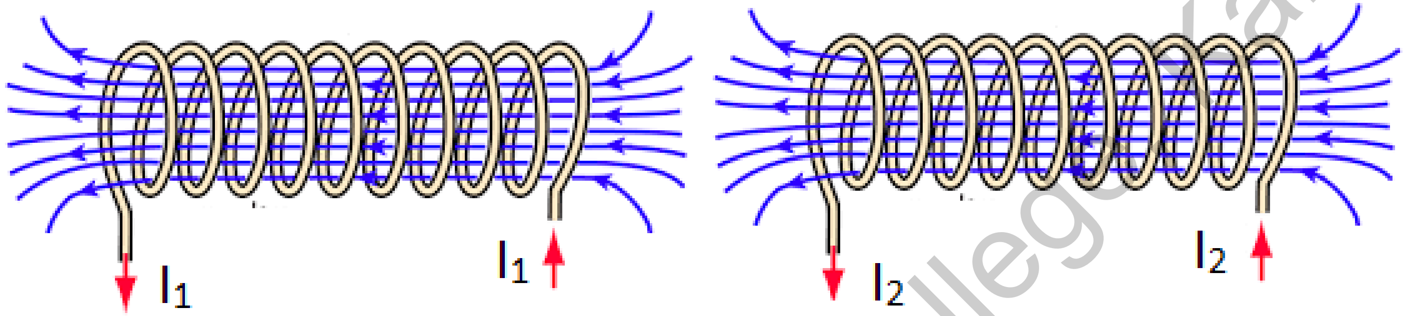
$$\phi = L\, I$$

$$\boxed{L = \mu_0 n^2 A l}$$





Mutual Induction



The phenomenon of the production of induced emf in a circuit/loop due to the change in current in near by circuit /loop is called as mutual induction.

$$\phi_1 = M_{12} I_2$$
$$\phi_2 = M_{21} I_1$$

$$e_1 = -M_{12} \frac{dI_2}{dt}$$
$$e_2 = -M_{21} \frac{dI_1}{dt}$$

Reciprocity Theorem

$$M_{12} = M_{21}$$

The mutual inductance of coil 1 with w.r.t. 2 is equal to mutual inductance of coil 2 w.r.t. 1. The mutual inductance (coefficient of mutual induction) between two near by loops/circuits is denoted by M.

$$\phi_2 = M I_1$$

$$e_2 = -M\frac{dI_1}{dt}$$

If I_1=1 amp

$$\phi_2 = M$$

If dI_1/dt=1 amp/sec

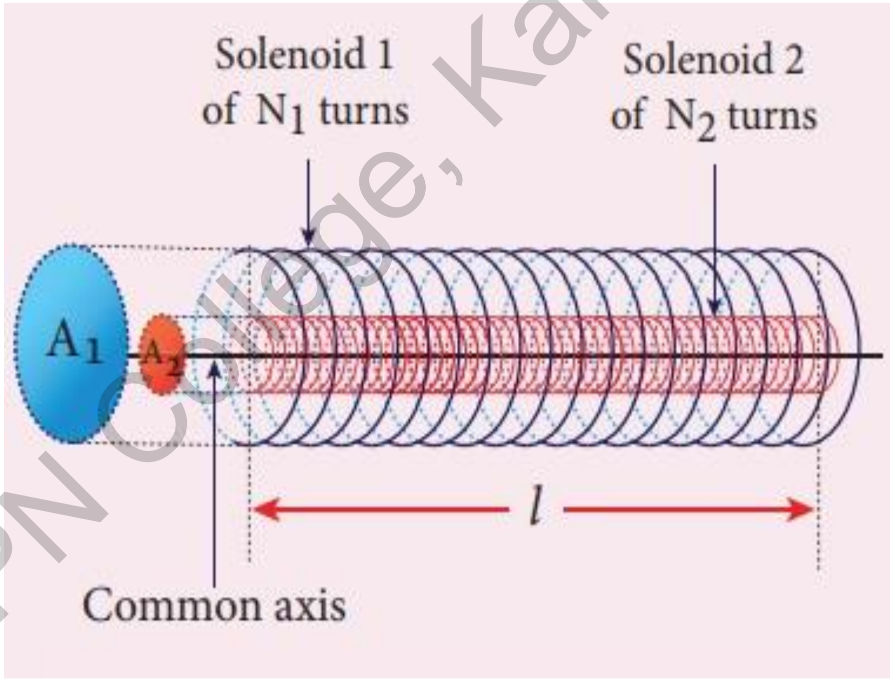
$$|e_2| = M$$

Mutual Inductance of solenoid

n_1: number of turn per unit length in Ist solenoid

n_2: number of turn per unit length in IInd solenoid

and let $A_2 = A_1 = A$



$$B_1 = \mu_0 n_1 I_1$$

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

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

$$M = \mu_0 n_1 N_2 A$$

Coefficient of Coupling

K: coefficient of coupling

If the two coils are loosely coupled then total flux of one coil does not link to other. Only fraction of one is linked to other. In this situation,

$$K = \frac{M}{\sqrt{L_1 L_2}} \quad \Rightarrow \quad M = K\sqrt{L_1 L_2}$$

If the two coils are closely coupled each other such that total flux of one coil is linked to other. Then K=1

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

Magnetic energy density

$$U_m = w == \frac{1}{2} L I^2$$

$$B = \mu_0 n I \Rightarrow I = \frac{B}{\mu_0 n}$$

$$u_m = \frac{U_m}{\text{volume}} = \frac{1}{2} \frac{\left(\mu_0 n^2 A l\right) I^2}{A l} = \frac{1}{2} \mu_0 n^2 I^2$$

$$u_m = \frac{1}{2} \frac{B^2}{\mu_0}$$

Combination of Inductors

L1 and L2 : inductance of two coils which are placed at large distance.

$$L = L_1 + L_2$$

In series combination

$$\frac{1}{L} = \frac{1}{L_1} + \frac{1}{L_2} \Rightarrow L = \frac{L_1 L_2}{L_1 + L_2}$$

In parallel combination

L1 and L2 : inductance of two coils which are placed at small distance.

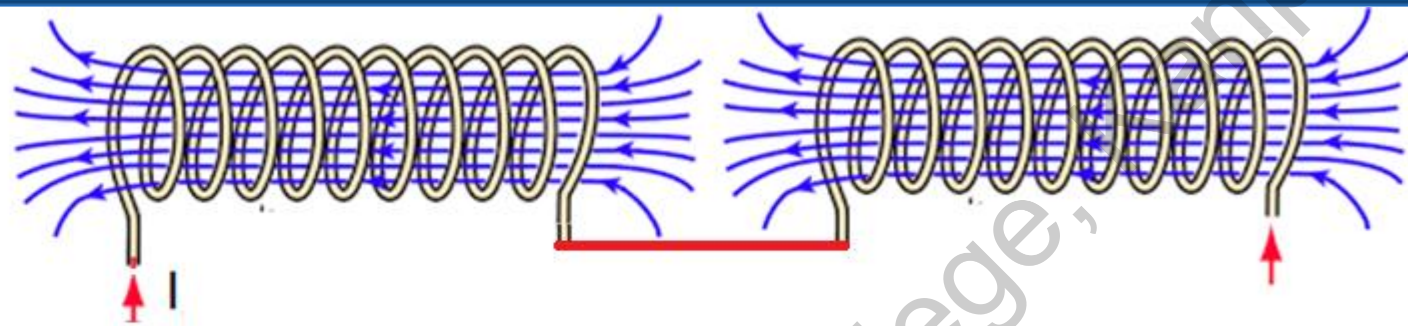
$$L = L_1 + L_2 \pm 2M$$

In series combination

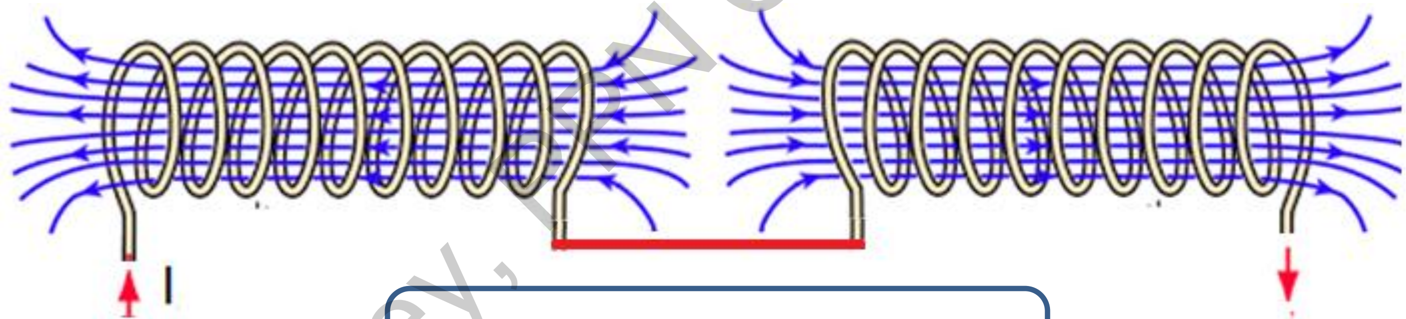
$$L = \frac{L_1 L_2 - M^2}{L_1 + L_2 \pm M}$$

In parallel combination

Combination of Inductors



$$L_A = L_1 + L_2 + 2M$$



$$L_A = L_1 + L_2 - 2M$$

$$M = \frac{L_A - L_B}{4}$$

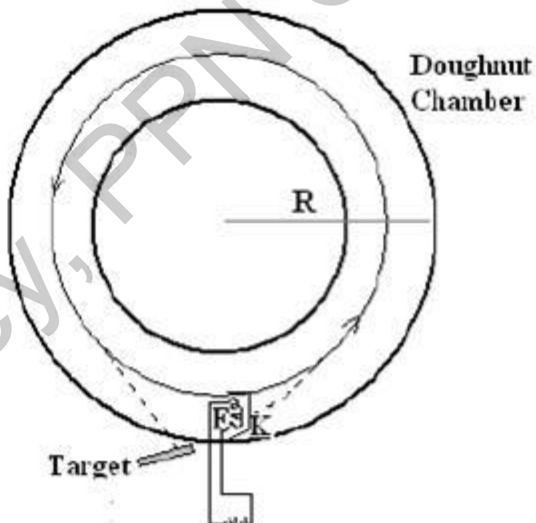
Betatron

1. **Electromagnetic Induction Accelerator.**
2. **Motion of electron in changing magnetic field.**
3. **Accelarates electrons upto 100-500 MeV.**
4. **No electric field to accelerate but changing magnetic field is used.**

Quartz glass Doughnut shaped vacuum tube placed between pole pieces of electromagnet

$$\phi = 2\,\phi'$$

$$\phi' = \pi R^2 B$$



Magnetic flux in betatron is equal to twice of magnetc flux linked with same area of circular surface in uniform B.

Skin Effect

1. Steady current flowing trough wire is distributed uniformly over whole cross section of wire.
2. Alternating current of high frequency flows in outer layers of wire due to em induction effect.
3. Alternating current of very high frequency flows through surface layer of wire. This effect of em induction is called as Skin effect. Very high frequency current are confined wholly to the surface.
4. Inner region →outer region : magnetic field increases
5. Magnetic fulx change in inner region large in comparison to outer
6. Larger emf at inner side than outer side. This emf oppses the applied emf. So, High hindrance at inner than outer. Thus Cuurent flows in outer layers.

A Lot of Thanks

for kind attention