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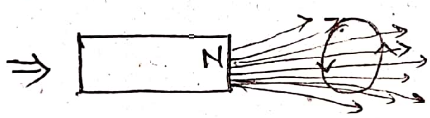
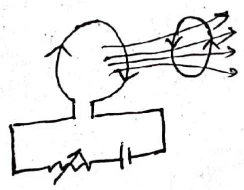
Topic — Electromagnetic induction

Electromagnetic induction := Whenever there is a relative motion ~~When ever~~ between a closed circuit and a magnet or a current in an auxilliary circuit changes i.e magnetic flux linked up through a coil changes then an emf is produced through the coil, hence a current flows through the circuit. This phenomena is called electromagnetic induction.

The emf produced due to electromagnetic induction is called induced emf.

The current produced due to electromagnetic induction is called induced current.





Laws of electromagnetic induction :=

Faraday gives two laws and Lenz gives another law related to electromagnetic induction.

1st law :- Whenever there is a variation of magnetic lines of force linked up with the coil, at that moment an induced emf is produced.

2nd law := The magnitude of induced emf in a closed circuit is proportional to the rate of change of magnetic flux linked up with the coil.

3rd law (Lenz):= The direction of induced current will be such that it tends to oppose the very cause of it.

Faraday's law :=

If $|e|$ be the magnitude of induced emf due to change in flux $d\phi$ in time dt linked up with a coil,

then $|e| \propto \frac{d\phi}{dt}$

or, $|e| = k\frac{d\phi}{dt}$

If rate of change of flux linked up with a coil is unity then induced emf produced within it is also unity.

i.e $\frac{d\phi}{dt} = 1$ then $|e| = 1$, hence $k = 1$

$\therefore |e| = \frac{d\phi}{dt}$

According to Lenz's law $e = -\frac{d\phi}{dt}$

Differential form of Faraday's law :=

We know, Faraday's law of electromagnetic induction,

$$e = -\frac{d\phi}{dt} \quad \text{--(1)}$$

Again magnetic flux associated with an elementary area ds

$$d\phi = \vec{B}.\hat{n}ds$$

$$\text{or, } \phi = \int_s \vec{B}.\hat{n}ds$$

Again induced emf generated in a closed curve is equal to workdone to rotate a unit positive charge in a closed orbit.

$$\text{ie } e = \oint \vec{F}.d\vec{l} \quad \text{for } q = +1$$

$$= \oint \vec{E}.d\vec{l} \quad \text{as } \vec{F} = q\vec{E}$$

putting in equation (i), we get.

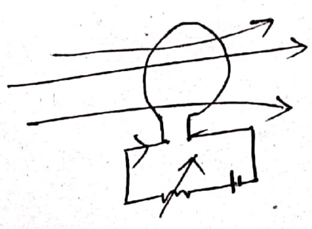
$$\oint \vec{E}.d\vec{l} = -\int_s \frac{\partial \vec{B}}{\partial t}.\hat{n}ds$$

$$\text{or, } \int_s (\vec{\nabla}\times\vec{E})\hat{n}\,ds = -\int_s \frac{\partial \vec{B}}{\partial t}.\hat{n}ds$$

$$\text{or, } \int_s \left(\vec{\nabla}\times\vec{E} + \frac{\partial \vec{B}}{\partial t}\right).\hat{n}ds = 0$$

$$\therefore \boxed{\vec{\nabla}\times\vec{E} = -\frac{\partial \vec{B}}{\partial t}}$$

Self induction :- Due to change in own current through a coil as magnetic flux associated with it changes, hence an induced emf is produced with in it. This phenomena is called self induction.



Magnetic flux through a coil (ϕ) is linearly proportional to the current (i) passing through

ie $\phi \propto i$

or, $\phi = Li$

Where L is called self inductances or coeff. of self induction.

Again $e = -\frac{d\phi}{dt} = -\frac{d}{dt}(Li)$

or, $e = -L\frac{di}{dt}$

Self inductance — $\phi = Li$; when $i = 1$, then $\phi = L$.

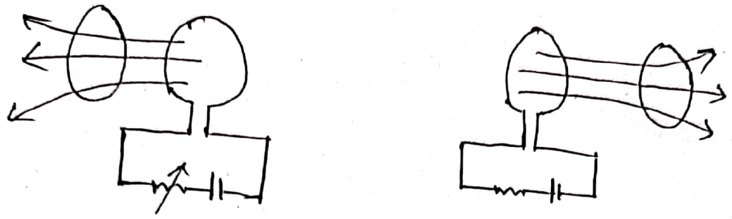
When unit current flows through a circuit then the numerical value of flux associated with the coil is called self inductance of that coil.

S.I unit of self inductance — Henry.

$L = \frac{\phi}{i}$ or, $1 \text{ Henry} = \frac{1 \text{ weber}}{1 \text{ Amp.}}$

When 1 amp current passes through a circuit, if the flux associated with the coil is 1 weber, then self inductance of that coil is called 1 Henry.

Mutual induction := When two coils are closed together, then due to change in current in one coil, induced emf is produced in the another coil. This phenomena is called mutual induction.



Magnetic flux associated with the 1st coil (ϕ_1) is proportional to the current in the second coil (i_2)

ie $\phi_1 \propto i_2$

or, $\phi_{12} = M_{12} i_2$

Similarly, $\phi_{21} = M_{21} i_1$

Actually, $M_{12} = M_{21}$ hence $\phi_{21} = M i_1$

$\phi_{12} = M i_2$

Induced emf $e_{21} = -\frac{d\phi_{21}}{dt}$

$\therefore \quad e_{21} = -M\frac{di_1}{dt}$

and $e_{12} = -M\frac{di_2}{dt}$

Where M is called mutual inductance or coefficient of mutual induction.

Mutual inductance := $\phi_{21} = M i_1$; when $i_1 = 1$ then $\phi_{21} = M$.

ie when unit current flows through one circuit, then ~~numerical~~ value of flux associated with the second coil is called mutual inductance between two coils.