# Electro-Magnetic Induction

13 September 2020 18:30

**Faraday's & Henry's exp:→**

" if the magnetic flux linked to any coil changes w.r.t time, an EMF as well as a current get induced in it, this phenomenon is called Electro-Magnetic Induction."

understanding of EMI can be done with the help of following series of Experiments.

**Experiment 1:→**

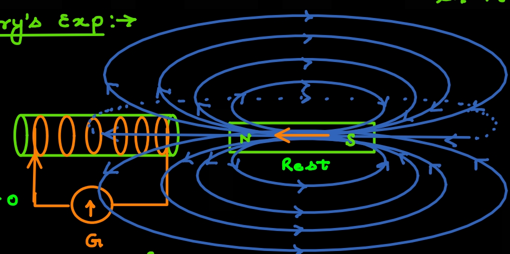
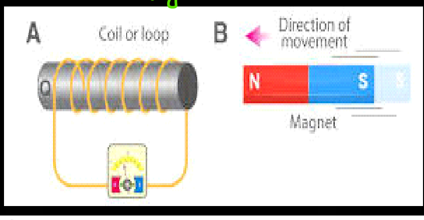



fig. 1

when a bar magnet is kept relatively at rest co-axially with a coil connected to a G, the G shows no deflection. (fig 1)

But when the N-pole of the bar magnet is pushed towards the coil, the pointer in the G deflects, indicating the presence of current in the coil. The deflection lasts as long as the magnet is in motion. (fig 2)



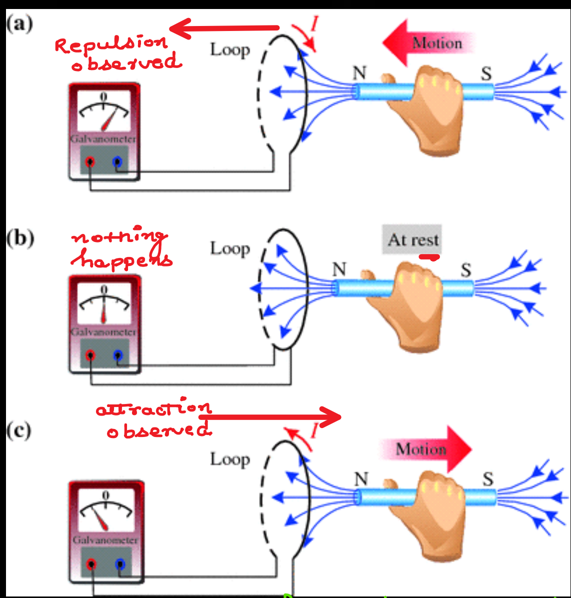

(fig 2)

when the magnet is pulled away from the coil, the G shows deflection in the opposite direction, which indicates a current in the opposite direction.

Moreover, when the South pole of the bar magnet is moved towards & away from the coil, the deflection in the G are opposite to that observed with the N-pole in similar movements.

Further the deflection (ie the current) is found larger, when the magnet is pushed or pulled faster.

It was also observed that the coil shows a repulsion when the magnet is pushed towards the coil & it shows an attraction when it is pulled away from the coil.




" so it was concluded that the relative motion b/w the coil & the magnet is responsible for induction of current in the coil."

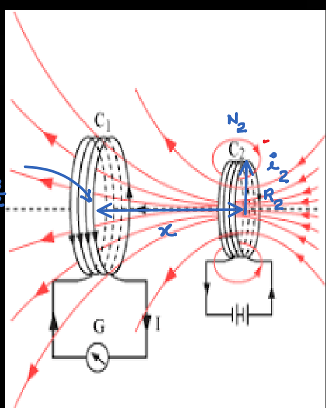
" the relative motion of the bar magnet changing the magnetic induction on the axis of the coil."

**Experiment 2:→**

Now the bar magnet is replaced by another current carrying coil (Electromagnet) $C_2$. The steady current in $C_2$ produces a constant magnetic field on the axis of $C_1$.

At is moment the G connected with $C_1$ shows no deflection.

$$B_1 = \frac{\mu_0 \cdot N \cdot i_2 \cdot R_2^2}{2 (R_2^2 + x^2)^{3/2}}$$




But as the $C_2$ is brought closer to $C_1$, the induction on the axis of $C_1$ increases & the G shows a deflection.

when $C_2$ is pushed away from $C_1$, again the G shows a deflection but this time in the opposite direction.

again attraction b/w the coils is observed when $C_2$ is pulled away from $C_1$ & a repulsion when $C_2$ is pushed towards $C_1$.

" Again it is the relative motion b/w the coils which induces electric current."

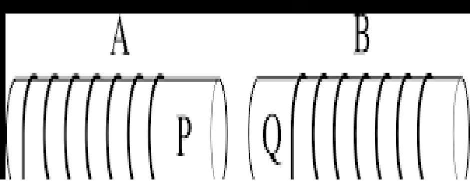
**Experiment 3:→**

In the above two experiments current induction is observed due to the relative motion.

But it is not the only requirement.

In fig 1. there are two stationary coils A & B

B is connected with a G & A with a Battery & current controller (ie: Rheostat).

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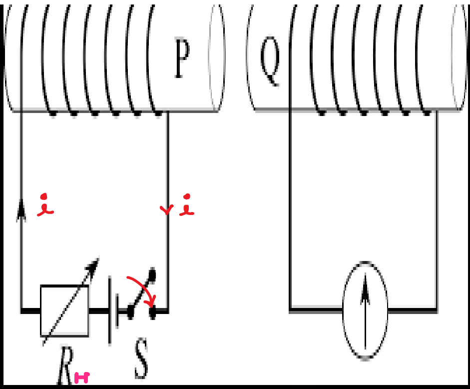
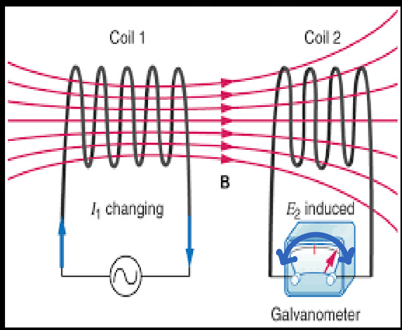



fig 2:




In fig 1: there are two stationary coils A & B. B is connected with a (G) & A with a Battery & current controller (ie: Rheostat).

if the current in A is kept steady, the (G) connected to B shows no deflection.

as we increase the current in coil A with the help of the Rheostat, the (G) shows deflection.

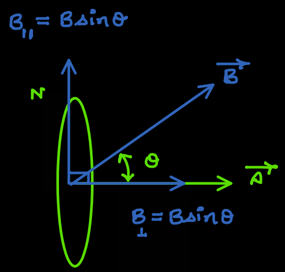
Again if we decrease the current in coil A, (G) again deflects but this time in opposite direction.

Again a repulsion was observed with increase in current of A & attraction in decrease in current of A.

"Therefore it is concluded that current can be induced in any coil by changing the current of any nearby coil."

"it was further noticed that the (G) in the second coil oscillates if current in coil 1 is alternating current."

**Faraday's Law of EMI:→** The observations from the above Experiment are concluded as Faraday's Law of EMI.




"According to this Law the EMF induced in any coil is directly proportional to the rate of change of magnetic flux through it."

ie; $\varepsilon_{in} \propto \frac{d\phi_B}{dt}$

for a coil of 'N' turns

$\varepsilon_{in} \propto N \cdot \frac{d\phi_B}{dt}$

induced EMF $\boxed{\varepsilon_{in} = -N \cdot \frac{d\phi_B}{dt}}$ volt

"The negative sign is due to Lenz Law".

if the resistance of the coil is R then;

induced current $\boxed{i_{in} = \frac{\varepsilon_{in}}{R} = -\frac{N}{R} \cdot \frac{d\phi_B}{dt}}$ Amp

as; $\phi_B = \vec{B} \cdot \vec{A}$

$\phi_B = B \cdot A \cdot \cos\theta$ wb.

$$\boxed{\begin{array}{l} \varepsilon_{in} = -N \cdot \frac{d}{dt}(B \cdot A \cdot \cos\theta) \\ \& \\ i_{in} = -\frac{N}{R} \cdot \frac{d}{dt}(B \cdot A \cdot \cos\theta) \end{array}}$$

$\theta$ is the angle b/w $\vec{B}$ & $\vec{A}$

∴ to induce EMF or current in any coil, either the magnetic induction at the center of the coil or the area of the coil or the angle b/w $\vec{B}$ & $\vec{A}$ must be changed w.r.t. time.

**Lenz Law :→** According to this law the direction of induced EMF or induced current is always in such a manner that it always opposes the change in flux ie the cause of its own birth.
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The negative sign in Faraday's Law is the description of Lenz's Law.

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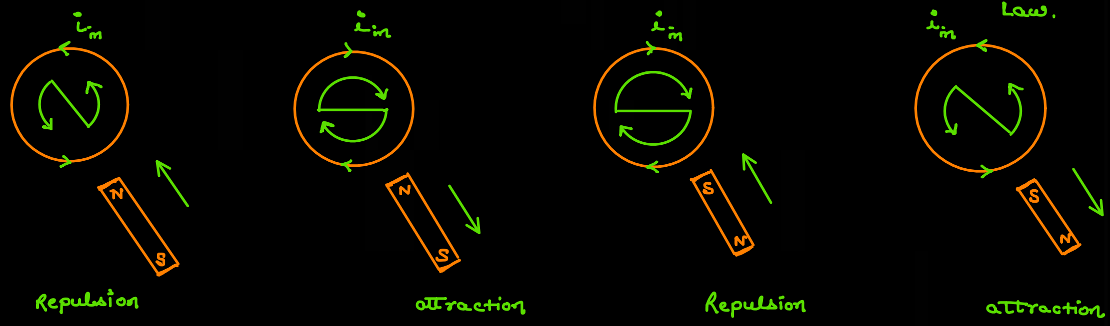
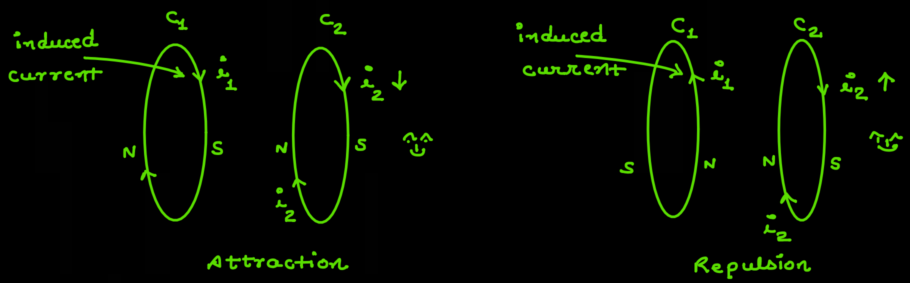
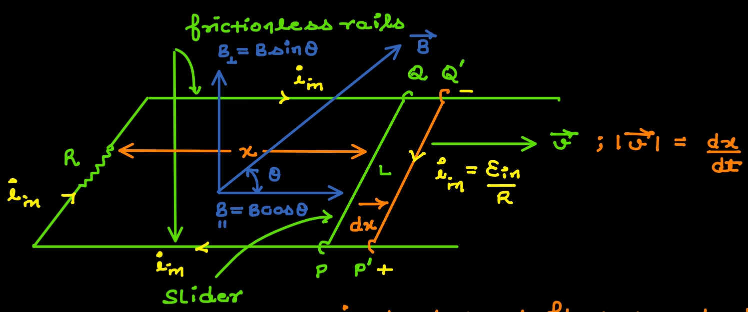



Motional EMF :→ when a conductor sweeps the magnetic flux perpendicular to its plane of motion, the EMF that induces about its ends is called motional EMF.




instantaneous flux swept by the slider

$$d\phi_B = \vec{B}_\perp \cdot d\vec{A}$$
$$= B_\perp \cdot dA \cdot \cos 0^\circ$$
$$= B_\perp \cdot dA$$
$$\Rightarrow d\phi_B = B\sin\theta \times L \times dx \quad \text{wb.}$$
$$\Rightarrow \frac{d\phi_B}{dt} = B \cdot \sin\theta \cdot L \cdot \frac{dx}{dt}$$
$$\because \frac{dx}{dt} = v$$
$$\Rightarrow \frac{d\phi_B}{dt} = B \cdot v \cdot L \cdot \sin\theta$$
$$\because \mathcal{E}_{in} = \left|-\frac{d\phi_B}{dt}\right|$$

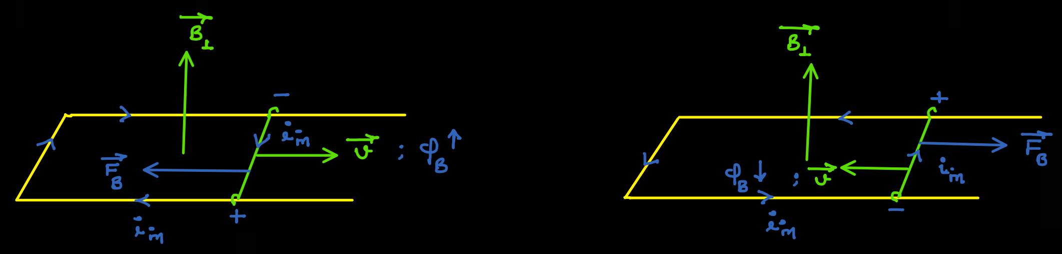
Motional EMF $\therefore$ $\boxed{\mathcal{E}_{in} = B \cdot v \cdot L \cdot \sin\theta}$ —(1)

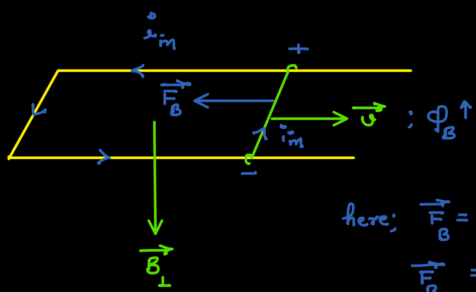
$\because$ induced current $(i_m) = \frac{\mathcal{E}_{in}}{R}$

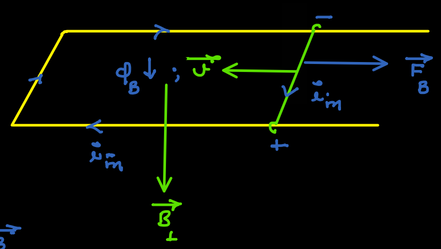
$\therefore$ $\boxed{i_m = \frac{B \cdot v \cdot L \cdot \sin\theta}{R}}$ —(2) Amp.

here θ is the angle made by $\vec{B}$ from the plane of motion of the slider.

# Direction of induced EMF & current from Lenz Law :-




here; $\vec{F}_B = \int d\vec{F}_B$

$$\vec{F}_B = \int i\, d\vec{l} \times \vec{B}_\perp$$

which is the Lorentz force experienced by the conductor always opposite to the motion of the conductor which is an description of the Lenz Law & hence opposes the change in flux.