ELECTROMAGNETIC INDUCTION

INTRODUCTION

As in 1820, Hans Oersted discovered that electric currents produce magnetic fields. Since then, many scientists try to observe its reverse effect i-e; magnetic field may produce electric field.

In 1831, Michael Faraday in England and Joseph Henry in USA observed that when a conductor is moved across a magnetic field, then a current and an emf is set up in the conductor. The current is flowing through the conductor as long as it moved in the magnetic field. The current produced in the conductor is called induced current and emf produced across the conductor is called induced emf and such phenomenon is known as electromagnetic induction.

INDUCED CURRENT

The current produced in a conductor due to magnetic field is called induced current.

INDUCED EMF OR INDUCED VOLTAGE

The emf or voltage produced across a conductor due to changing magnetic field is called induced emf or induced voltage.

It is denoted by $\mathcal{E}$.

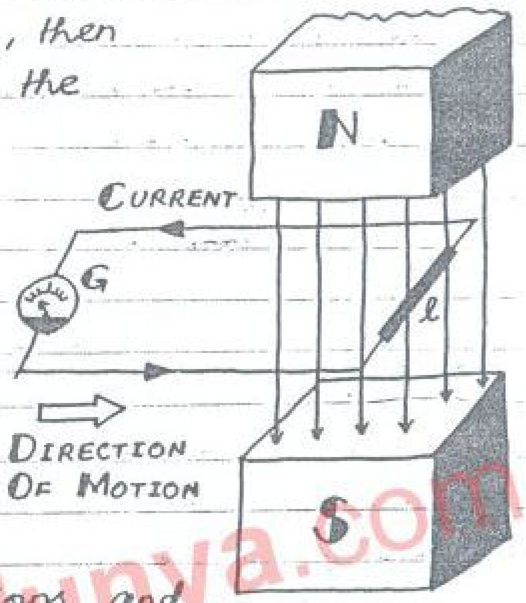
ELECTROMAGNETIC INDUCTION

The phenomenon of producing induced emf and induced current in a conductor or a coil due to changing magnetic field is called electromagnetic induction.

EXPLANATION

Consider a straight conductor of

length l placed in a magnetic field of a permanent magnet as shown in figure. The conductor is connected with a sensitive galvanometer which forms a closed path or a closed loop without any battery. When the loop is at rest in the magnetic field, then no current is shown by the galvanometer. If we move the loop from left to right across the magnetic field, then a current flows through the loop which can be shown by the deflection of the galvanometer. As we stop the loop from moving, current also stops and galvanometer shows no deflection. Now, if we move the loop in opposite direction, then again current is produced but in opposite direction which can be shown by the deflection of galvanometer in opposite direction.



FORMULA OF INDUCED EMF

The induced current depends upon the speed of the conductor in the magnetic field and the resistance of the loop. If the resistance of the loop changes by placing different resistors in the loop and move it with same speed every time in the magnetic field, we see that the product of induced current I and the resistance R of the loop remains constant i-e;

$$I \times R = \text{Constant}$$

This constant is called induced emf $\mathcal{E}$.

$$\therefore \boxed{\text{Induced emf} = \mathcal{E} = I \times R}$$

FACTORS AFFECTING INDUCED CURRENT

The induced current and induced emf can be increased by

(i) Using a stronger magnetic field.
(ii) Moving the loop or conductor faster.
(iii) Replacing the loop by a coil of many turns.

It should be noted that if we perform the above experiment in the other way i-e; if move the magnet and loop becomes stationary, then it is observed that results will be same.

CONCLUSION

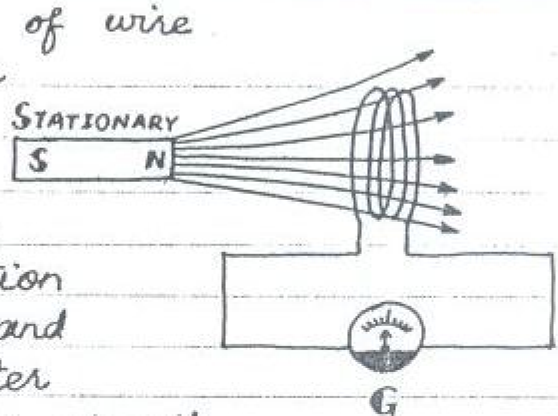
It is experimentally observed that the induced emf is produced due to the relative motion of the loop and the magnet. Actually, the relative motion changes the magnetic flux through the loop. So, it can be concluded that the induced emf is produced in a loop whenever the magnetic flux through it changes. The greater the rate of change of magnetic flux, the larger is the induced emf.

DIFFERENT METHODS TO PRODUCE INDUCED EMF

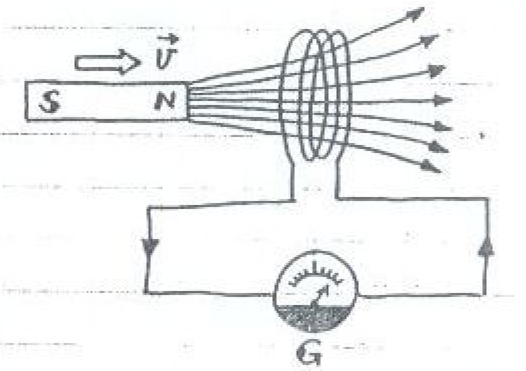
There are some methods described below to produce induced emf by changing magnetic flux through it.

1. DUE TO BAR MAGNET AND A COIL OF WIRE

Consider a coil of wire connected to a galvanometer and placed in the magnetic field of a bar magnet as shown in figure. When there is no relative motion between the bar magnet and the coil, the galvanometer shows no current in the circuit.



If we move the magnet towards the coil, then the magnetic flux through the coil changes and induced current is produced in the coil and galvanometer shows some deflection as shown in figure.



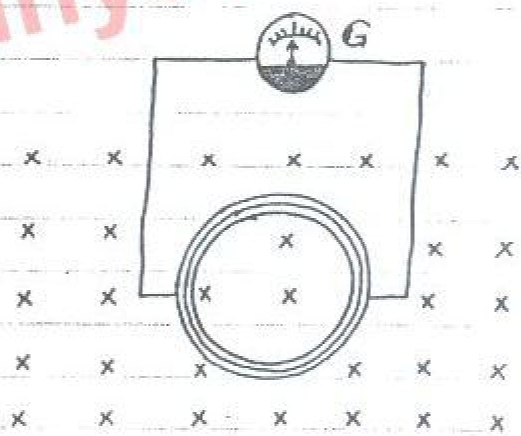
When the bar magnet moves away from the coil, then current is induced in the coil but in opposite direction.

The current can also be induced by keeping the magnet stationary and moving the coil.

2. Due To Changing The Area Of The Coil

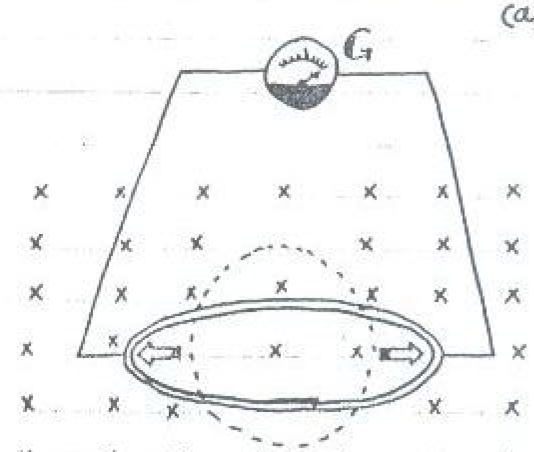
Induced current can be produced by changing the area of the coil in a constant magnetic field.

Figure (a) shows that no induced current is produced in the coil of constant area placed in a constant magnetic field.



(a)

Figure (b) shows that when the area of the coil is reduced by distorting the coil, then an induced current is produced in the same coil which can be shown by the deflection of the galvanometer. No current will be produced if area of coil is no longer changing. Now if the distorted coil is brought to its original

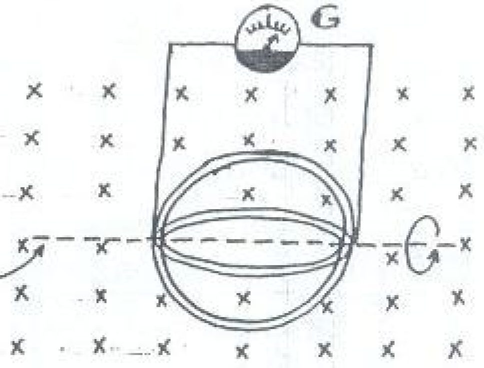


(b)

circular shape, then its area increases and again current is induced in opposite direction which lasts as long as the area is changing.

3. Due To Rotating A Coil Of Constant Area

When a coil is rotated in a uniform magnetic field, then due to change in flux through the coil, current will be induced in it. This is the basic principle of electric generators.



4. Mutual Induction

Consider two coils P and S placed side by side as shown in figure (a). The coil P is connected in series with a battery, a rheostat and a switch, while the coil S is connected with a sensitive galvanometer only.

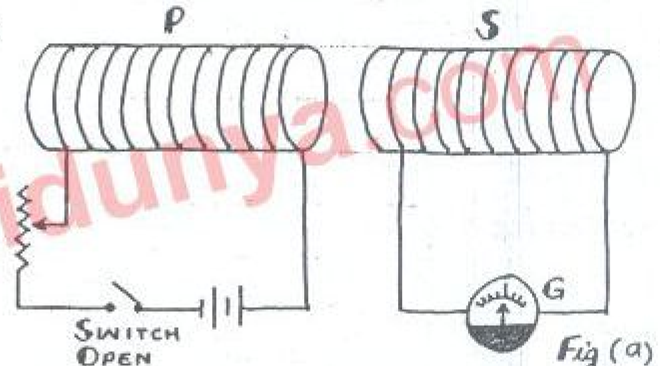


Fig (a)

When switch is open, then there is no current in both the coils and galvanometer shows no deflection. When switch is closed, the current in coil P increases from zero to maximum value and due to change in flux through coil S, current is induced in coil S for an instant. When the current in coil P reaches its maximum or steady value, then no current is

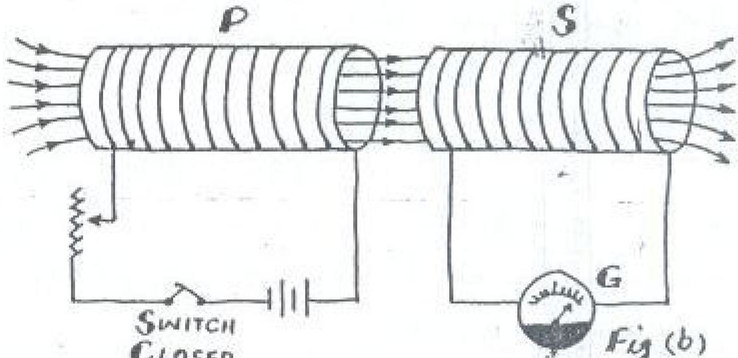


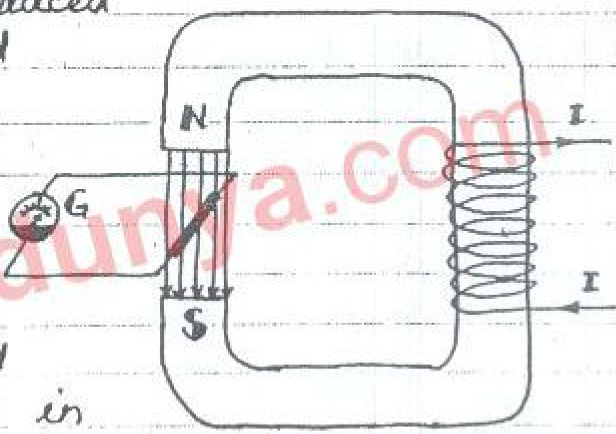
Fig (b)

is induced in coil S. Similarly, when switch is opened, then the current in coil P decreases from maximum to zero value, then magnetic flux through coil S suddenly decreased and an induced current is again produced in coil S for an instant in opposite direction. This is indicated by the galvanometer which suddenly deflects and then returns to zero. Current in the coil P can also be changed with the help of rheostat.

Such process is known as mutual induction.

5. Due To Electromagnet And A Coil

Consider a coil is placed in an electromagnet field as shown in figure. When the current in the electromagnet is changed, then the magnetic flux through the coil is also changed and current is induced in the coil which can be shown by the deflection of the galvanometer while the coil and electromagnet both are at rest.



Motional EMF

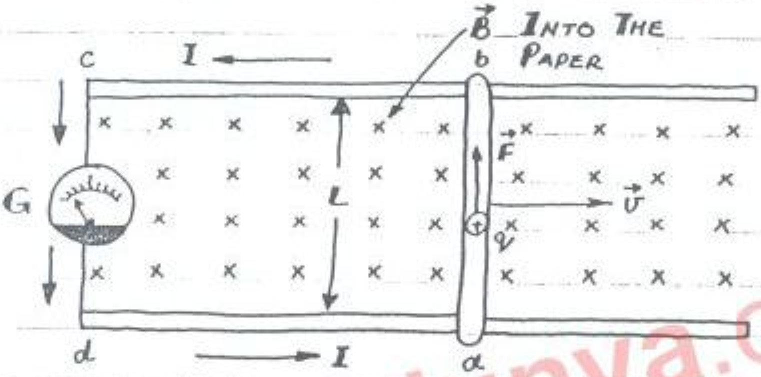
The emf induced by the motion of a conductor across a magnetic field is called motional emf. It is denoted by $\mathcal{E}$.

Explanation

When a conductor is moved across a magnetic field, emf will be induced between its ends. The emf induced in the moving conductor is similar to that of a battery whose ends are connected with a conductor by a wire to make a closed circuit, then a current flows through it.

Derivation Of Motiona EMF

Consider a conducting rod ab of length 'L' placed on two parallel conducting metal rails separated by a distance 'L'. A sensitive galvanometer is connected between ends c and d of the rails. So, it form a closed conducting loop abcd as shown in figure. A uniform magnetic field $\vec{B}$ is applied which is directed into the paper.



Initially, when the rod is stationary, then the galvanometer shows no current in the loop abcd. If the rod is moved towards right with constant velocity $\vec{v}$, the galvanometer shows some deflection i-e; current flowing through the loop abcd. Thus the current is induced due to the motion of the conducting rod across the magnetic field. So, the moving rod is acting as a source of emf $\mathcal{E}$ given as

$$\mathcal{E} = \Delta V = V_a - V_b$$

Where

V_a = Higher potential at point a.

V_b = Lower potential at point b.

ΔV = Potential difference between a and b.

When the rod moves over the conducting rails, then a charge q within the rod also moves with the same velocity $\vec{v}$ as that of the rod in the magnetic field $\vec{B}$ and it experiences a force as

$$\vec{F} = q(\vec{v} \times \vec{B}) = qvB\sin\theta \cdot \hat{n}$$

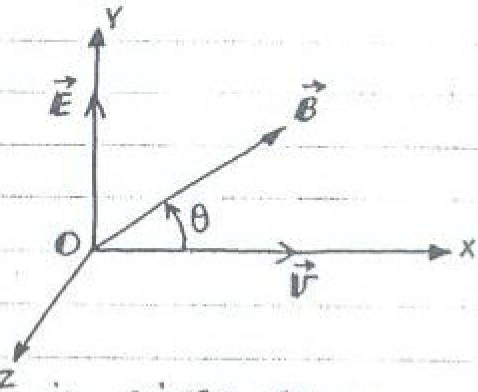
The magnitude of force is

$$F = qvB\sin\theta$$

Where θ is the angle between $\vec{v}$ and $\vec{B}$. As, $\vec{v}$ and $\vec{B}$ are perpendicular, so $\theta = 90^\circ$

$$\therefore \quad F = qvB\sin 90^\circ = qvB(1)$$

$$\text{or} \quad F = qvB \longrightarrow (1)$$



According to right hand rule, the force $\vec{F}$ is directed from a to b in the rod and current begins to flow from a to b. So, a uniform electric field $\vec{E}$ is induced along the rod as shown in figure. Its magnitude is given as

$$E = \frac{F}{q}$$

Put value of F from equation (1)

$$E = \frac{qvB}{q}$$

$$\text{or} \quad E = vB \longrightarrow (2)$$

As we know that electric intensity is negative potential gradient, so

$$E = -\frac{\Delta V}{\Delta r}.$$

Where, $\Delta V = \mathcal{E}$ = Potential difference between a and b.
$\Delta r = L$ = Length of the rod from a to b.

$$\therefore \quad E = -\frac{\mathcal{E}}{L} \longrightarrow (3)$$

Comparing equation (2) and (3)

$$-\frac{\mathcal{E}}{L} = vB$$

$$\text{or} \quad \boxed{\mathcal{E} = -vBL} \longrightarrow (4)$$

This is the magnitude of motional emf when $\vec{v}$ and $\vec{B}$ are perpendicular to each other i.e; $\theta = 90^\circ$.

Now, the motional emf when angle between $\vec{v}$ and $\vec{B}$ is θ given as

$$\boxed{\mathcal{E} = vBL\sin\theta} \longrightarrow (5)$$

This equation shows that when rod is stationary, then $v = 0$, so $\mathcal{E} = 0$. Hence, no emf is induced if rod is stationary.

FACTORS AFFECTING MOTIONAL emf

Motional emf depends upon

(i) Speed of the rod.

(ii) Length of the rod.

(iii) Magnetic field strength.

(iv) Angle between $\vec{v}$ and $\vec{B}$.

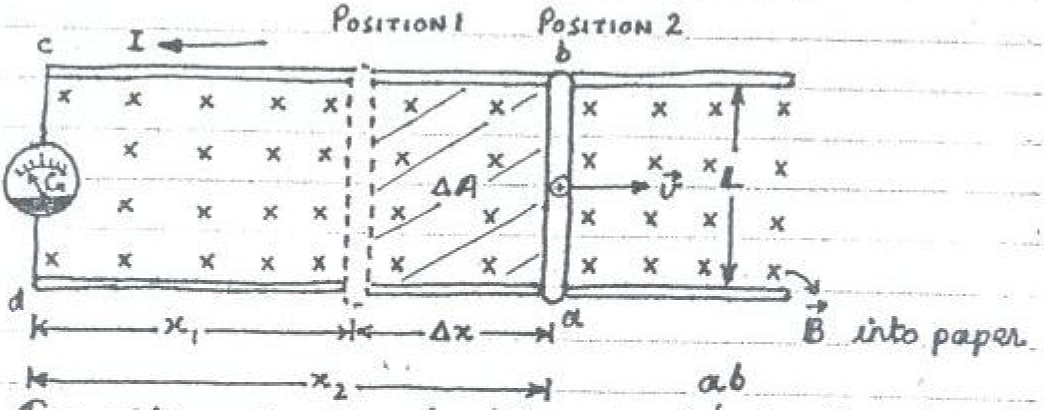
FARADAY'S LAW

The average emf induced in a conducting coil of N loops or turns is equal to the negative of the time rate of change of magnetic flux through the coil.

This statement is known as Faraday's Law.

$$\text{emf Induced} = \mathcal{E} = -N\frac{\Delta\phi}{\Delta t}$$

DERIVATION



Consider a conducting rod L of length L placed over two conducting rails. The ends c and d are connected with a galvanometer as shown in figure. Let the conducting rod is moving from position 1 to position 2 in a small time interval Δt and cover a distance Δx given as

$$\Delta x = x_2 - x_1$$

The conducting rod is moving with constant velocity v given as

$$v = \frac{\Delta x}{\Delta t} \longrightarrow ①$$

As motional emf induced in a rod moving perpendicular to the magnetic field $\vec{B}$ is

$$\mathcal{E} = -vBL$$

Put value of v from equation ①

$$\mathcal{E} = -\frac{\Delta x}{\Delta t} BL$$

$$\mathcal{E} = -\frac{B(\Delta x . L)}{\Delta t} \longrightarrow ②$$

When the rod moves through a distance Δx, then area of loop abcd increases by ΔA given as

$$\Delta A = \Delta x . L$$

As, magnetic flux $\phi = BA$, so if area A increases by ΔA, then magnetic flux increases by $\Delta\phi$ given as

$$\Delta\phi = B\Delta A \qquad (\because \Delta A = \Delta x . L)$$

or $\Delta\phi = B(\Delta x . L)$

Put this value in equation ②, we get

$$\mathcal{E} = -\frac{\Delta\phi}{\Delta t}$$

If coil consists of N no. of loops, then the induced emf is

$$\boxed{\mathcal{E} = -N\frac{\Delta\phi}{\Delta t}} \longrightarrow ③$$

As this expression is derived by using motional emf but it is true in general for all types of induced emf. This result was first noted by Faraday so this is known as Faraday's law.

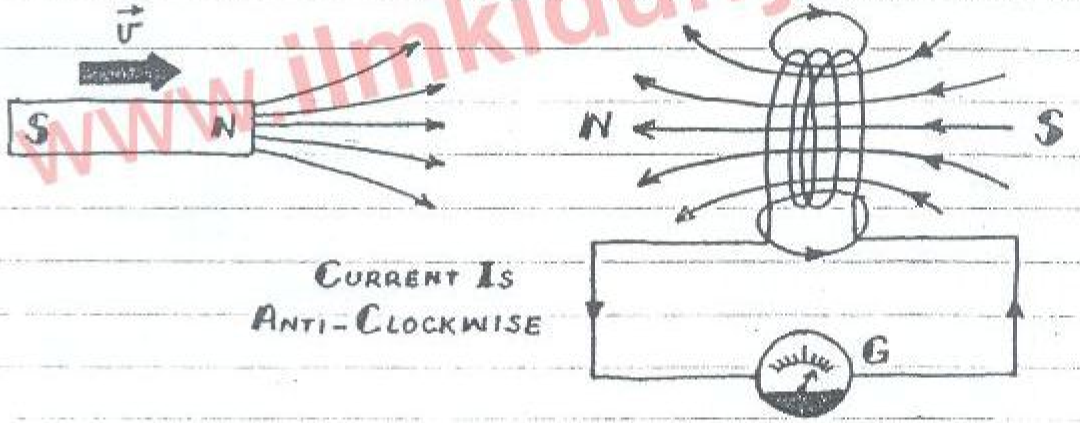
The negative sign in the expression shows that the direction of induced emf is such that it always opposes the cause which produces it:

LENZ'S LAW

STATEMENT: "The direction of induced current is always so as to oppose the change which causes the current."

EXPLANATION

Let us apply Lenz's law to the coil in which current is induced by the movement of a bar magnet. We know that when the induced current flows in the coil, then it produces a magnetic field similar to that of a bar magnet. One face of the coil acts as the north pole while the other face acts as the south pole as shown.



According to Lenz's law, the magnetic field produced by the induced current in the coil is such that it opposes the motion of the bar magnet, so the face of the coil towards the bar magnet must be a north pole as shown in figure. Thus, the two north poles now repel each other. If right hand rule is applied to the coil, then it is observed that the induced current must be anti-clockwise in this case.

According to Lenz's law, the "PUSH" of the magnet is the change that produces the induced current, and the current acts to oppose the push. On the other hand if we pull the magnet away from the coil, the induced current will oppose the "PULL" by creating a south pole on the face of the coil towards the bar magnet.

LENZ'S LAW AND LAW OF CONSERVATION OF ENERGY

Lenz's law is according to law of conservation of energy.

In order to understand this, consider a rod of length L which is moving over two conducting rails in a magnetic field directed into the paper as shown in figure (a). When rod is moved towards right, then an emf induced in it and an induced current flows through the loop in anti-clockwise direction. As conducting rod is moving in the magnetic field, so it experiences a magnetic force $\vec{F}_m$ whose magnitude is

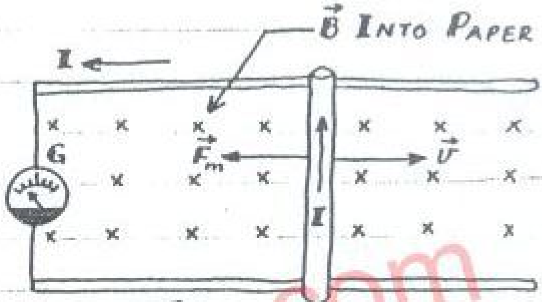


Fig (a)

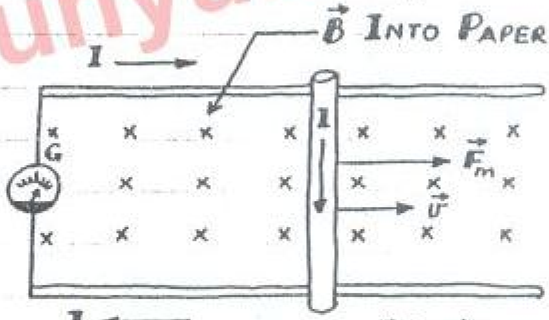


Fig (b)

$$F_m = ILB \sin\theta \qquad (\because \theta = 90^\circ)$$

$$F_m = ILB \sin 90^\circ = ILB(1)$$

$$F_m = ILB$$

According to Right hand rule, if we rotate $\vec{L}$ or I towards $\vec{B}$, it should be noted that the direction of magnetic force $\vec{F}_m$ is opposite to that of $\vec{v}$. So this force tends to stop the rod as shown in figure (a). This in order to move the rod on the rails, an external force equal to F_m in magnitude but opposite in direction must be applied to the rod. This force provides energy for the induced current to flow through the rod. So, this energy is the source of induced current. Thus, electromagnetic induction is exactly according to law of conservation of energy.

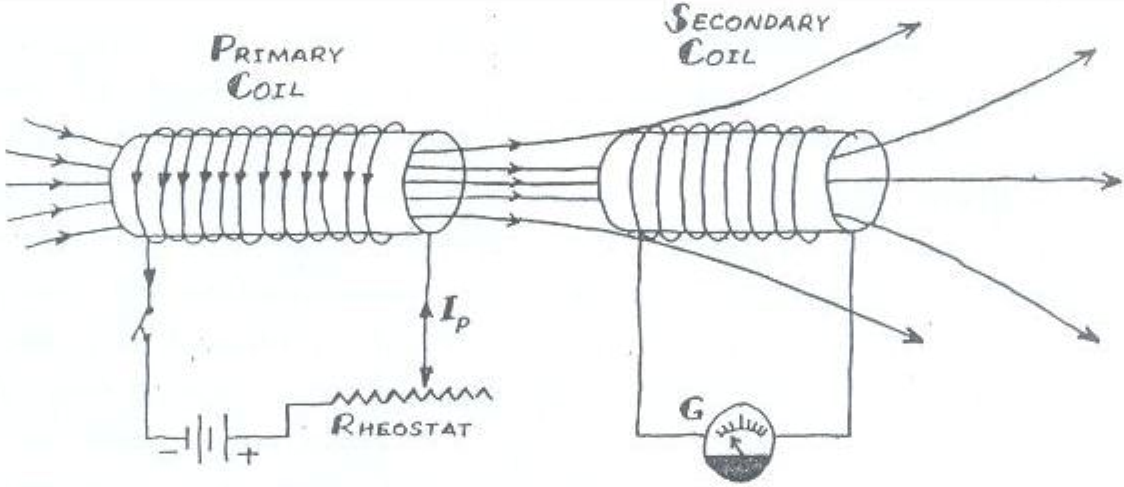
If the direction of current induced in the loop is clockwise as shown in figure(b), then according to right hand rule, the magnetic force $\vec{F}_m$ will be along $\vec{v}$ and so the velocity of rod will be increased. As, $\vec{v}$ increases, I also increases which increases $\vec{B}$ and hence the magnetic force $\vec{F}_m = I(\vec{L} \times \vec{B})$ will also be increased. This increases the velocity of the rod further and this process will continue forever. It means that the system starting with a very small energy and attain K.E. which will go on increasing forever i.e; energy is being created, which is against the law of conservation of energy.

MUTUAL INDUCTION

The phenomenon in which a changing current in one coil induces an emf in the other coil is called mutual induction.

EXPLANATION

Consider two coils placed very close to each other as shown in figure. One coil is connected with a battery through a switch and a rheostat, called Primary Coil. The other coil is connected with a galvanometer, called Secondary Coil. If the current in the primary coil is changed by varying the resistance of the rheostat, then the magnetic flux in the surrounding space changes. As the secondary coil is in the magnetic field of primary coil, so the changing flux also links with the secondary coil which produces an induced emf in the secondary coil.



MATHEMATICAL DERIVATION

According to Faraday's law, the emf induced in the secondary coil is

$$\mathcal{E}_s = -N_s \frac{\Delta \phi_s}{\Delta t} \longrightarrow (1)$$

Where

$\mathcal{E}_s$ = emf induced in the secondary coil.

$\Delta\phi_s/\Delta t$ = Rate of change of flux through secondary coil.

N_s = Number of turns in the secondary coil.

Let ϕ_s is the flux through one loop of the secondary coil. If N_s is total number of loops of the secondary coil, then total flux through N_s loops is $N_s \phi_s$. As this flux is proportional to the magnetic field produced by the current I_p in the primary and magnetic field itself proportional to I_p, so

$$N_s \phi_s \propto B \quad \text{and} \quad B \propto I_p$$

$$\Rightarrow \quad N_s \phi_s \propto I_p$$

$$\Rightarrow \quad N_s \phi_s = (\text{Constant})\, I_p$$

$$\Rightarrow \quad N_s \phi_s = M I_p \longrightarrow (2)$$

$$\text{or} \quad M = \frac{N_s \phi_s}{I_p}$$

Where M is proportionality constant, called the mutual inductance of the two coils. Mutual inductance depends upon following factors.

(i) Number of turns of both coils.
(ii) Area of cross-section of both coils.
(iii) Separation between two coils.
(iv) Nature of the core material upon which the two coils are wound.

According to Faraday's law, the emf induced in the secondary coil is given by the rate of change of flux through the secondary coil as (from eq. 1)

$$\mathcal{E}_S = -N_S \frac{\Delta \Phi_S}{\Delta t}$$

or

$$\mathcal{E}_S = -\frac{\Delta (N_S \Phi_S)}{\Delta t}$$

From eq. 2 $N_S \Phi_S = M I_P$

$$\therefore \quad \mathcal{E}_S = -\frac{\Delta (M I_P)}{\Delta t}$$

or

$$\boxed{\mathcal{E}_S = -M \frac{\Delta I_P}{\Delta t}} \longrightarrow 3$$

This equation shows that the emf induced in the secondary coil is directly proportional to the time rate of change of current in the primary. The negative sign shows that the emf induced in the secondary coil is in such a direction as to oppose the change of current in the primary coil.

MUTUAL INDUCTANCE

From equation 3, M can be written as

$$\boxed{M = \frac{\mathcal{E}_S}{\Delta I_P / \Delta t}} \longrightarrow 4$$

So, <u>mutual inductance is defined as</u>
"The ratio of the average emf induced in the secondary coil to the time rate of change of current in the primary coil."

UNITS OF MUTUAL INDUCTANCE

The SI-units of mutual inductance M is henry (H) given as

$$H = \frac{\text{volt}}{A/s} = \text{volt} \cdot A^{-1} s$$

HENRY

The mutual inductance of the pair of coils is said to be one henry if a rate of change of current of one ampere per second in the primary causes an induced emf of one volt in the secondary.

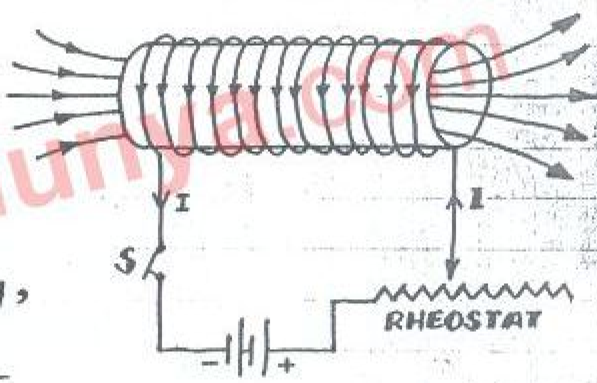
SELF INDUCTION

The phenomenon in which a changing current in a coil induces an emf in itself is called self induction.

EXPLANATION

Consider a coil is connected in series with a battery and a rheostat through a switch as shown in figure.

When current **I** is flowing through the coil, then the magnetic flux is passing through the coil. If the current is changed by varying the rheostat quickly, then magnetic flux through the coil also changes that causes an induced emf in the coil. Such an emf induced is called as self induction.



MATHEMATICAL DERIVATION

Let

Number of turns of the coil $= N$

Flux through one loop of the coil $= \phi$

Flux through N loops of the coil $= N\phi$

As, flux ϕ is proportional to the magnetic field which is proportional to the current **I** in the coil, so

$$N\phi \propto I$$

or $$N\phi = (\text{Constant})\, I$$

or $$N\phi = LI \longrightarrow (1)$$

or $L = \frac{N\phi}{I}$

Where L is the constant of proportionality, called the self inductance. Its value depends upon

(i) Number of turns of the coil.
(ii) Area of cross-section of the coil.
(iii) Nature of the material of the core of coil.

According to Faraday's law, the emf induced in the coil is

$$\mathcal{E}_L = -N\frac{\Delta\phi}{\Delta t}$$

or $$\mathcal{E}_L = -\frac{\Delta(N\phi)}{\Delta t} \qquad \text{(As } N \text{ is constant)}$$

Put value of $N\phi = LI$ from equation ①

$$\therefore \quad \mathcal{E}_L = -\frac{\Delta(LI)}{\Delta t} \qquad (\because L \text{ is constant})$$

or $$\boxed{\mathcal{E}_L = -L\frac{\Delta I}{\Delta t}} \longrightarrow ②$$

This equation shows that the self inductance in a coil is proportional to the time rate of change of current in the coil.

It should be noted that by winding the coil around a ferromagnetic core (soft iron core), the magnetic flux and hence the inductance can be increased significantly relative to that of an air core.

Self Inductance

From equation ②, we have

$$\boxed{L = \frac{\mathcal{E}_L}{\Delta I/\Delta t}} \longrightarrow ③$$

Self inductance L may be defined as

"The ratio of the average induced emf in the coil to the rate of change of current in the coil."

Units Of Self Inductance

The SI-units of self inductance is henry (H).

$$1\,\text{henry (H)} = \frac{1\,\text{volt}}{1\,\text{ampere/second}} = V \cdot A^{-1} \cdot s$$

HENRY

The self inductance in a coil is said to be one henry if current in the coil is changing at the rate of one ampere per second produces an emf of one volt in the same coil.

BACK EMF

The relation of self induced emf is

$$\mathcal{E}_L = -L\frac{\Delta I}{\Delta t}$$

The negative sign in this equation shows that self induced emf must oppose the change that produces it. That is why, self induced emf is sometimes called as back emf. If current is increased in the coil, then the induced emf will be opposite to that of battery and if current is decreased, then the self induced emf will be in the same direction as that of battery. This is exactly in according with the Lenz's law.

INDUCTORS

The coils of wire due to their self inductance are known as inductors. Inductors are widely used in electronics. In case of alternating current, inductors behave like resistors.

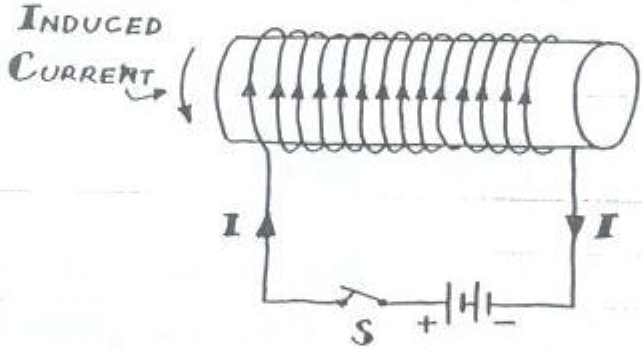
ENERGY STORED IN AN INDUCTOR

As we know that energy can be stored in an electric field between the plates of a capacitor. Similarly, energy can be stored in the magnetic field of an inductor.

DERIVATION OF FORMULA

CASE (i) IN TERMS OF CURRENT

Consider a coil connected to a battery and a switch S in series as shown in figure.



When the switch S is closed, then voltage V is applied across the ends of the coil and current through it rises from zero to its maximum value I. Due to change of current, an emf is induced which is opposite to that of battery. Work is done by the battery to move charges against the induced emf.

Consider a small charge Δq, then the work done by the battery in moving charge Δq is

$$\Delta W = \Delta q \cdot \mathcal{E}_L \longrightarrow (1)$$

Where $\mathcal{E}_L$ is the magnitude of induced emf, given by

$$\mathcal{E}_L = L\frac{\Delta I}{\Delta t} \longrightarrow (2)$$

Where $\frac{\Delta I}{\Delta t}$ = Rate of change of current.
L = Self inductance of coil.

Put value of $\mathcal{E}_L$ from equation (2) in eq. (1)

$$\Delta W = \Delta q \cdot L\frac{\Delta I}{\Delta t}$$

or $$\Delta W = \frac{\Delta q}{\Delta t} \cdot L\,\Delta I \longrightarrow (3)$$

So, total work done is found by putting the values of $\Delta q/\Delta t$ and ΔI. Where

ΔI = Change in current
$\Delta q/\Delta t$ = Average current

Now,

$$\text{Average current} = \frac{\Delta q}{\Delta t} = \frac{I_i + I_f}{2} = \frac{0 + I}{2} = \frac{I}{2}$$

$$\Delta I = I - 0 = I$$

Put these values in equation ③

$$\Delta W = \frac{I}{2} \cdot L \cdot I$$

or $$\boxed{\Delta W = \frac{1}{2} L I^2}$$

This work is stored as potential energy in the inductor. Hence, the P.E. U_m stored in an inductor is

$$\boxed{U_m = \frac{1}{2} L I^2} \longrightarrow ④$$

Case (ii) Energy Stored Interms Of In Terms Of Magnetic Field

As in case of a capacitor, energy is stored in the electric field between the plates. Similarly, energy stored in an inductor in the magnetic field. So, equation ④ can be expressed in terms of the magnetic field B.

Consider a solenoid having 'n' no. of turns per unit area and area of cross-section 'A'. When current I is passed through it, then magnetic field is produced inside the solenoid. The magnetic field strength inside the solenoid is

$$B = \mu_o n I$$

Where μ_o is permiability of free space.

Now, the magnetic flux through the coil is

$$\phi = BA$$

or $$\phi = \mu_o n I A \longrightarrow ⑤ \quad (\because B = \mu_o n I)$$

We know that for a solenoid

$$LI = N\phi$$

or $$L = N\phi / I$$

Put value of ϕ from equation ⑤

$$L = \frac{N \mu_o n I A}{I}$$

or $$L = \mu_o n N A \longrightarrow ⑥$$

Let, No. of turns of solenoid $= N$

Length of the solenoid $= l$

No. of turns per unit length $= n = N/l$

$$\Rightarrow \quad N = nl$$

Put $N = nl$ in equation ⑥

$$\therefore \quad L = \mu_o n N A = \mu_o n (nl) A$$

$$\text{or} \quad L = \mu_o n^2 A l$$

Put this value in equation ④

$$\therefore \quad U_m = \frac{1}{2} L I^2 = \frac{1}{2} (\mu_o n^2 A l) I^2 \longrightarrow ⑦$$

For solenoid, $B = \mu_o n I$

$$\Rightarrow \quad I = B/\mu_o n$$

Put this value in equation ⑦

$$\therefore \quad U_m = \frac{1}{2} (\mu_o n^2 A l) \left(\frac{B}{\mu_o n}\right)^2$$

$$\text{or} \quad U_m = \frac{1}{2} (\mu_o n^2 A l) \left(\frac{B^2}{\mu_o^2 n^2}\right)$$

$$\text{or} \quad \boxed{U_m = \frac{1}{2} \frac{B^2}{\mu_o} (A l)} \longrightarrow ⑧$$

Which is the P.E. interms of magnetic field.

ENERGY DENSITY

The energy stored per unit volume inside a solenoid is called energy density. (u_m).

$$\text{Energy Density} = \frac{\text{Energy stored}}{\text{Volume}}$$

$$\text{or} \quad u_m = \frac{U_m}{A l}$$

$$\text{or} \quad u_m = \frac{\frac{1}{2} \frac{B^2}{\mu_o} (A l)}{A l}$$

$$\text{or} \quad \boxed{u_m = \frac{1}{2} \cdot \frac{B^2}{\mu_o}}$$

Alternating Current Generator or A.C. Generator

A device which is used to convert mechanical energy into electrical energy is called current generator or A.C. generator.

Principle

The principle of an electric generator is based on Faraday's law of electromagnetic induction. When a coil is rotated in a magnetic field by some mechanical means, magnetic flux through the coil changes and hence an emf is induced in the coil.

Generator Output

If the generator is connected to an external circuit, an electric current is the output of the generator.

Construction Of A.C. Generator

The main parts of an A.C. generator are

(i) Coil or Armature
(ii) Field Magnet
(iii) Slip Rings
(iv) Carbon Brushes

Coil

An A.C. generator consists of a rectangular coil abcda of area A placed in a uniform magnetic field B. The coil is rotated about z-axis through its centre at constant angular velocity ω.

Field Magnet

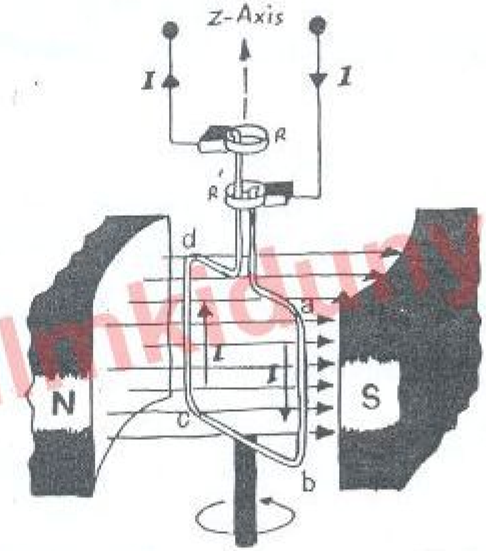
The rectangular coil is placed in a uniform magnetic field which is produced by a permanent magnet, called field magnet. The pole pieces of the magnet are made concave, so that it produces a strong uniform magnetic field.

Slip Rings

One end of the coil is attached to a metal ring R and the other end to a ring R'. These rings are called the slip rings. The centres of slip rings are concentric with the axis of the coil and rotate with it.

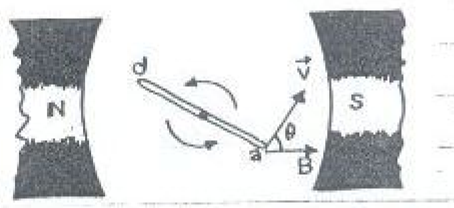
Carbon Brushes

Slip rings R and R' are slided against stationary carbon brushes. The external circuit is connected with the carbon brushes.



Expression For Alternating EMF

To calculate the relation for induced emf produced in an A.C. generator, consider a rectangular loop of area A placed in a uniform magnetic field of strength $\vec{B}$. Let the loop is rotated about Z-axis in anti-clockwise direction with constant angular velocity ω as shown in figure.



Consider the position of the loop while it is rotating in anti-clockwise direction as shown.

Let the vertical side ab of the loop is moving with velocity $\vec{v}$ in the magnetic field $\vec{B}$. If the angle between $\vec{v}$ and $\vec{B}$ is θ, then the motional emf induced in the side ab has the magnitude

$$\mathcal{E}_{ab} = vBL\sin\theta$$

Where L is the length of the side ab or cd. The direction of induced current in the side ab is same as that of magnetic force $\vec{F}$ experienced by the positive charges in the side ab i-e; from top to the bottom. The same amount of emf is induced in the side cd but the direction of current is from bottom to the top. So

$$\mathcal{E}_{cd} = vBL\sin\theta$$

The motional emf's induced in sides bc and da are zero because the force acting on the charges inside bc and da are not along the wire according to the right hand rule. So

$$\mathcal{E}_{bc} = \mathcal{E}_{da} = 0$$

As both the emf's in sides ab and cd drive current in the same direction around the loop, therefore the total emf $\mathcal{E}$ in the loop is

$$\mathcal{E} = \mathcal{E}_{ab} + \mathcal{E}_{cd}$$

or $$\mathcal{E} = vBL\sin\theta + vBL\sin\theta$$

or $$\mathcal{E} = 2vBL\sin\theta$$

If the loop is replaced by a coil of N turn then the total emf in the coil is

$$\mathcal{E} = N(2vBL\sin\theta)$$

or $$\mathcal{E} = 2NvBL\sin\theta \longrightarrow (1)$$

If v is the linear speed of the vertical wire and ω is the angular speed, then

$$v = r\omega$$

Put this value in equation (1)

$$\mathcal{E} = 2N(r\omega)BL\sin\theta$$

or $$\mathcal{E} = N\omega(2rL)B\sin\theta \longrightarrow (2)$$

Where r is the radius of circle of rotation of coil and is equal to the distance of the vertical wire from the centre of the coil as shown in figure.

Also

$$2rL = A = \text{Area of the coil}$$

Put this value in equation (2)

$$\therefore \quad \mathcal{E} = N\omega AB\sin\theta \longrightarrow (3)$$

As the angular displacement $\theta = \omega t$, so the equation (3) becomes as

$$\mathcal{E} = N\omega AB\sin(\omega t) \longrightarrow (4)$$

This equation shows that the induced emf varies sinusoidally with time. The induced emf $\mathcal{E}$ has maximum value when

$$\sin(\omega t) = 1, \text{ so } \mathcal{E} = \mathcal{E}_o = \text{Maximum emf}$$

So equation (4) becomes as

$$\mathcal{E}_o = N\omega AB(1)$$

or $$\mathcal{E}_o = N\omega AB \longrightarrow (5)$$

Put $\mathcal{E}_o = N\omega AB$ in equation (4), we have

$$\boxed{\mathcal{E} = \mathcal{E}_o\sin(\omega t)} \longrightarrow (6)$$

The angular speed ω of the coil is related to its frequency of rotation f as

$$\omega = 2\pi f$$

So equation (6) can be written as

$$\boxed{\mathcal{E} = \mathcal{E}_o\sin(2\pi f t)} \longrightarrow (7)$$

Relation For Induced Current

If the resistance of the coil is R, then the induced current in the coil is given by using Ohm's law as

$$\mathcal{E} = IR \quad \Rightarrow \quad I = \mathcal{E}/R$$

$$\Rightarrow \quad I = \frac{\mathcal{E}_o}{R} \cdot \sin(\omega t) \qquad (\because \mathcal{E} = \mathcal{E}_o \sin(\omega t))$$

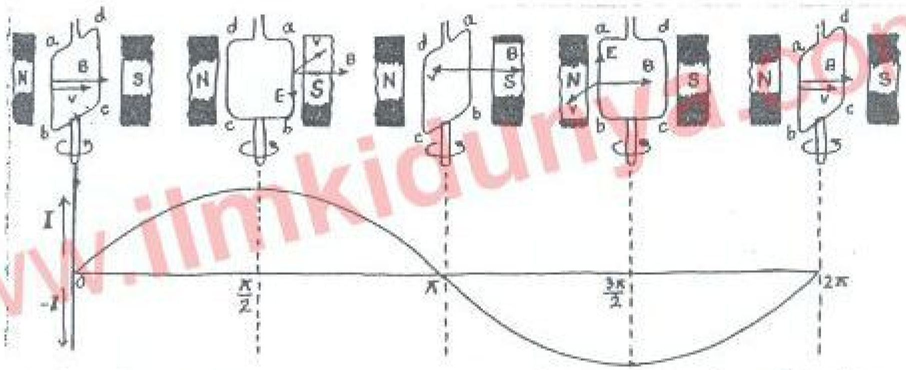
Where $\frac{\mathcal{E}_o}{R} = I_o$ = Maximum current

$$\therefore \quad \boxed{I = I_o \sin(\omega t)} \qquad (\because \omega = 2\pi f)$$

$$\text{or} \quad \boxed{I = I_o \sin(2\pi f t)} \longrightarrow (8)$$

VARIATION OF CURRENT WITH θ

The variation of current for the different positions of one loop of the coil is shown in the graph drawn below.



(i) When the angle between $\vec{v}$ and $\vec{B}$ is $\theta = 0°$, then the plane of the loop abcda is perpendicular to $\vec{B}$ and current $I = I_o \sin\theta = 0$. $(\because \sin 0° = 0)$

(ii) As θ increases, current also increases and at $\theta = 90°$ or $\pi/2$ rad, the loop is parallel to $\vec{B}$ and current is maximum i-e;

$$I = I_o \sin\theta = I_o \sin 90° = I_o$$

Its direction is along abcda.

(iii) If θ further increases $(90° < \theta < 180°)$, then current decreases and at $\theta = 180°$ or π rad, the current becomes zero as the loop is again perpendicular to $\vec{B}$.

i-e; $\quad I = I_o \sin\theta = I_o \sin 180° = 0$

(iv) For $180° < \theta < 270°$, current increases but reverses its direction and current is now directed along dcbad as shown in figure. At $\theta = 270°$ or $\frac{3\pi}{2}$ rad, current is maximum in the reverse direction as the loop is parallel to $\vec{B}$. i-e;

$$I = I_o \sin\theta = I_o \sin 270° = -I_o$$

(v) At $\theta = 360°$ or 2π rad, one rotation of the loop is completed and the current decreases to zero as the loop is perpendicular to $\vec{B}$. i-e;

$$I = I \sin\theta = I_o \sin 360° = 0$$

After one rotation, the cycle repeats itself. As the current alternates once in one cycle, so such a current is called alternating current which reverses its direction f times in one second.

Armature And Electromagnet

In actual practice, a number of coils are wound around an iron core cylinder which is rotated in the magnetic field. This assembly is called an armature. The magnetic field is usually provided by an electromagnet. Armature is rotated by a fuel engine or a turbine run by a waterfall.

In some commercial generators, field magnet is rotated around a stationary armature.

D.C. Generator

A device used to produce the direct current is called D.C. generator.

Principle

Its principle is based on Faraday's law of electromagnetic induction i-e; when a coil is rotated in a magnetic field by some mechanical means, magnetic flux through the coil changes and hence an emf is induced in the coil.

Construction

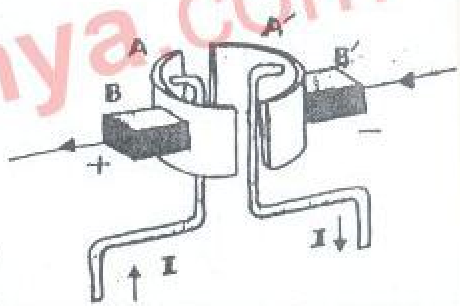
The construction of a D.C. generato is similar to the A.C. generator with the differe that **Slip Rings** are replaced by **Split Rings**.

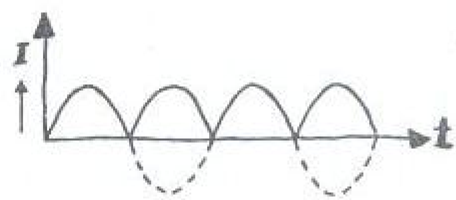
Split Rings or Commutator

In 1834, William Sturgeon invented a simple device, called a commutator that prevents the direction of current from changing. The split rings are two halves of a ring that act as a commutator. Figure shows the split rings A ana A′ attached to the two ends of the coil that rotates in the magnetic field.

Function Of Split Rings

When the current in the coil is zero and is about to change direction, the split rings also change the contacts with the carbon brushes BB′. Hence, the output from BB′ remains in the same direction, although the current is not constant in magnitude as shown in the curve.





Armature

The curve drawn between current I and time t is similar to a sine curve with the lower half inverted. The alternations of the output can be significantly reduced by using many coils rather than a single coil. Multiple coils are wound around a cylinder-ical core to form the armature. Each coil is connected to a separate commutator and the output of every coil is tapped only as it reaches its peak or maximum value. Hence, the emf in the outer circuit is almost constant.

BACK MOTOR EFFECT IN GENERATORS

A generator is the source of electricity production. It converts mechanical energy into electrical energy.

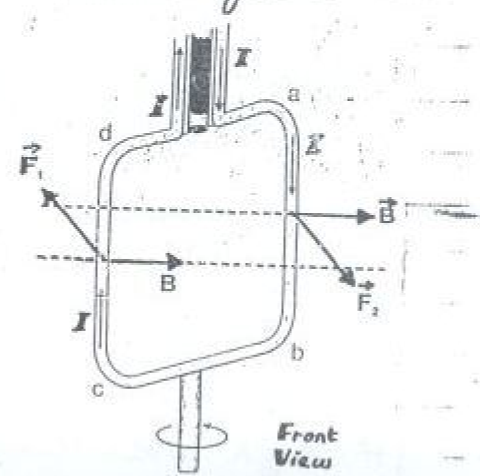
Practically, generators are not so simple. A large turbine is turned by high pressure steam or waterfall. The shaft of the turbine is attached to the coil of the generator which rotates in a magnetic field. It converts the mechanical energy of the driven turbine to electrical energy. The generator supplies current to the external circuit.

LOAD

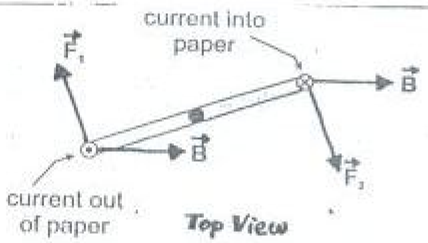
The devices in the circuit that consumes electrical energy are known as load.

The greater is the load, the larger the current is supplied by the generator. When the circuit is open, the generator does not supply electrical energy and a very small force is needed to rotate the coil. But when the circuit is closed, a current is drawn through the coil and the magnetic field exerts force on the current carrying coil.

Figure shows the forces acting on the coil. Force $\vec{F_1}$ is acting on the left side of the coil whereas an equal and opposite force $\vec{F_2}$ acts on the right side of the coil. These forces are such that



they produces a counter torque that opposes the rotational motion of the coil. This effect is sometimes referred as "Back Motor Effect in Generators".



The larger the current drawn, the greater is the counter torque produced. It means that more mechanical energy is required to keep the coil rotating with constant angular speed. This is in agreement with the law of conservation of energy. This energy consumed by the "load" must come from the "energy source" used to derive turbine.

D.C. MOTOR

A device which converts electrical energy into mechanical energy, called a motor.

PRINCIPLE

The basic principle of an electric motor is that when a current carrying conductor is placed in a magnetic field, it experiences a force.

CONSTRUCTION

The construction of a D.C. motor is similar to a D.C. generator, having

(i) Armature
(ii) Magnetic field
(iii) Commutator or Split ring, and
(iv) Carbon brushes

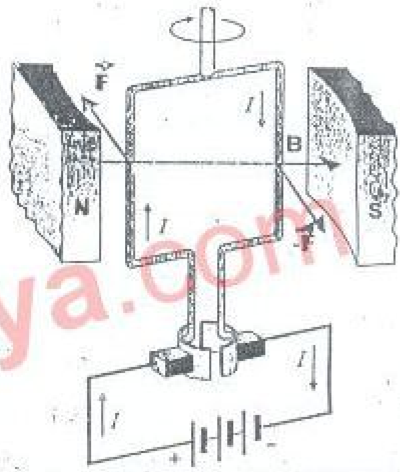
DIFFERENCE BETWEEN GENERATOR AND ELECTRIC MOTOR

In the generator, the armature is rotated in the magnetic field and current is the output. In the D.C, magnetic field and current is the output. In the D.C. motor, the brushes are connected to a D.C. supply or battery. When current flows through the armature coil, the force on conductor produces a torque, that rotates the armature. The amount of this torque depends upon

(i) The amount of current
(ii) The strength of magnetic field
(iii) The area of the coil, and
(iv) The number of turns of the coil.

FUNCTION OF D.C. MOTOR

If the current flowing in the coil were all the time in the same direction, then the torque act on it would be reversed after each half cycle. But at this moment, commutator reverses the direction of current that keeps the torque always in the same direction. A little problem arises due to the use of commutator, that is, the torque vanishes each time when the current changes its direction. This creates jerks in the smooth running of the armature. However, this problem is overcome by using more than one coils wrapped around a soft-iron core. This results in producing a more steady torque.



ELECTROMAGNET

The magnetic field in the motor is provided by a permanent magnet or an electromagnet. The windings of the electromagnet are usually called the field coils. The field coils may be in series or in parallel to the armature coils.

BACK EMF EFFECT IN MOTORS

A motor is similar to a generator running in reverse. When the coil of the motor rotates across the magnetic field by the applied potential difference V, an emf $\mathcal{E}$ is induced in it. The induced emf $\mathcal{E}$ is in such a direction to oppose the emf V running the motor. Due to this reason, the induced emf is called back emf of the motor.

As V and $\mathcal{E}$ are in opposite direction, the net emf in the circuit is $(V-\mathcal{E})$. If R is the resistance of the coil and I be the current drawn by the motor, then according to Ohm's law

$$I = \frac{V-\mathcal{E}}{R}$$

or $$V-\mathcal{E} = IR$$

or $$V = \mathcal{E} + IR$$

When the motor is just started, back emf is almost zero and hence a large current is passing through the coil. As the motor speeds up, the back emf increases and the current becomes smaller and smaller. However, the current is sufficient to provide torque on the coil to drive the load and to overcome losses due to friction.

OVERLOADING

If the motor is overloaded, it slows down. Hence, the back emf decreases and allows the motor to draw more current. If the motor is overloaded beyond the limits, the current could be so high that it may burn the motor out.

TRANSFORMER

An electrical device to change a given alternating emf into a larger or smaller alternating emf, called a transformer.

OR

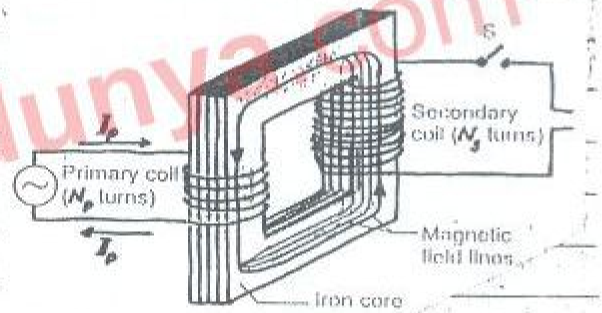
An electrical device used to step-up or step-down alternating emf, called a transformer.

PRINCIPLE

It works on the principle of mutual induction between two coils, that is, when flux through primary coil is changed, then an emf is induced in the secondary coil.

CONSTRUCTION

According to principle, the transformer consists of two coils of copper which are electrically insulated from each other, wound on the same iron-core. The coil to which A.C. power is supplied is called '**PRIMARY COIL**' and that coil from which power is delivered to the circuit is called the '**SECONDARY COIL**'.



WORKING

Let us consider that

N_P = Number of turns of primary coil.

N_S = Number of turns of secondary coil.

V_P = Voltage applied across primary coil.

V_S = Voltage or induced emf across secondary.

As, there is no electrical connection between the two coils but they are magnetically linked with each other. Consider that an alternating emf V_P is applied to the primary coil. If at some instant, the flux is changing in the primary coil at the rate of $\Delta\phi/\Delta t$, then there will be back emf induced in the primary which will oppose the applied voltage. Hence, the instantaneous value of the self induced emf is

$$\text{Self Induced emf} = -N_P\left[\frac{\Delta\phi}{\Delta t}\right]$$

If the resistance of the coil is negligible, then the back emf is equal and opposite to the applied voltage V_P, so

$$V_P = -(\text{Back or Self Induced emf})$$

or $$V_P = -\left(-N_P\left[\frac{\Delta\phi}{\Delta t}\right]\right)$$

or $$V_P = N_P\left[\frac{\Delta\phi}{\Delta t}\right] \longrightarrow (1)$$

Consider that the flux through the primary also passes through the secondary. If the two coils are tightly coupled, then the rate of change of flux in the secondary will also be $\Delta\phi/\Delta t$ and magnitud of the induced emf across the secondary is

$$V_S = N_S\left[\frac{\Delta\phi}{\Delta t}\right] \longrightarrow (2)$$

Dividing equation (2) by (1)

$$\frac{V_S}{V_P} = \frac{N_S\left[\frac{\Delta\phi}{\Delta t}\right]}{N_P\left[\frac{\Delta\phi}{\Delta t}\right]}$$

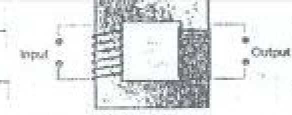
or $$\boxed{\frac{V_S}{V_P} = \frac{N_S}{N_P}} \longrightarrow (3)$$

This equation is known as transformer equation. This equation is also known as mathematical principle of transformer.

TYPES OF TRANSFOMER

There are two types of transformer

STEP-UP TRANSFORMER

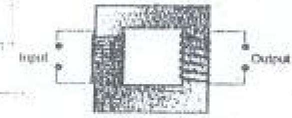


Step up transformer

If $\quad N_S > N_P$
then $\quad V_S > V_P$

Such a transformer in which voltage across secondary is greater than the primary voltage, is called a step-up transformer.

STEP-DOWN TRANSFORMER



Step down transformer

If $\quad N_S < N_P$
then $\quad V_S < V_P$

Such a transformer in which voltage across secondary is less than the primary voltage, is called a step-down transformer.

POWER TRANSFORMATION IN TRANSFORMER

In a transformer, the electrical power is transferred from its primary to the secondary coil by means of changing flux.

PRINCIPLE OF ELECTRIC SUPPLY NETWORK IN TRANSFORMER

For an ideal transformer, the power input to the primary is nearly equal to the power output from the secondary i-e;

POWER INPUT = POWER OUTPUT

$$\Rightarrow \quad V_P I_P = V_S I_S$$

$$\Rightarrow \quad \frac{I_P}{I_S} = \frac{V_S}{V_P}$$

$$\Rightarrow \quad \boxed{\frac{V_S}{V_P} = \frac{I_P}{I_S}} \longrightarrow (4)$$

Where I_P is the current in the primary and I_S in the secondary coil. Hence, the currents are inversely proportional to their respective voltages. Therefore, in a step-up transformer when the voltage across the secondary is raised, the value of current is reduced. This is the principle behind its use in the electric supply network where transformer increases the voltage and reduces the current, so that it can be transmitted over long distances without much power loss.

Power Loss Due To Resistance Of Wires

When current I passes through a resistance R, then power loss due to heating effect is I^2R.

Consider that R is the resistance of transmission line. In order to minimize the loss during transmission, it is not possible to reduce R because it requires the use of thick copper wire which becomes highly uneconomical. The purpose to minimize power loss is well served by reducing I. At the generating power station, the voltage is stepped up to several thousand of volts and power is transmitted to long distances without much loss. Step down transformers then decrease the voltage to a safe value at the end of the line where the consumer of electric power is situated.

Inside a house, a transformer may be used to step down the voltage from 250 volts to 9 volts for ringing bell or operating a transistor radio. Transformers with several secondaries are used in television and radio receivers where several different voltages are required.

Ideal Transformer

A transformer in which output power is nearly equal to the input power, is called an ideal transformer.

Hence, for an ideal transformer

Output Power = Input Power

ACTUAL OR REAL TRANSFORMER

In an actual transformer, the output power is always less than the input power due to power losses.

MAIN CAUSES OF POWER LOSSES

There are two main causes of power loss

(i) Eddy Currents

(ii) Magnetic Hysteresis

EDDY CURRENTS

In order to increase the magnetic flux, the primary and secondary coils of the transformer are wound on soft iron core. The flux generated by the coils also passes through the core. As magnetic flux changes through a solid conductor, so induced currents are set up in closed paths in the body of the solid conductor. These induced currents are set up in a direction perpendicular to the flux and are known as eddy currents. It results in power dissipation and heating of the core material.

MINIMIZATION OF EDDY CURRENTS

In order to minimize the power loss due to flow of eddy currents, the core is laminated with insulatio between layers of laminations which stops the flow of eddy currents.

MAGNETIC HYSTERESIS

Hysteresis loss is the energy expended to magnetize and demagnetize the core material in each cycle of the A.C.

NOTE

Due to these power losses, a transformer is fa from being an ideal. Its output power is always le than its input power.

Efficiency Of Transformer

The ratio between output power and input power of a transformer is called the efficiency of transformer (E).

$$E = \frac{\text{Output Power}}{\text{Input Power}} \times 100$$

Methods To Improve The Efficiency

In order to improve the efficiency of a transformer, care should be exercised to ~~improve~~ minimize all the power losses.

For example,

(i) Core should be assembled from the laminated sheets of a material whose hysteresis loop area is very small.

(ii) The insulation between laminated sheets should be perfect so as to stop the flow of eddy currents.

(iii) The resistance of the primary and secondary coils should be minimum.

(iv) Power transfer from primary to secondary coil takes place through flux linkages, so the primary and secondary coils should be wound in such a way that flux coupling between them is maximum.

QUESTIONS

15.1. *Does the induced emf in a circuit depend on the resistance of the circuit? Does the induced current depend on the resistance of the circuit?*

Ans. The induced emf does not depend upon resistance of circuit. It depends upon the rate of change of magnetic flux only.

The induced current is equal to induced emf divided by resistance of circuit. Therefore, greater is resistance of circuit the smaller is value of induced current. Induced current $= \frac{\text{Induced emf}}{\text{Resistance}}$

15.2. *A square loop of wire is moving through a uniform magnetic field. The normal to the loop is oriented parallel to the magnetic field. Is an emf induced in the loop? Give a reason for your answer.*

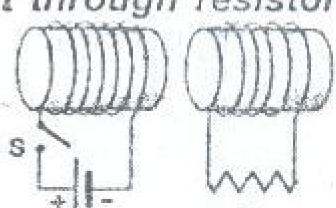
Ans. When a rectangular coil is moved with normal to its face area parallel to uniform magnetic field, then magnetic flux passing through the coil remains constant. So no change of magnetic flux takes place. Hence induced emf is zero.

15.3. *A light metallic ring is released from above into a vertical bar magnet (Fig. Q. 15.3). Viewed from above, does the current flow clockwise or anticlockwise in the ring?*

Ans. A light metalic rung is allowed to fall freely from certain height above the N-Pole of bar magnet. Due to its motion, the magnetic flux passing through the ring changes, and induced emf is developed which causes electric current in the ring. According to Lenz's law its effect must oppose the cause, which produced it. Due to this we expect N-pole formed on the facing side of ring. This shows that we have S-pole on the upper face of ring. It is due to clockwise direction of current, when viewed from above.

15.4. *what is the direction of the current through resistor R in Fig. Q.15.4? As switch S is*

(a) Closed
(b) Opened



Ans. As shown in figure, we have a coil connected with battery and a switch. When switch is made ON. Then current in this coil grows from zero to certain maximum value. This causes change of magnetic flux, in the coil placed nearby it. (Shown in fig). This produces emf across the resistance. R. The direction of current is R is always opposite to direction of current, which causes it.

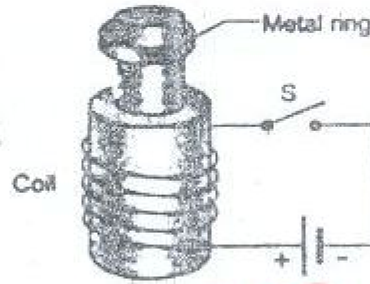
Hence, the direction through 'R' is

"From right to left when circuit is closed. And it is from right to left when circuit is opened. It is according to the Lenz's Law.

15.5. *Does the induced emf always act to decrease the magnetic flux through a circuit?*

Ans. The induced emf tries to oppose any change in flux. If flux is increasing then it acts to decrease it. And if magnetic flux is decreasing, then the induced emf acts to increase it value.

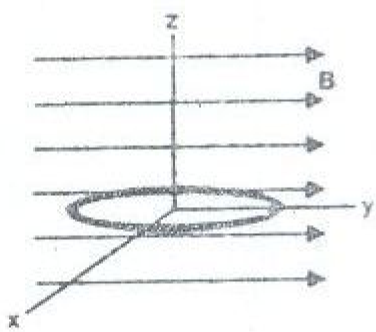
15.6. *When the switch in the circuit is closed a current is established in the coil and the metal ring jumps upward (Fig.Q.15.6). Why? Describe what would happen to the ring if the battery polarity were reversed?*



Ans. When switch of the circuit is closed then electric current flows in the coil and becomes magnet. Current increases from zero to a maximum value. Due to which electric flux changes in the coil, causes. This change of magnetic flux through the ring also, and produces induced emf in it. Due to induced current in the ring the ring also becomes magnetic with similar pole facing the coil's (according to Lenz's law) gives repulsion to the ring and it jumps up.

When polarity of battery is reversed then process is similar, again, jumping of ring is observed, according to same reasons given above.

15.7. *When the switch in the circuit is closed a current is established in the coil and the metal ring jumps upward (Fig. Q.15.6). Why ?*



Solution:

The given data is

No. of turns = N = 250

Self inductance = $L = 2.4 \times 10^{-3}$ H

Flux linked with one turn = ϕ_1 = ?

Current = I = 2A

$$\frac{\Delta I}{\Delta t} = 20 \text{A S}^{-1}$$

E = ?

Formula

$$\phi = L\,I$$

Putting values we get

$$\phi = 2.4 \times 10^{-3} \times 2$$

$$\phi = 4.8 \times 10^{-3}$$

$$\phi_1 = \frac{\phi}{250}$$

$$\phi_1 = \frac{4.8 \times 10^{-3}}{250}$$

$$\boxed{\phi_1 = 1.92 \times 10^{-5}\ \text{wb}}$$

15.8. How would you position a flat loop of wire in a changing magnetic field so that there is no emf induced in the loop?

Ans. When plane of a flat loop of wire is parallel to the changing magnetic field, then no flux passes through it. Therefore change of magnetic flux through the loop is also zero and, hence, no induced emf is produced.

15.9. In a certain region the earth's magnetic field points vertically down. When a plane flies due north, which wingtip is positively charged?

Ans. The formula for magnetic force on moving electric charge is

$$\vec{F} = q\,\vec{V} \times \vec{B}$$

This means that $\vec{F}_m$ acts at right angle to $\vec{V}$ is towards north and $\vec{B}$ IS vertically down ward, so, by using right – hand rule the direction of $\vec{F}$ is directed towards west hence the west wingtip is positively charged.

15.10. Show that ε and $\frac{\Delta\Phi}{\Delta t}$ have the same units?

Ans. The unit of emf are simplified as follows units of emf = joule per coulomb

$$= J\,C^{-1} = N\,m\,C^{-1} \quad \text{---------------- (1)}$$

And

$$\text{Units of } \frac{\Delta\phi}{\Delta t} = Wb\,S^{-1}$$

$$= N\,m\,A^{-1}\,S^{-1}$$

$$= N\,m\,(CS^{-1})^{-1}\,S^{-1}$$

$$= N\,m\,C^{-1} \quad \text{---------------- (2)}$$

From (1) and (2) we see that unit of ε and those of $\frac{\Delta\phi}{\Delta t}$ are same.

15.11. When an electric motor, such as an electric drill, is being used, does it also act as a generator? If so what is the consequence of this?

Ans. When an electric motor works, then its armature revolves due to which change of magnetic flux occurs. And induced emf is generated. This is called back emf of motor. This shows that working electric motor behaves like a generator. The produced emf is used to produce heat dissipation.

15.12. Can a D.C motor be turned into a D.C generator? What changes are required to be done?

Ans. The construction of a D.C. motor and D.C. generator are exactly same. If the voltage is supplied by connecting a battery to the slip rings of a D.C. generator then generator works as motor. Because the coils on armature of motor experience torque when current is passed through it. This torque rotates the armature and generator acts like motor, which converts electrical energy into mechanical energy. This process is reverse of the process of a generator.

15.13. Is it possible to change both the area of the loop and the magnetic field passing through the loop and still not have an induced emf in the loop?

Ans. If area of a loop is changed at a particular rate, so that it could compensate any change in the magnetic flux passing through the loop. And value of magnetic flux remains constant. Then no emf would be induced.

15.14. Can an electric motor be used to drive an electric generator with the output from the generator being used to operate the motor?

Ans. An electric motor converts electrical energy into mechanical energy, which may be used to drive a generator. The induced voltage generated by the generator can be used to drive the same electric motor.

But, the induced emf produced by the generator has a property that its effects oppose the cause, which produced it. Therefore it cannot be used to drive the electric generator.

Hence a generator connected to a motor from a single system that requires external energy to run this system.

15.15. A suspended magnet is oscillating freely in a horizontal plane. The oscillations are strongly damped when a metal plate is placed under the magnet. Explain why this occurs?

Ans. If a suspended magnet is made free to oscillate in a horizontal plane, then magnetic field/ flux changes in a region of space close to it. The metal plate placed below it also experiences this change of magnetic flux due to which eddy currents are produced in side it. The effect of these opposes the cause, which produce it. This is why the oscillations of suspended magnet are strongly damped.

15.16. Four unmarked wires emerge from a transformer. What steps would you take to determine the turns ratio?

Ans. The four unmarked wires emerging from a transformer are two of them as ends of "primary" and the remaining two as the ends of "secondary" coils. These two coils do not have any electric connection between them. we can make the following step to find their turn ratio.

(1) First the continuity test is made to identify two ends of same coil.

(2) The electrical resistance is measured by using Ohmmeter of the two coils. If it is step down transformer, then greater resistance coil is "secondary" and the other two ends of four wires are that of primary coil.

(3) The primary coil is supplied with known voltage of a.c. supply. EP denotes it. The voltage induced across secondary coil is measured and denoted by E_S.

(4) By using the equation.

$$\frac{E_S}{E_P} = \frac{N_S}{N_P}$$

The turn ratio can be calculated.

15.17. a) Can a step-up transformer increase the power level?
b) In a transformer, there is no transfer of charge from the primary to the secondary. How is, then the power transferred?

Ans. a) The principle of an ideal transformer is that (input power) = (output power)

Some of the power input many be lost due to eddy currents produced in the core etc. this makes the output power some what less than input power. in case of real transformer. This shows that transformers cannot increase the power.

b) In transformers electric power is transferred from its primary coil to its secondary coil with the help of magnetic field.

15.18. When the primary of a transformer is connected to a.c mains the current in it

a) is very small if the secondary circuit is open, but

b) Increases when the secondary circuit is closed. Explain these facts.

Ans. a) When secondary coil circuit is open then output power used is zero, or very small. This require input is power also very small. As a result of which value of current drawn by primary coil, from the mains also become very very small.

b) When load across secondary is increased by making the secondary coils circuit ON. Then this requires input power must be equal to output power. For this reason the current drawn by the primary coil from the mains is increased.