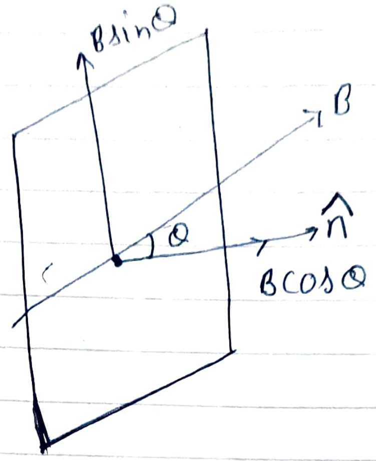
ELECTROMAGNETIC INDUCTION - 6

Magnetic flux → It is defined as the total No. of magnetic field lines passing normal to the given surface area.



$\phi = B_n A$

$B_n = B\cos\theta$

$\phi = B\cos\theta\, A$

$$\boxed{\phi = \vec{B} \cdot \vec{A}}$$

From the above equation we can conclude that flux is a scalar quantity.

- ☆ SI unit of flux is ~~Webber~~ Weber (Wb)
- ☆ CGS unit of flux is maxwell

$$\boxed{1\text{ Maxwell} = 10^{-8}\text{ Weber}}$$

☆ **Dimensional formula for magnetic flux**

$\phi = [ML^2T^{-2}A^{-1}]$

Electromagnetic Induction - 6

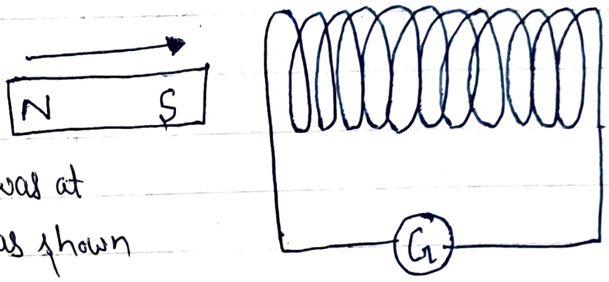
It is the phenomenon of producing electric field with the help of ~~vartgi~~ varying magnetic field.

Faraday's And Henry's Experiment.

Experiment No-1 ⇒ A magnet induces current due to relative motion.

The apparatus consisted of a coil with a galvanometer and a bar magnet.

Observation ⇒



(i) When the bar magnet was at rest No deflection was shown by galvanometer.

(ii) When the galvanometer is moved to and fro inside the coil then the galvanometer shows deflection.

(iii) Direction of deflection changes with change In the direction of movement of ~~galvanometer~~ bar magnet.

(iv) The deflection of galvanometer was large when the ~~deflecte~~ magnet was moved fast inside the coil.

Conclusion ⇒ Whenever there is a relative motion b/w a Coil and magnet, induced current flows through coil.

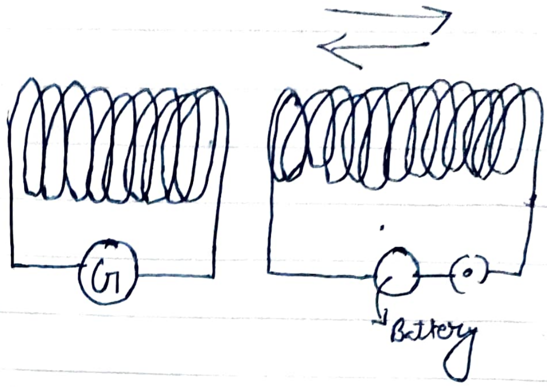
Experiment No:-2 ⇒ Current induces current due to relative motion of Coils.

- In this experiment bar magnet was replaced with a current carrying coil.

(ii) When a coil connected with galvanometer is moved to and fro relative to the current carrying coil then there is deflection in the coil.

(iii) The deflection in the galvanometer was large when the speed of coil was fast.

Conclusion ⇒ Induced e.m.f or current is produced in the secondary coil when there is a relative motion b/w primary coil and secondary coil carrying current.



Experiment No-3 ⇒ Changing current induces current without relative motion of coils.

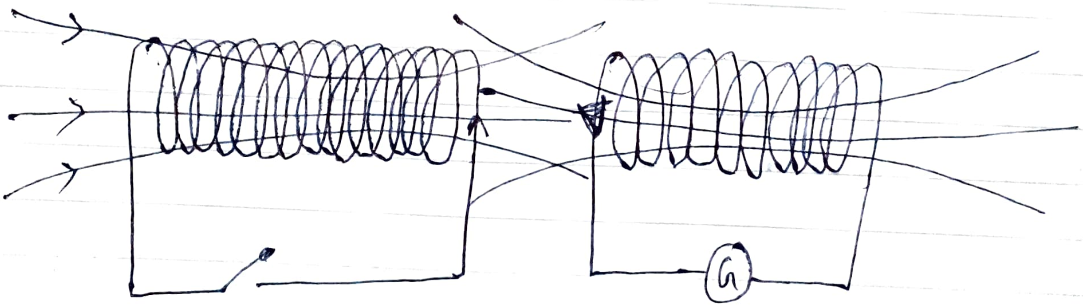
(i) In this experiment two coils C_1 and C_2 are placed over a wooden core.

(ii) The coil C_1 is connected to a galvanometer while coil C_2 is connected to a battery with a key.

(iii) When the key is switched on there is ~~a~~ momentary deflection in the galvanometer connected to the coil C_1.

(iv) When the key is switched off then ~~th~~ again the galvanometer shows deflection.

Conclusion ⇒ When ~~a~~ ~~curre~~ current in the neighbouring coil is changed then current is induced in the coil.



Faraday's law of Electromagnetic Induction ⇒

(i) **Faraday's First law of EMI ⇒** Whenever the magnetic flux linked with coil or conductor is changed emf is induced.

(ii) **Faraday's Second law ⇒** The rate of change of magnetic flux linked with a coil is directly proportional to the emf induced in the coil.

$$|\varepsilon| \propto \frac{d\phi}{dt}$$

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

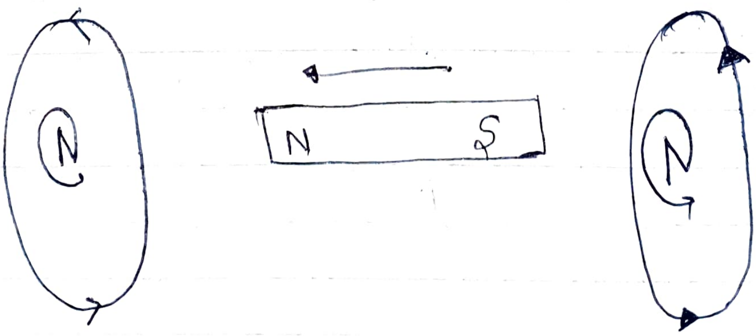
$$\boxed{|\varepsilon| = \frac{d\phi}{dt}}$$ In SI unit $\boxed{K=1}$

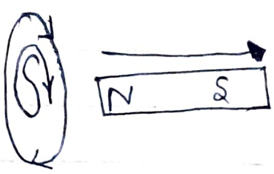
If the coil has N turns then

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

Limitation of second law of EMI ⇒ It does not give the polarity of induced EMF.

Lenz's law ⇒ The polarity of induced emf is such that it opp the cause which has produced it.





Faraday - Lenz's law

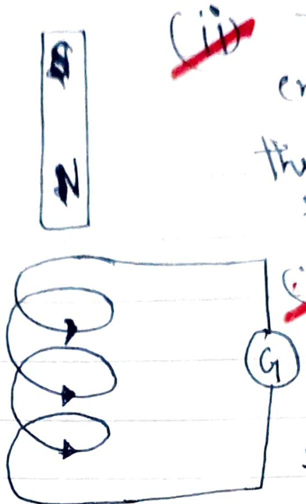
$$\varepsilon = -N\frac{d\phi}{dt}$$

$(-) \rightarrow$ It is due to Lenz's law.

$N\frac{d\phi}{dt} \rightarrow$ Due to Faraday's law.

Lenz's law And law of conservation of Energy.

(i) When a bar magnet's north pole is approaching the coil then the magnetic flux linked with coil is changed and emf is induced in the coil.



(ii) The direction of induced emf is such that it opposes the movement of North pole towards the coil.

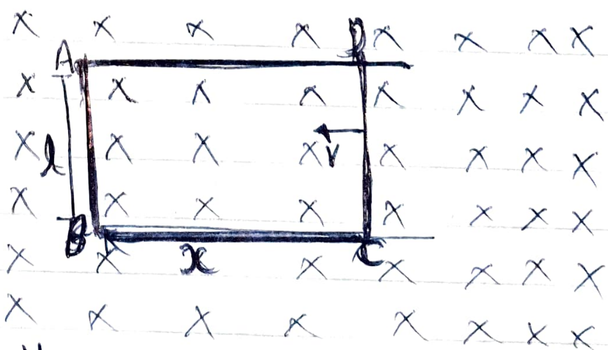
(iii) In order to move magnet's North pole towards the coil we have to do work.

(iv) That work get converted into emf and then into current or electrical energy. Which proves that Lenz's law follows law of conservation of energy.

Motional EMF

Let us consider a rectangular coil placed in a magnetic field. Let the side CD of the coil is free to move.

Let the magnitude of magnetic field be B and is directed inside the plane of paper.



Let the free side CD is moved with a speed v.

$\phi = B \cdot A$

$\phi = BA\cos\theta \qquad \theta = 0°$

$\phi = BA$

$A = lx$

$\phi = Blx$

$\varepsilon = -\frac{d\phi}{dt} \Rightarrow \varepsilon = -Bl\frac{dx}{dt}$ $\left\{ \frac{dx}{dt} = v \right.$

$$\boxed{\varepsilon = -Blv}$$

(ii) **Current in the rectangular coil** ⇒ If the resistance of the coil is R then the current in the coil will be

$\varepsilon = IR$ $\left\{ \text{from ohm's law } \boxed{V = IR} \right.$

$I = \frac{\varepsilon}{R} = \frac{-Blv}{R}$

$$\boxed{I = -\frac{Blv}{R}}$$

(iii) **Heat produced** in the coil ⇒

$H = I^2RT = \frac{B^2l^2v^2}{R^2} \times RT$

$$\boxed{H = \frac{Bl^2v^2T}{R}}$$

(iv) **Force Required to Move the coil**

$F = BIl\sin\theta$ $\theta = 90°$

$I = -\frac{Blv}{R}$

$$\boxed{F = \frac{B^2l^2v}{R}}$$

(v) **Power ~~delived~~ Delivered** ⇒ $P = Fv$

$$\boxed{P = \frac{B^2l^2v^2}{R}}$$

Induced Emf in a conductor Rotated In Magnetic field

Let us consider a conductor of length l rotated in a magnetic field with angular velocity ω. Let the strength of magnetic field be B.

If the conductor is turned to small angle θ then area swept by conductor

$$A = \frac{1}{2} \text{base} \times \text{height}$$

$$A = \frac{1}{2} l (l\theta)$$

$$A = \frac{1}{2} l^2 \theta$$

$$\theta = \frac{x}{l} \Rightarrow x = l\theta$$

$$\phi = BA$$

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

$$\mathcal{E} = -\frac{B l^2}{2} \frac{d\theta}{dt}$$

$$\mathcal{E} = -\frac{1}{2} B l^2 \omega$$

Eddy Currents [Foucault Currents]

The induced circulating current produced in the conductor due to change in the magnetic flux linked with the conductor are called eddy currents.

* This current was discovered by Focault.
* The direction of eddy current ~~was~~ is given by Lenz's law.

Advantage of Eddy Current

(i) Induction furnace
(ii) Speedometer
(iii) Dead beat Galvanometer
(iv) Electric Brakes in trains.

(v) Energy Meter (vi) Induction Motors.

Disadvantage

(i) Produces Dampening Effect (ii) It breaks insulation of Conductor

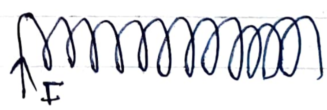
(ii) Loss of Energy in the form of heat.

☆☆☆ Method to minimise Eddy current

In place of using a solid metallic core it is replaced by thin laminated sheets arranged parallel to each other. So eddy current produced in ~~the~~ one sheet breaks the path of eddy current in the second sheet. So the eddy current reduces.

Self Induction ⇒ Self induction is the property of a coil by virtue of which it opposes the growth or decay of the current flowing through it.

Let I be the current flowing through a coil then magnetic flux linked with the coil is



found to be directly proportional to the strength of the ~~coil~~ current flowing in the coil.

$\phi \propto I$

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

{ L = Coefficient of self induction.

if $I = 1$ $\boxed{\phi = L}$

Coefficient of self induction is defined as the magnetic flux linked with the coil when unit current passed through it.

Ideal Inductor ⇒ It has high value of inductance but zero resistance.

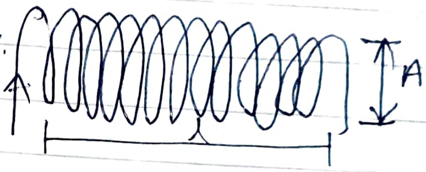
$$\mathcal{E} = -L\frac{dI}{dt}$$

Unit of self Inductance is Henry (H) $[VAS^{-1}]$

Dimension $[ML^2T^{-2}A^{-1}]$

Self Inductance of a solenoid →

Consider a long solenoid of length l, area of cross section A and number of turns per unit length is n. Let I be the current flowing through it



Magnetic field produced in the coil
$B = \mu_0 n I$

Magnetic flux linked with each turn = $BA = \mu_0 n I A$

Total No of turns in the solenoid N = No of turns per unit length × length of solenoid

$$N = nl$$

Now total magnetic flux linked with each turn of the solenoid

ϕ = magnetic flux linked with each turn × total No of turns

$\phi = \mu_0 n I A \times nl$

$\phi = \mu_0 n^2 I A l$ —— (1)

Also $\phi = LI$ —— (2)

from (1) and (2)

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

$$L = \mu_0 n^2 A l$$

Inductor ⇒ An element of an electric circuit like a tightly wound coil of insulated wire which opposes the change in the current through it is called inductor. It's symbol is ─ꟷmmmm─

Factors on which self inductance depends

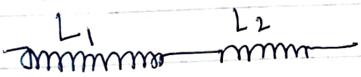
(i) Length of solenoid (ii) Area of cross section of solenoid
(iii) Medium inside the core of solenoid.
(iv) Number of turns.

Question Why self induction is also known as inertia of the coil?

Ans:⇒ Because it opposes the growth or decay of current in the coil

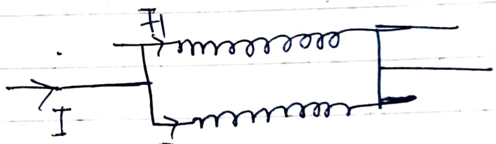
Combination of Coil

Series Combination



$$L_s = L_1 + L_2$$

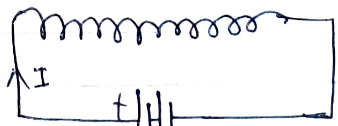
Parallel Combination



$$\frac{1}{L_p} = \frac{1}{L_1} + \frac{1}{L_2}$$

Energy Stored in an Inductor

$$\mathcal{E} = -L\frac{dI}{dt}$$



To drive the current through inductor against the induced emf $\mathcal{E}$ the external voltage V is applied

$$V = -\mathcal{E} = L\frac{dI}{dt}$$

Let in a small time dq charge is given to the inductor. So work done by external voltage is given by

$$dW = \mathcal{E}\, dq$$

$\left\{ V = \frac{W}{Q} \quad \boxed{W = VQ} \right.$ $\quad V = \mathcal{E}$, $W = \mathcal{E}Q$

$$dW = L \frac{dI}{dt} dq \qquad \left\{ I = \frac{dq}{dt} \right.$$

$$dW = L I \, dI$$

for total work done

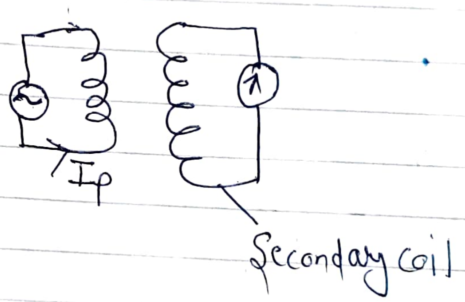
$$\int_0^W dW = L \int_0^{I_0} I \, dI$$

$$\boxed{W = \frac{1}{2} L I_0^2}$$

Mutual Inductance

Mutual Inductance is the phenomenon of inducing emf in a coil due to rate of change of current in a nearby coil.

It is found that flux linked with the secondary coil is directly proportional to the current in primary coil



$$\phi_s \propto I_p$$

$$\boxed{\phi_s = M I_p} \qquad \left\{ M = \text{coefficient of mutual inductance.} \right.$$

※ SI unit of mutual inductance is Henry.

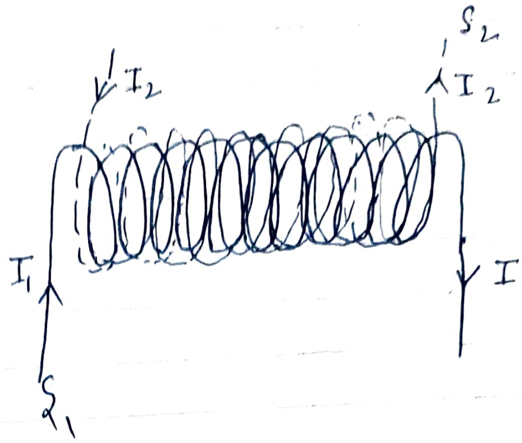
$$\boxed{\varepsilon_s = -M \frac{dI_p}{dt}}$$

If $I = 1$ $\qquad \boxed{\phi_s = M}$

Coefficient of mutual inductance is defined as the flux in the secondary coil when a unit current is passed through primary coil.

Mutual Inductance of two long solenoid placed Co-axialy.

Let us Consider two long Co-axial solenoid having length A l and cross-sectional Area A.



Let

n_1, n_2 = No. of turns in coil 1 and coil 2 per unit length

N_1, N_2 = Total No. of turns in coil 1 and coil 2

Magnetic field produced by coil ②

$$B_2 = \mu_0 n_2 I_2$$

Magnetic flux linked with coil 1 with each Turn

$$\phi_1 = B_2 A$$

$$\phi_2 = \mu_0 n_2 I_2 A$$

total magnetic flux linked with ~~each turn~~ Coil =

= magnetic flux linked with one turn × total No. of turns

$$\boxed{\phi_1 = \mu_0 n_2 I_2 A \times n_1 l} \quad —①$$

{ total No. of turns = $n_1 = \frac{N}{l}$, $N = n_1 l$ }

$$\boxed{\phi_1 = M I_2} \quad —②$$

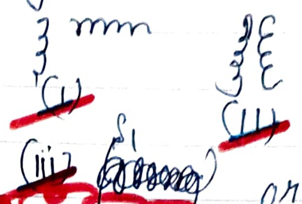
from ① and ② equation

$$M \cancel{I_2} = \mu_0 n_2 \cancel{I_2} A n_1 l$$

$$M = \mu_0 n_2 n_1 l A$$

Factors on which Mutual Inductance depends

(i) length of solenoid
(ii) Area of solenoid
(iii) No. of turns in each solenoid
(iv) Medium of core
(v) Relative orientation of two turns.



(iii) > (ii) > (i) — order of mutual inductance

Alternating Current Generator

It is a device which converts mechanical energy into electrical energy.

Principle ⇒ It is based upon the principle of electro-magnetic induction.

Construction

(i) **Armature ⇒** Armature coil consist of large no. of turns of insulated copper wrapped over a soft iron core.

(ii) **Strong Field Magnet ⇒** A strong permanent magnet or electromagnet is used to create strong magnetic field.

(iii) **Slip Rings ⇒** The two ends of the armature coil are connected to two brass slip rings R_1 and R_2. These rings rotate along with armature coil.

(iv). Two Carbon brushes (B_1 and B_2) are pressed against the slip rings.

Working ⇒ (1) When the armature coil ABCD rotates in magnetic field provided by the strong field magnet. it cuts the magnetic lines of force.

(ii) The magnetic flux linked with the coil changes due to rotation of the armature and hence induced emf is set up in the coil.

(iii) The direction of induced emf is given by Fleming's right hand Rule.

Theory ⇒ Consider the plane of the coil to be perpendicular to the magnetic field B.

Let the coil is to be rotated in anticlock wise direction with angular velocity ω.

Let A = Area of the coil
B = Strength of magnetic field
θ = Angle b/w magnetic field and Normal of the coil.
φ = flux
n = No. of turns in the coil

$\phi = nBA\cos\theta$

$\theta = \omega t$

$\phi = nBA\cos\omega t$

$E = -\dfrac{d\phi}{dt}$

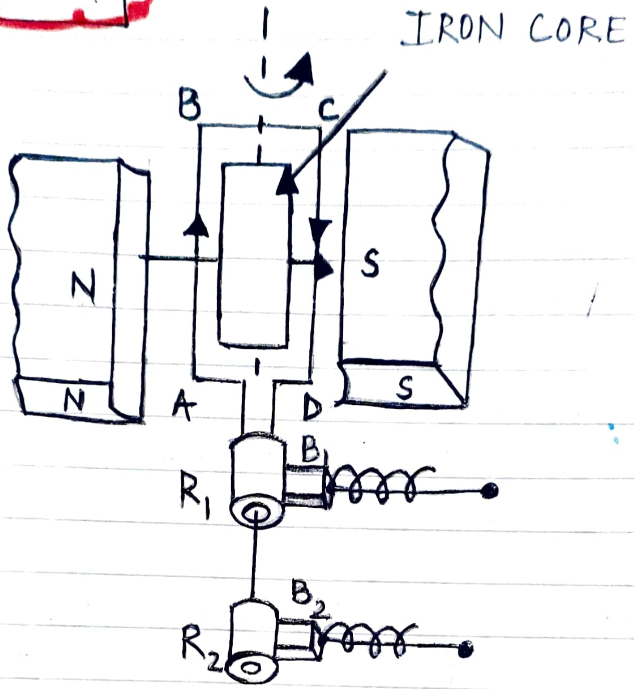
$E = -nBA\dfrac{d}{dt}\cos\omega t$

$\mathcal{E} = +\omega n B A \sin \omega t$

when $\theta = \omega t = 90^\circ$ $\quad \mathcal{E} = \mathcal{E}_0$

$\mathcal{E}_0 = \omega n B A$

$$\mathcal{E} = \mathcal{E}_0 \sin \omega t$$



A.C. GENERATOR