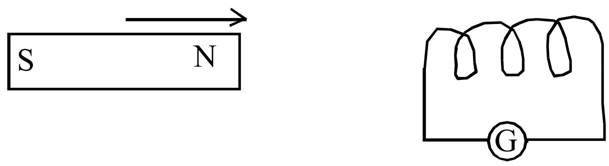
Chapter 6

ELECTROMAGNETIC INDUCTION

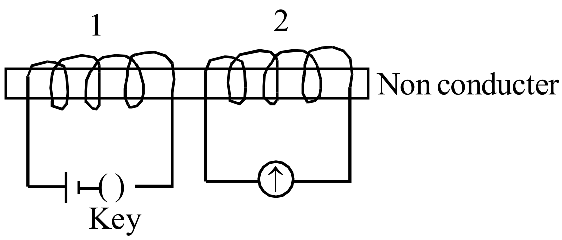
Michel Faraday and Joseph Henry demonstrated that a moving magnetic field (changing magnetic flus) can produce emf and hence electric current.

Experiments:

1) Coi-Magnet experiment - Galvanometer show deflection when N-pole moving towards the coil. It shows deflection in the opposite direction if the pole is moving away from the coil. It shows Zero deflection when the magnet is kept stationery inside the coil.
Thus an emf hence electric current is induced in the coil due to the relative motion of the magnet. (Source of Magnetic field)



2) **Coil - Coil experiment**
By making and breaking the current through the coil 1, an emf and hence electric current is induced in the coil 2.



- Electromagnetic Induction : The process of inducing emf and hence electric current as a result of change in magnetic field or magnetic flux linked with a conductor.

- **Laws of electromagnetic Induction :**
  i) **Faraday's Rule or Flux Rule :** When magnetic flux linked with a conductor changes there will be an induced emf
  The induced emf is directly proportional to the rate of change of magnetic flux (φ_B)
  Induced emf $|e| \alpha \frac{d\varphi_B}{dt}$
  ii) **Lenz's Rule :** The direction of induced emf and hence induced current is such that itop poses the change in magnetic flux which is responsible for induced emf.

$$e = \frac{-d\varphi_B}{dt}$$, -ve sign shows e opposes φ_B

It is the consequence of Law of conservation of energy.

- **Lenz's Rule and Conservation of energy** :
  In fig (1) in order to move the magnet towards the coil work has to be done against the force of repulsion in fig. (2). In order to move the magnet away from the coil work has to be done against the force of attaraction.

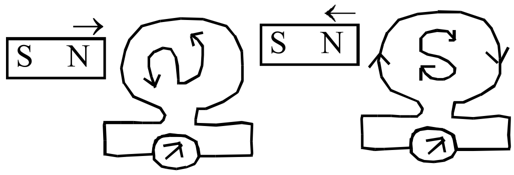


Fig (1) Fig (2)

  This work appears in the coil as emf. Hence energy is therefore conserved.

- A bar magnet is accelerated through a coil with its length parallel to the axis of the coil as shown what is the relation between a and g, in fig (1) and (2).

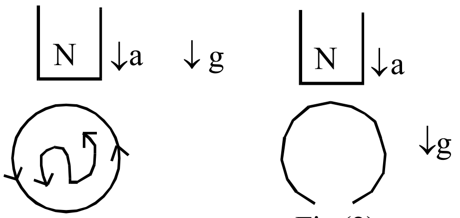


Fig (1) Fig (2)

(Note : Direction of induced current - clock wise (S) - Induces S - Pole. Anti clockwise (N) - Induces - N Pole)

In fig (1), a<g, since magnet experiences force of repulsion.
In fig (2), a=g, since there is no current is flowing, Because curcuit is open.

- Predict the polarity of the capacitor.

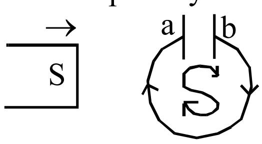


Plate a is +ve (current entering)
Plate b is -ve (current leaving)

- A conductor of length ℓ is moving with a velocity v in a perpendicular magnetic field B, emf induced in the conductor e=Blv. emf induced is called motion at emf.

- An aeroplane with wing span of 25m flies at a horizontal speed of 1800 km/h at a place where the magnetic field of earth is 5G and dip angle is 30^0. What is Potential difference between the tip fo the wing.
  Induced emf $e = B_v \ell v$, where $B_v = B\sin 0 = 5 \sin 30 = 2.5x10\text{-}4T$

$$\therefore e = 2.5\times10^{-4}\times25\times\frac{1800\times10^{-3}}{60\times60} = 3.13V$$

- Magnetic Lorenz force is the reason for Electro-magnetic induction.

Note: B-magnetic field of earth
δ -dip angle
$B_V = B \sin\delta$, Vertical component
$B_H = B \cos\delta$, Horizontal Component

- The magnetic flux passing perpendicular to the plane of a coil is varying according to the relation $\varphi_B = 6t^2 + 7t + 1$ What is the magnitude of emf induced in the loop when t=2s. φ_B is in mwb.

$$|e| = \frac{d\varphi_B}{dt}, \quad |e| = \frac{d}{dt}(6t^2 + 7t + 1) = 12t + 7$$

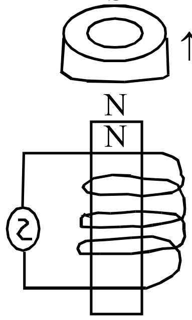
When t = 2s e = 24+7 = 31mv

- **Eddy Current (Foucault's Current:**

When a non magnetic metallic block (Cu/Aℓ) is placed in a varying magnetic field or moves in a magnetic field, induced circular current setup inside the block due to electromagnetic induction. Such currents are called Eddy Currents.

Demonstration -

Metallic Block moves up and down due to eddy current in accordance with Lenz's Rule.

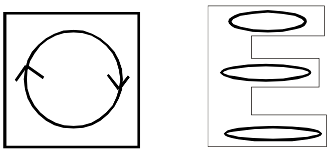


- **Demerit -**

Eddy current results in wastage of energy in the form of heat.

a) The slots cut across the block reduces induced Eddy Current. (Area available for the flow of eddy current decreased)

b) The metal block is laminated and insulated from each other reduces induced Eddy current (increase the resistance to the flow of eddy current)



Difference betweeen metal block and slots cut metal clock.

- To minimise the energy loss due to eddy current the core of dynamo and transformer are made of slots cut thin sheets of iron insulated from each other.

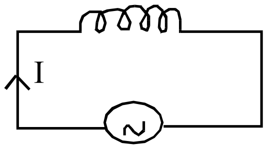
- Practical uses of Eddy current - speedometer, Induction oven, Breaking system in modern trains, Dead beat galvanometer.

- **Inductance -** Electrical property of a conductor by which it opposes the growth or decay of current through it.

φ_B - Magnetic flux linked with the coil.

I - Current, Then $\varphi_B \alpha I$

$$\varphi_B = LI$$



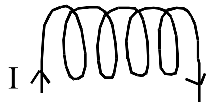
L - Inductance of the coil. Its unit is Henry (H)

But $|e| = \frac{d\varphi_B}{dt}$ induced emf $e = L\,dI/dt$

- **Expression for inductance of a solenoid**

  Let l - length, A - area cross section, n - number of turns / unit length, I - current.

  Magnetic field inside the solenoid, $= B = \mu_0 nI$

  Magnetic flux each turn of the solenoid $d\varphi_B = BA$

  $= B = \mu_0 nI$ Note : $\varphi_B = BA\cos\theta$
  $\theta = 0$

  Total number of turns in the solenoid, $N = n\ell$.

  Therefore Total flux linked with the solenoid $\varphi_B = N(d\varphi_B)$

  $$\varphi_B = n\ell\mu_0 nIA$$

  Induced emf $e = \frac{d\varphi_B}{dt} = n^2 l\mu_0 A\frac{dI}{dt}$ .... (1)

  If L is the inductance of the solenoid

  $$e = \frac{-LdI}{dt} \text{ .... (2)}$$

  Note : $\varphi_B = LI$ $e = \frac{d\varphi_B}{dt}$

  From equations (1) and (2),

  $$L = \frac{dI}{dt} = \mu_0 n^2 A\ell\frac{dI}{dt}$$

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

  $$= \frac{\mu_0 N^2 A}{\ell}$$

  i.e., Inductance depends on (1) size (*l*) and shape (A) of the coil (Geometry of the Coil) (2) Number of turns (N).

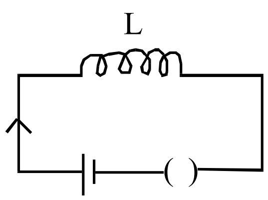
  If the core is filled with a material of relative permiability, μ_r, $L = \frac{\mu_0\mu_r N^2 A}{\ell}$

- Choke Coil : Inductance coil having large number of turns and made of thick copper wire of small resistance/used to control AC through a Circuit without loss of energy.

- Sparks are produced across the switch when light is switched off - large induced emf is produced due to self induction.

- Expression for energy stored in an inductor.

  Let I be the current through the inductor L at a certain time t

during the growth of current from 0 to max (Io).

then $\varphi_B = LI$

Back emf induced $e = \frac{LdI}{dt}$ Note : $\int IdI = \frac{I^2}{2}$

Work done by the source dw = eIdt

LIdI

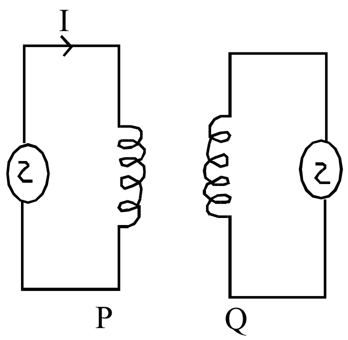
$\therefore$ Total work done $W = \int_O^{I_o} dw$

$$W = \frac{LIo^2}{2}$$

This work is stored as energy $u = \frac{1}{2} LT_0^2$, in the form of magnetic field.

- Self inductance plays the role of inertia in a coil.

- **Mutual Induction :** When electric current flowing through a coil (P) changes, the magnetic flux linked with the neighbouring coil (φ_B) changes which induces an emf and hence current in the neighbouring coil.



I - Current through P.

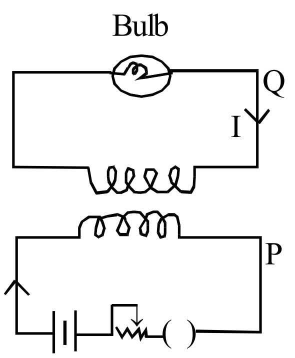
φ_B Magnetic flux linked with Q

$\varphi_B \alpha I$

$\varphi_B = MI$ where I - Mutual inductance of the coil Q.

But $|e| = \frac{d\varphi_B}{dt}$

Induced emf $e = \frac{M.dI}{dt}$

- 

(i) What do you observe when Key K is (1) just closed coil (2) Being closed (3) Just opened coil P. Why?

a) Bulb glows, Magnetic flux linked with the coil Q changes an emf is induced.

b) Bulb does glow. There is no change in flux. Hence no emf.

(ii) What is the phenomenon called - Mutual Induction.

(iii) How can you increase the brightness of the bulb in the coil Q.

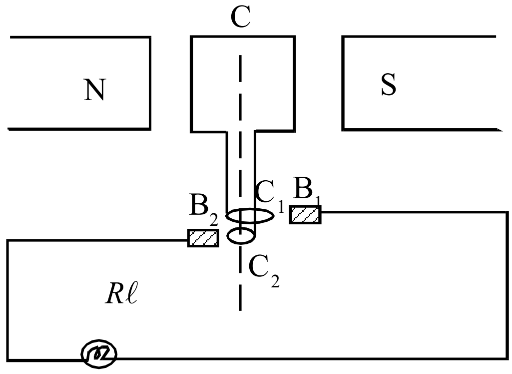
Increase the number of turns in the coil Q.

(iv) Can you name an instrumcnt which works on this principle - Transformer.

- Applications of electromagnetic Induction -

  (1) AC generator (2) Transformer.

  AC Generator : Converts Mechanical energy into Electrical energy.



NS - Field Magnet - used for producing magnetic field, usually electromagnet.

C - Armature Coil - Insulated copper wire wound over an iron drum.

C_1C_2 - Slip Rings, B_1B_2 - Graphite brushes. $R\ell$ - Bulb. (Load resistance)

When armature coil rotates in the Magnetic field B, the magnetic flux linked with the coil changes. So an emf and hence current is induced in the coil due to electromagnetic induction.

N - Number of turns in the armature coil.

A - Area of the coil.

B - Magnetic field produced by the field magnet.

Total Magnetic flux linked with the coil $\varphi_B = N(B.A)$.

$= NBA \cos\theta$

where θ is the angle between B and A (Area Vector)

If the coil rotates with an angular velocity w, at a particular time t, $\theta = wt$.

Then $\varphi_B = NAB\cos wt$.

By laws of electromagnetic induction,

Induced emf, $e = \frac{d\varphi_B}{dt}$

$e = NABW\sin wt$, Instantaneous emf.

$e = Vo\sin wt$ ---------- (1) where $Vo = NABW$ - Amplitude of emf.

If R is the resistance of the armature coil.

Induced current, $I = \frac{e}{R}$

$I = \frac{e_0}{R}\sin\omega t$

$I = I_o \sin wt$ -------------- (2) where $I_0 = {}^{l_0}\!/_R = \frac{NAB\omega}{R}$ Amplitude of current.

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