MAGNETISM AND ELECTROMAGNETISM 14

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14.1 MAGNETIC FIELD OF INDUCTION:

When an electric charge is stationary, it is not influenced by magnetic field. But an electric charge in motion produce around it a field which is fundamentally of a different type from electric field (This field exerts force on other charges only when charge move in the field). This field is called the magnetic field intensity or Magnetic flux density. Its S.I. Unit is Newton per ampere per meter which is also called as weber/m^2.

14.2 FORCE ON A CHARGE MOVING IN A UNIFORM MAGNETIC FIELD:

Consider a point charge of magnitude "q" moving in a uniform magnetic field of induction having strength B with a velocity v. The angle between velocity and magnetic intensity is "θ". Force experienced by the charge depends directly upon the following factors:

(i) The magnitude q of the charge:

$$F \propto q \quad \text{.................. (1)}$$

(ii) The velocity v of the charge:

$$F \propto v \quad \text{.................. (2)}$$

(iii) The strength of magnetic field

$$F \propto B \quad \text{.................. (3)}$$

(iv) The sine of the angle between force and velocity field:

$$F \propto \sin\theta \quad \text{.................. (4)}$$

By combining above four factors:

$$F \propto qvB \, Sin\,\theta$$

$$F = \text{Constant} \times qvB \, Sin\theta$$

This constant of proportionality depends upon the system of units used. If 1 coulomb charge enters perpendicularly in a magnetic field of 1 tesla with a velocity of 1m/s and experiences a force of 1N then in S.I. System of units value of this constant will be unity. Therefore,

$$\boxed{F = qvB \, Sin\theta}$$

CONDITION OF MAXIMA:

Force on a charged particle in a magnetic field will be maximum if it enters perpendicularly in the magnetic field, i.e. the angle between field $\overline{B}$ and velocity $\overline{V}$ is $\theta = 90^\circ$

$$F = qvB \, Sin90^\circ$$

$$\boxed{F = qvB} \quad (\text{as } Sin90^\circ = 1)$$

CONDITION OF MINIMA:

Force on a charged particle in a magnetic field will be minimum if it enters along the direction of magnetic field, i.e. the angle between field $\overline{B}$ and velocity $\overline{V}$ is $\theta = 0^\circ$

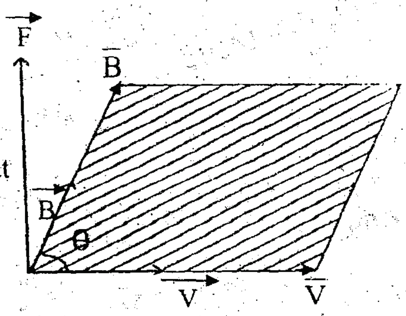
$$F = qvB \, Sin0^\circ$$

$$\boxed{F = 0} \quad (\text{as } \sin 0^\circ = 0)$$

DIRECTION OF FORCE:

The force on a charged particle always acts Perpendicularly on the plane defined by velocity of charged Particle $\vec{v}$ and the magnetic field $\vec{B}$. Mathemat

$$\vec{F} = q(\vec{v} \times \vec{B})$$



14.3 FORCE ON A CURRENT CARRYING CONDUCTOR IN A MAGNETIC FIELD:

A wire placed in magnetic field experiences a force when electric current is passed through it. It is due to the free electrons present in the conductor.

Consider a conductor wire of length "L" placed in magnetic field B. Let "A" be the cross-sectional area of the wire and "n" be the number of free electrons in unit volume of wire. The charge moving through the unit volume of elements is

$$q = nA\,Le \text{ ——— (a)}$$

As the force on a charged particle moving in a magnetic field is given by:

$$\vec{F} = q(\vec{v} \times \vec{B})$$

OR $\vec{F} = nALe(\vec{v} \times \vec{B})$ —— (1)

If the direction of drift velocity is specified by unit vector $\hat{r}$ then,

$$\vec{v} = v\hat{r}$$

Equation (1) => $\vec{F} = nA\,Le\,(v\hat{r} \times \vec{B})$

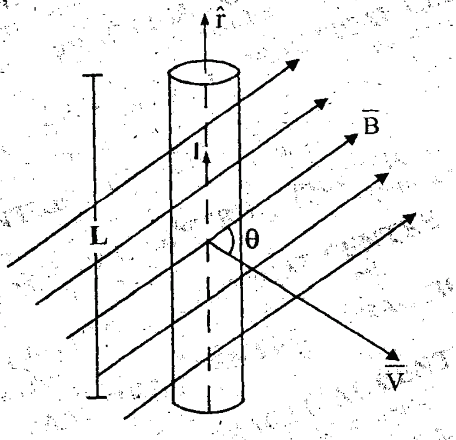
$\vec{F} = nAve(L\hat{r} \times \vec{B})$ —— (2)

∴ But $L\hat{r} = \vec{L}$

Equation (2) => $\vec{F} = nAve(\vec{L} \times \vec{B})$ —— (3)

Where $\vec{L}$ is the vector length. The magnitude of velocity of charge passing through length $\vec{L}$ of conductor in time t is given by,

$$v = \frac{L}{t}$$



Equation (3) => $\vec{F} = nA\frac{L}{t}e(\vec{L} \times \vec{B})$

$\vec{F} = \frac{nALe}{t}(\vec{L} \times \vec{B})$

From equation "a" $\vec{F} = \frac{q}{t}(\vec{L} \times \vec{B})$

But $\frac{q}{t} = I$

∴ $\vec{F} = I(\vec{L} \times \vec{B})$

OR $F = BIL\,Sin\theta$

CONDITION OF MAXIMA:

Force on a current carrying conductor will be maximum when conductor is placed perpendicularly on to the field, that is the angle between field $\vec{B}$ and vector length $\vec{L}$ is $\theta = 90^\circ$

$$F = BIL \sin 90^\circ$$
$$F = BIL \qquad (\text{as } \sin 90^\circ = 1)$$

CONDITION OF MINIMA:

Force on a current carrying conductor will be minimum when conductor is placed parallel to the field, that is the angle between field $\vec{B}$ and vector length $\vec{L}$ is $\theta = 0^\circ$

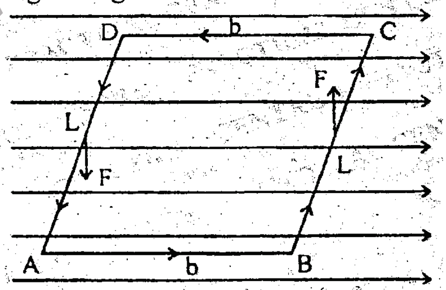
$$F = BIL \sin 0^\circ$$
$$F = 0 \qquad (\text{as } \sin 0^\circ = 0)$$

DIRECTION OF FORCE:

The force on a wire in a magnetic field acts perpendicularly on the plane of $\vec{L}$ the vector length and magnetic field $\vec{B}$.

14.4 TORQUE ON A CURRENT CARRYING COIL IN A UNIFORM MAGNETIC FIELD:

Consider a rectangular coil ABCDA Placed in a uniform magnetic field $\vec{B}$ with its plane parallel to the field and "I" current is flowing through it. The sides AB and CD are the widths of the coil represented by "b" and the sides BC and DA are the length of the coil represented by "L", as shown in figure.



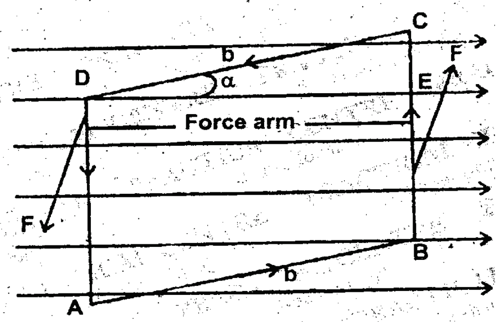
The force experienced on the conductor placed in a magnetic field is given by:

$$F = BIL \sin\theta$$

Since sides AB and CD are parallel to the field, so they will not experience any force but BC and DA are at right angle to the field, so the force experienced by these sides of coil is represented by:-

$$F = BIL$$

Since the force always acts perpendicular to the plane of $(\vec{L} \times \vec{B})$ so by applying the right hand rule, the direction of the force on side BC is found to be outward on the plane of paper and for side DA the direction of force is found to be inward on the plane of paper, therefore a couple is acting on the coil which will cause the coil to rotate about axis.



The torque of a couple of force is equal to the product of the magnitude of the couple of the force and the perpendicular distance between them, which is the width of the coil "b", therefore

$$\tau = F \times b$$

If coil is so placed that its plane makes an angle "α" with the magnetic field $\vec{B}$ then perpendicular distance (force arm) is given by:

$$\text{Cos}\alpha = \frac{\text{force arm}}{b} \quad \text{or force arm} = b\cos\alpha$$

Now the torque acting on the coil is given by:

$$\tau = Fb\,\text{Cos}\alpha$$

OR $\tau = BIL\,b\,\text{Cos}\alpha$

Where $Lb = A$; the area of the coil

$$\tau = BIA\,\text{Cos}\alpha$$

If "N" is the number of turns of the coil, then

$$\boxed{\tau = \mathbf{BIAN\,Cos\alpha}}$$

Condition of Maxima:

Torque in a coil will be maximum when plane of coil is placed parallel to the magnetic field i.e. $\alpha = 0^\circ$

=> $\tau = BIAN$

Condition of Minima:

Torque in a coil will be minimum when plane of coil is perpendicular on the magnetic field i.e. $\alpha = 90^\circ$

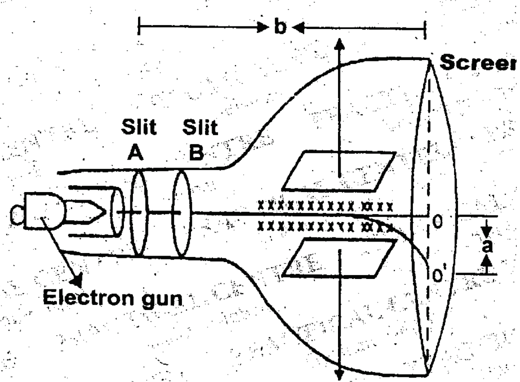
=> $\tau = 0$

14.5 DETERMINATION OF CHARGE TO MASS RATIO (e/m) OF AN ELECTRON:

Sir J.J. Thomson Determined the charge to mass ratio of electron in 1897 by noting down the deflection in the path of a beam of electron in uniform magnetic field.

CONSTRUCTION: *

The apparatus consist of a discharge tube having a tungsten filament, which is a cathode. When the filament is heated, electrons are ejected from it and are accelerated by a voltage 'V' applied by the slits. Electrons by traveling in a straight line hit the screen at point 'O' when a magnetic field 'B' is applied perpendicularly on electron beam, it deviates from their path and hit the screen at point 'O'', by following a curved path of radius 'r'. Hence electron beam is acted upon by magnetic and centripetal force, such that.



$$F_{mag} = F_c$$

OR

$$evB\sin\theta = \frac{mv^2}{r}$$

$$eB\sin\theta = \frac{mv}{r}$$

$$\frac{e}{m} = \frac{v}{Br\sin\theta}$$

Since the motion of electrons is perpendicular on the magnetic lines of induction, i.e. $\theta = 90^\circ$, therefore,

$$\boxed{\frac{e}{m} = \frac{v}{Br}} \quad \ldots\ldots\ldots\ldots\ldots (1)$$

In the above equation by putting the values on R.H.S, charge to mass ratio of electrons could be determined. Radius of circular arc of electron beam can be determined by knowing the shift of light spot, given by,

$$\boxed{r = \frac{b^2}{2a}}$$

Where 'b' is the distance travelled by electrons in the tube and 'a' is the shift of luminous light spot.

DETERMINATION OF VELOCITY OF ELECTRONS:

The velocity of electron can be determined by two methods, which are as follows:

i) Potential Difference Method:

As electrons are accelerated in the magnetic field by applying a high potential difference 'V' so it can be assumed that the Kinetic energy of electrons is equal to the electrical work done on electrons.

$$\therefore \quad \frac{1}{2}mv^2 = eV$$

OR

$$v^2 = \frac{2eV}{m}$$

$$\boxed{v = \sqrt{\frac{2eV}{m}}}$$

$\therefore$ **eq.(1) =>**

$$\frac{e}{m} = \frac{1}{Br}\sqrt{\frac{2eV}{m}}$$

$$\frac{e^2}{m^2} = \frac{1}{B^2r^2} \times \frac{2eV}{m}$$

OR

$$\boxed{\frac{e}{m} = \frac{2V}{B^2r^2}}$$

Above equation provides the charge to mass ratio of electron if the accelerating potential of electron is known.

ii) Particle Velocity Selector Method:

By considering the electric and magnetic fields set in the tube, velocity of electron can be determined also. Since both the fields are perpendicular on each other, therefore, intensity of electric field is gradually adjusted such that the luminous spot comes back from 'O'' to 'O'.

Since electrons travel undeflected through the crossed electric and magnetic field, therefore,

$$F_{mag} = F_{el}$$
$$evB = eE$$
$$\boxed{v = \frac{E}{B}}$$

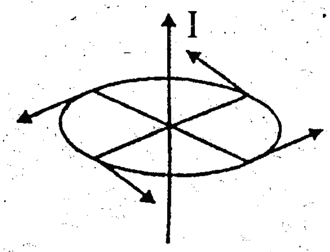
∴ eq.(1) => $\frac{e}{m} = \frac{E/B}{Br}$

OR $\boxed{\frac{e}{m} = \frac{E}{B^2 r}}$

The charge to mass ratio of electron thus found to be 1.7592×10^{11} Coul/Kg

14.6 BIOT-SAVAT'S LAW:

The relation between the magnetic field of a current carrying conductor and current passing through a conductor was studied by Biot and Savat.



Consider a long straight wire carrying a current "I" and a closed curve consisting of a circle of radius 'r' with the wire at the centre as shown in the figure.

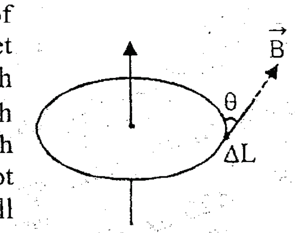
Biot-Savat deduced from the experience that the magnetic field 'B' around a long straight current carrying conductor is directly Proportional to the twice of current I passing through the conductor *and is inversely Proportional to the distance 'r' from the conductor, mathematically.*

$$B \propto \frac{2I}{r}$$
$$B = \frac{\mu_o}{{}^2\cancel{4}\pi} \times \frac{\cancel{2}I}{r}$$
$$\boxed{B = \frac{\mu_o I}{2\pi r}}$$

Where μ_o is the constant called the permeability of force space and its value is $4\pi \times 10^{-7}$ weber /A.m.

AMPERE'S LAW:-

A current carrying conductor has a magnetic field around it. Ampere's Law provides the relation between the magnetic flux density and the current enclosed. Consider a long straight.



Wire carrying a current 'I' with a magnetic field in the form of a closed curve consisting of a circle of radius 'r' around it. Let us divide the magnetic field into a large number of small length of elements ΔL, ΔL_2, ΔL_3, ... The direction of each length of element is along the direction of magnetic field which is tangent on the circle at each length of element. Taking dot product of tangential component of magnetic field with all length of elements.

$$\vec{B}.\Delta\vec{L}_1 = B\Delta L_1 \cos\theta$$

$$\vec{B}.\Delta\vec{L}_1 = B\Delta L_1 \cos 0^\circ$$

$$\vec{B}.\Delta\vec{L}_1 = B\Delta L_1$$

Similarly $\vec{B}.\Delta\vec{L}_2 = B\Delta L_2$

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$$\vec{B}.\Delta\vec{L}_N = B\Delta L_N$$

The sum of all dot Products is

$$\Sigma\vec{B}.\Delta\vec{L} = \Sigma B\Delta L$$

As tangial component of magnetic field 'B' remains constant at all length of elements, therefore,

$$\Sigma\vec{B}.\Delta\vec{L} = B\,\Sigma\,\Delta L$$

Where $\Sigma\Delta L$ is the circumference of the circle which is $2\pi r$ and 'B' is given by the Biot – Savat's Las as

$$B = \frac{\mu_o I}{2\pi r}$$

$$\therefore \quad \Sigma\vec{B}.\Delta\vec{L} = \frac{\mu_o I}{2\pi r} \times 2\pi r$$

$$\Sigma\vec{B}.\Delta\vec{L} = \mu_o I$$

$$\therefore \quad \Sigma\vec{B}.\Delta\vec{L} = \mu_o \times \text{Current}$$

This relation is called Ampere's Law and is stated as.

"The sum of the dot Product of the tangential component of magnetic field of induction and the length of an element of a closed curve taken in the magnetic field is μ_o times the current passing through the conductor."

14.7 APPLICATIONS OF AMPERE'S LAW:

I) FIELD DUE TO A SOLENOID:

A Solenoid is a long hollow pipe on which wire is wounded. The turns of the winding are closely spaced and may consist of one or more layers. The magnetic field produced by the solenoid in the middle of the solenoid is stronger and uniform but it is weaker and negligible outside the solenoid because magnetic lines are crowded and runs parallel with the axis of solenoid inside but they diverge outside the solenoid.

In order to determine the magnetic field B, consider a rectangular path abcda as shown in the figure. Let this path be divided into four elements of lengths as,

ab = L_1 , bc = L_2 , cd = L_3 and da = L_4. Such that the sum of dot product of magnetic field and the length of element is,

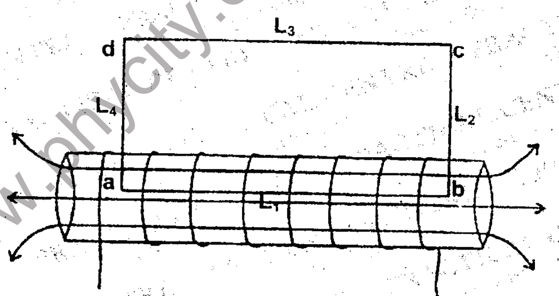
$$\Sigma \vec{B}.\Delta\vec{L} = BL_1Cos\theta_1 + BL_2Cos\theta_2 + BL_3Cos\theta_3 + BL_4Cos\theta_4$$

as L_1 is parallel to the magnetic field and lies inside the solenoid therefore,

$$\theta = 0^\circ$$

$$BL_1\ Cos\theta_1 = BL_1$$

L_2 and L_4 are perpendicular to the mangnetic field i.e. $\theta_2 = 90^\circ$ and $\theta_4 = 90^\circ$



$$BL_2Cos\theta_2 = 0$$

and $$BL_4Cos\theta_4 = 0$$

and L_3 lies outside the solenoid where the field is negligibly weaker,

i.e. $B = 0$

$\therefore$ $BL_3Cos\theta_3 = 0$

Putting all the values in eq (1).

$$\Sigma \vec{B}.\Delta\vec{L} = BL_1 + 0 + 0 + 0$$

$$\Sigma \vec{B}.\Delta\vec{L} = BL_1 \qquad \text{............... (2)}$$

According to the ampere's law

$$\Sigma \vec{B}.\Delta\vec{L} = \mu_o \text{ x current} \qquad \text{............... (3)}$$

If N is the number of turns of coil then

$$\text{Current} = NI$$

And if 'n' is the number of turns per unit length, then

$$n = \frac{N}{L_1}$$

OR $$N = nL_1$$

$\therefore$ $$\text{Current} = nL_1I$$

$\therefore$ eq. (3) => $$\Sigma \vec{B}.\Delta\vec{L} = \mu_o nL_1I \qquad \text{................ (4)}$$

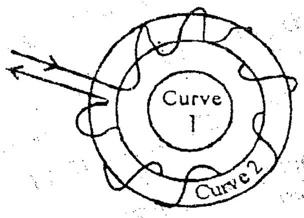
By comparing equation (2) and (4), we get

$$\mu_o n\cancel{L}_1 I = B\cancel{L}_1$$

OR $$\boxed{B = \mu_o nI}$$

II) FIELD DUE TO A TOROID:

A Toroid or a toroidal coil is a circular solenoid. When a current pass from a toroid circular magnetic lines of induction form inside the toroid. The field outside the toroid is almost zero, as magnetic lines are confined inside of the toroid only.



For determining the field B, let us divide the loop into a large number of very small elements, so that each element is considered as straight. The direction of $\vec{B}$ at any point is tangent to the circle passing through that point and having center at the center of the toroid. By symmetry $\vec{B}$ is constant everywhere along the loop and its direction is parallel to each of the elementary length $\Delta\vec{L}$, such that the sum of all dot products of $\vec{B}$ and $\Delta\vec{L}$ is given by

$$\sum\vec{B}.\Delta\vec{L} = B\Delta L_1 Cos0^\circ + B\Delta L_2 Cos0^\circ + \text{---------}$$

$$\sum\vec{B}.\Delta\vec{L} = \sum B\Delta L$$

OR $$\sum\vec{B}.\Delta\vec{L} = B\sum\Delta L$$

Where $\sum\Delta L$ is the circumference of the toroidal coil. If "r" is radius of toroid then:

$$\sum\Delta L = 2\pi r$$

$$\therefore \quad \sum\vec{B}.\Delta\vec{L} = B \times 2\pi r \text{ ----------- (1)}$$

But according to Ampere's Law

$$\sum\vec{B}.\Delta\vec{L} = \mu_0 \times \text{current}$$

If I is the current flowing through each turn of the toroid "N" then the current enclosed will be NI.

OR $$\sum\vec{B}.\Delta\vec{L} = \mu_0 NI. \text{ ----------- (2)}$$

By comparing eq. (1) and (2), we get $\Rightarrow \mu_0 NI = B \times 2\pi r$

OR $$\boxed{B = \frac{\mu_0 NI}{2\pi r}}$$

14.8 MAGNETIC FLUX:

The measure of magnetic lines of force passing through a given area placed in a magnetic field is called as Magnetic flux or mathematically it is defined as ***the dot product of flux density and vector area,***

$$\phi_m = \vec{B}\,.\,\overline{\Delta A} = B\Delta A\, Cos\theta$$

Where θ is the angle between $\vec{B}$ and $\overline{\Delta A}$. Flux will be maximum when magnetic lines of induction and surface area are parallel to each other, i.e. $\theta = 0^\circ$ and minimum when surface area and magnetic lines of induction are perpendicular on each other i.e. $\theta = 90^\circ$. S.I. unit of Magnetic flux is Weber.

14.9 ELECTROMAGNETIC INDUCTION:

The generation of electric current in a conductor due to change of magnetic flux through it is called the phenomenon of Electromagnetic Induction. The current thus produced is called the ***Induced current*** and the emf produced is called ***Induced emf.***

14.10 FARADAY'S LAWS OF ELECTROMAGNETIC INDUCTION:

A Detailed investigation of magnetic field of induction leads to two laws known as Faraday's Laws, which are state as:

(1) ***"An emf is induced in a coil through which the magnetic flux is changing. The emf lasts so long as the change of flux is in progress and becomes zero as soon as the flux through the coil becomes constant."***

(2) ***"The magnitude of induced emf depends only upon the number of turns and the rate of change of flux linked with the circuit."***

$$\text{Inducted e.m.f.} = -\frac{\Delta N\varphi}{\Delta t}$$

Where N is the number of turns of coil, and the negative sign arises from lenz's law.

14.11 LENZ'S LAW:

The direction of induced current was carefully studied by H.E.F Lenz a German scientist and the results were generalized most elegantly into a rule in 1835 called Lenz's Law. The Law states that:

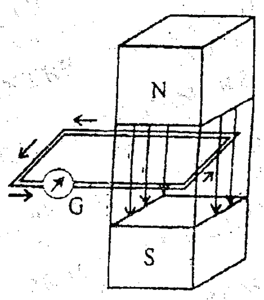
"The induced current always flows in such a direction so as to oppose the cause which gives rise to it."

EXPLANATION:

The cause of the current may be the motion of a conductor in a magnetic field, or it may be the change of flux through a stationary conductor. The current in the moving conductor is such that it opposes the motion of the conductor. In the second case the induced current oppose the cause, which is the change of magnetic flux through the circuit. If the original field is increasing, the direction of induced e.m.f will be such that the magnetic field generated by these currents will decrease the original field and vice-versa.

EXAMPLE:

If we drag a loop of wire leftwards in a uniform magnetic field acting in a downward direction, then the induced current produced in the wire is directed inward on the paper. The force due to this current, as determined by right hand rule is directed rightward, opposite to the dragging force, thereby opposing the cause which has produced it.



14.12 LENZ'S LAW AND ENERGY CONSERVATION:

Lenz's law is also directly related with the law of conservation of energy. When we drag the wire across the magnetic field we do work against the magnetic field arising from the interaction of the original magnetic field and that of the induced current and in doing so we impart energy to the loop. This energy is the source of induced current. The electromagnetic induction is exactly according to the law of conservation of energy.

14.13 MUTUAL INDUCTION:

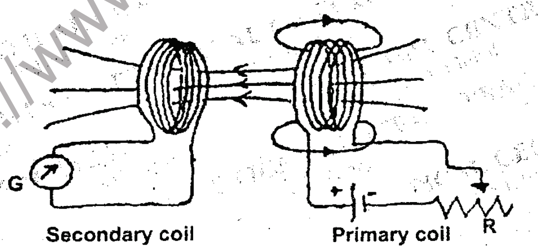
If the two coils are placed close together, then a changing current in one coil (the primary) sets up a changing magnetic field in the other (the secondary) and so induce an e.m.f. in the second coil. This effect is known as ***mutual induction*** and can be defined as ***"The phenomenon of inducing e.m.f. in the secondary coil by changing the magnetic flux of the primary coil with the help of a varying current through it is called Mutual induction."***

Consider two coils located near each other. The coil with the battery circuit is called the primary coil and the coil joined with the galvanometer circuit is called the secondary coil. The secondary coil is within the magnetic field of the current carrying primary coil. The current in the primary coil can be changed with the help of rheostat.

If the current is changed in the primary coil, the magnetic flux through the secondary coil due to primary coil also changes. So, an e.m.f. is induced in the secondary coil.

$$E_s \propto -\frac{\Delta I_p}{\Delta t}$$

$$E_s = -\frac{M\Delta I_p}{\Delta t} \quad \text{......................} \quad (1)$$



Where M is the constant of proportionality called a Mutual induction and negative sign arises due to Lenz's Law.

According to the Faraday's Law of electromagnetic induction

$$E_s = \frac{-N_s\Delta\phi}{\Delta t} \quad \text{..............................} \quad (2)$$

By equating equation (1) and (2), we get

$$\frac{-M\Delta I_p}{\Delta t} = \frac{-N_s\Delta\phi}{\Delta t}$$

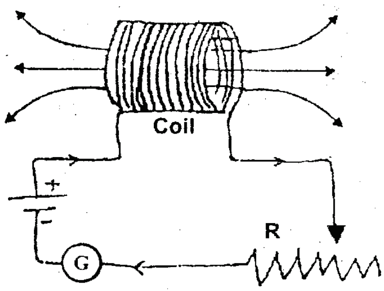
$$\boxed{M\Delta I_p = N_s\Delta\phi}$$

The S.I unit of self induction is Henry.

14.14 SELF INDUCTION:

The change in the magnetic flux in a coil may be due to the relative motion of the coil and the magnetic field or due to the change of current in the coil itself. ***Phenomenon of inducing emf in the coil due to change of current in coil itself is called self Induction.***

Let us consider a coil of N turns with a battery, a galvanometer and a rheostat in its circuit. If current in the coil is changed with the help of rheostat, then the change of magnetic flux would also be felt by the coil itself, thereby inducing an emf in it.



The induced emf in the coil is

$$\text{emf} \propto -\frac{\Delta I}{\Delta t}$$

$$\text{emf} = -\frac{L\Delta I}{\Delta t} \quad \text{.......} \quad (1)$$

According to Faraday's Law of electromagnetic induction

$$\text{emf} = -\frac{\Delta N\varphi}{\Delta t} \quad \text{.......} \quad (2)$$

By equating equation (1) and (2), we get

$$\frac{-L\Delta I}{\cancel{\Delta t}} = \frac{-\Delta N\varphi}{\cancel{\Delta t}}$$

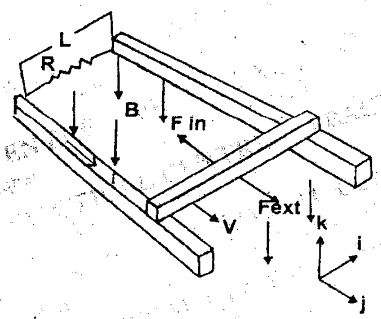
$$L\Delta I = \Delta N\phi$$

Where L is the constant called as self induction. The S.I. Unit of self-induction is Henry.

14.15 MOTIONAL EMF:

If a conductor is moved in a region where magnetic flux is changing then an emf is induced in the conductor, called as Motional emf.

Consider the situation as shown in figure, where a conductor of length L is sliding with velocity v along fixed conducting rails in a region of uniform magnetic field B, which is perpendicular to the plane of the rails and the conductor. An external force pulls the bar along the rails at a constant speed v. if a positive charge q moves within the moving conductor, then it will experience a force in magnetic region in the j-direction, given by:



$$\vec{F}_{mag} = q(\vec{v} \times \vec{B})$$

OR $$F_{mag} = qvB\,\text{Sin}\theta$$

As the velocity of the conductor is perpendicular to the direction of magnetic lines, therefore,

$$F_{mag} = qvB \quad \text{.......} \quad (1)$$

The external force that pulls the sliding conductor provides the work required to move the charges around the circuit through the length "l" of the conductor,

$$W = F_{mag}\, l$$
$$W = qvBl$$

As emf is the work done on the charge, given by

$$\text{emf} = \frac{\text{work}}{\text{charge}}$$

OR

$$V = \frac{qvBl}{q}$$

$$V = vBl$$

Where V is the motional emf. If the direction of velocity of conductor and magnetic lines are at the angle θ with each other, then

$$\boxed{V = vBl\,Sin\theta}$$

14.16 ALTERNATING CURRENT GENERATOR:

A device which converts mechanical energy into electrical energy is called generator. A generator which produces alternating voltage and current is called A.C generator.

PRINCIPLE:

Its principle based upon Farady Law when coil rotates by any means in a magnetic field, the magnetic flux changes and induced emf is produced.

CONSTRUCTION:

The main parts of an A.C generator are

(i) Field Magnet:

It is a strong permanent magnet which produces a strong and uniform magnetic field between it poles. (In commercial generator electromagnet is used).

(ii) Armature:

A rectangular coil ABCD of N turns closely wound on a iron cylinder (core) rotates about as axis oo′ which is perpendicular to the magnetic field. The assembly (coil + cylinder) is called armature.

(iii) Slip Rings:

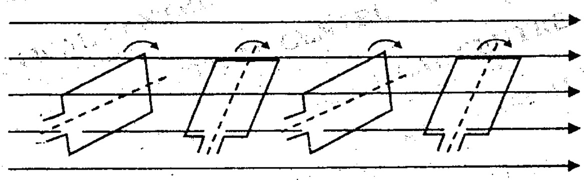
S and S′ are the two copper circular rings called slip rings which are connected to the ends of the coil the slip rings rotate with coil.

(iv) Carbon Burshes:

b and b′ are the two carbon brushes slide-over the slip ring (SS′) and connected the coil to the external circuit.

WORKING:

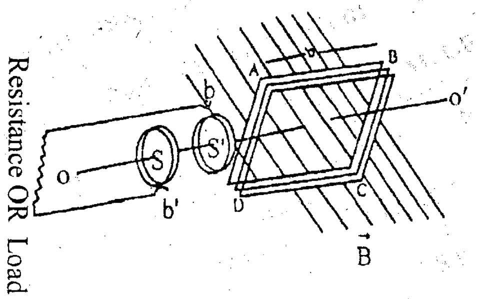
When the coil ABCD is made to rotate by any means in the magnetic field about an axis oo′. The magnetic flux through the coil changes.



According to Faraday's Law induced current or emf is produced is it. Consider different position of the coil during one rotation as shown in the figure.

When the coil rotates from 0° to 90° the flux decreases from maximum to zero and induce current increases and becomes maximum.

During rotation from 90° to 180°, the flux increases from zero to maximum the induce current decreases from maximum to zero.



During rotation from 180° to 270°, the flux decreases from maximum to zero and induce current increases and becomes maximum but in opposite direction.

During rotation from 270° to 360°

EXPRESSION FOR EMF:

As we know that the induced e.m.f in a conductor of length "L" moving in a magnetic field of strength B with velocity v is given by:

$$V = BvL\ Sin\theta$$

During the first half rotation, which is positive

$$V_+ = BvL\ Sin\theta$$

During the second half rotation which is negative

$$V_- = -BvL\ Sin\theta$$

Total emf in one cycle is

$$V = V_+ - V_-$$

$$V = BvL\ Sin\theta - (-BvL\ Sin\theta)$$

$$V = 2BvL\ Sin\theta$$

If the coil has N turns or loops

$$V = 2BvNL\ Sin\theta \quad \text{.............................} (1)$$

As $V = r\omega$

Where 'r' here is the half of width of coil

$$r = \frac{b}{2}$$

$$\therefore \quad V = \frac{b}{2}\omega$$

equation (1) ⇒ $V = 2B\frac{b}{2}\omega NLSin\theta$

OR $V = LbBN\omega Sin\theta$

But $Lb = A$; the area of coil

$$V = ABN\omega\ Sin\theta$$

As $\theta = \omega t$

$$\therefore \quad V = ABN\omega\ Sin\omega t$$

And $\omega = 2\pi f$

$$\therefore \quad V = ABN\omega\ Sin2\pi ft \quad \text{..........................} (2)$$

for maximum emf putting $Sin2\pi ft = 1$

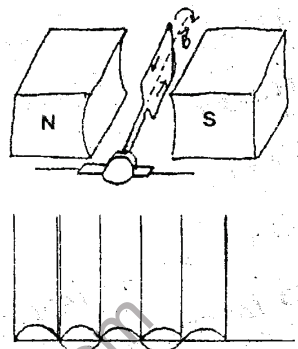
$$V_{max} = ABN\omega$$

Equation (2) ⇒ $V = V_{max}\ Sin2\pi ft$

$$\boxed{V = V_o\ Sin2\pi ft}$$

14.17 D.C GENERATOR:

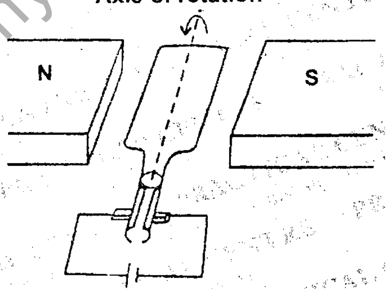
The current induced in the coil of A.C. Generator is passed to the external circuit by the two carbon brushes, pressed against copper slip rings. As the coil rotates, the emf is induced in the coil. In one rotation the vertical position of coil reverses, so the emf cycle also alters and thus the current produced is called alternating current. But if the slip rings are replaced by a simple split called commutator or split rings, the alternations in the cycle can be eliminated, because during the reversion of vertical position of coil, the two halves of the split rings exchange contact with the brushes and thus the direction of induced emf in the circuit remains unaltered,. This emf increase from zero to a maximum and then falls to zero when the coil is back to the initial vertical position. A generator modified for this function is called a D.C generator and the current so obtained is called a D.C current.



Pulsating current

14.18 ELECTRIC MOTOR:

An electric motor is the device which converts electrical energy into mechanical energy. It is essentially a generator runs backward. Like generator, a simple motor consists of a coil rotating in the field produced by a magnet. A simple Electric motor is shown in the figure, in which the coil is situated between the pole pieces of a magnet. This magnet is an electromagnet and not a permanent magnet. The coil itself is wound on an iron core to intensify the magnetic field resulting from the current through it. The current carrying coil itself acts as a bar magnet. Its strength increases many fold due to iron core.



North pole of the coil is repelled by the north pole of the permanent magnet, and the coil will be made to rotate in the counter-clockwise direction by the mutual repulsion of the poles. After rotating through 180^0, the north pole of the coil will be next to the south pole of the pole of the permanent magnet and would have to be retarded from rotating away that position. However, when it reaches that position, the sliding contacts on the ring slide over the gap and the current flowing through the coil reverses. This in turn reverses the poles of the coil, and so once again the situation shown in figure is achieved. Repulsion is maintained, and as a result rotation continues.

14.19 TRANSFORMER:

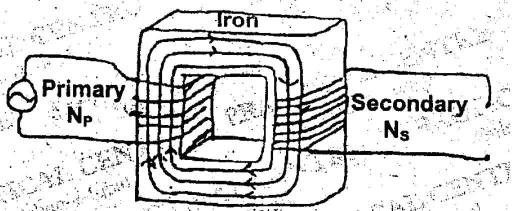
Transformer is the device which is used to change the voltage of an alternating current to a desired value.

PRINCIPLE:

The principle of transformer is "The Mutual Induction.", ***i.e. the rate of change of current in the primary coil induced emf in the secondary coil.***

CONSTRUCTION:

A transformer consists of two coils, one of them acts as primary coil and the other as secondary. These coils are wound on the same rectangular or circular soft iron core which is in the form of sheets and are insulated by some means.



WORKING:

A changing current in the primary coil induces an emf in the secondary coil. On supplying voltage V_P to the primary coil with N_P turns, the resulting current I causes a varying flux in the iron core according to the Faraday's Law. The magnitude of induced emf V_S in the secondary coil, having "N_s" turns is given by.

$$V_s = -\frac{N_s \Delta\phi}{\Delta t} \quad \text{.......................} \quad (1)$$

As the varying flux in the iron core induces emf in the secondary coil, it also induces emf in the primary coil. According to the Faraday's Law.

$$V_p = -\frac{N_P \Delta\varphi}{\Delta t} \quad \text{.......................} \quad (2)$$

Dividing equation ⇒(1) by equation ⇒(2)

$$\frac{V_s}{V_p} = -\frac{N_s \Delta\varphi}{\Delta t} \div -\frac{N_p \varphi}{\Delta t}$$

$$\frac{V_s}{V_p} = -\frac{N_s \Delta\varphi}{\Delta t} \times -\left[\frac{\Delta t}{N_p \Delta\varphi}\right]$$

$$\boxed{\frac{V_s}{V_p} = \frac{N_s}{N_p}} \quad \text{.......................} \quad (3)$$

This result shows that for a step up transformer, i.e. for $V_s > V_P$, there should be $N_s > N_P$ and for step down transformer, i.e. for $V_s < V_P$ there should be $N_s < N_P$.

From the energy conservation principle, power input in primary coil = power output from secondary coil:

$$V_P I_P = V_S I_S$$

OR

$$\boxed{\frac{V_s}{V_p} = \frac{I_p}{I_s}}$$

i.e. in step-up transformer the current at secondary coil decreases, and in step-down transformer the current in secondary coil increases. The efficiency of a transformer is given by:

$$E = \frac{\text{Power output}}{\text{Power input}} \times 100$$

TYPES OF TRANSFORMER:

Transformer can be classified as follows:

(i) STEP UP TRANSFORMER:

The transformer which raises the input voltage, i.e. voltage of primary coil at the output, i.e. voltage on secondary coil.

(ii) STEP DOWN TRANSFORMER:

The transformer which decreases the input voltage, i.e. voltage of primary coil at the out put, i.e. voltage on secondary coil.

(iii) CENTER TAPPED TRANSFORMER (stabilizer):

The transformer which maintains the output voltage, i.e. the voltage of secondary coil at some particular desired value.

14.20 SOURCES OF POWER LOSS IN TRANSFORMER:

There are many factors which effects the efficiency of transformer, some of which are outlined as:

(1) Change of magnetic flux in primary coil when induced secondary coil, some of electrical energy converts into heat energy, thereby reduces the power delivered to the secondary coil. In order to avoid heating effect, the layers of coil are laminated by a layer of insulating varnish.

(2) Due to internal resistance of conducting wire of coil, some energy dissipates as heat energy which is overcome by using thicker wire.

(3) Some loss of energy occurs because a small amount of the flux associated with the primary fails to pass through the secondary.

(4) Due to alternating cycle, the direction of magnetization also alters, therefore, some energy wastes in overcoming internal friction. This is known as hysterias is loss and it produces heating effect. It is minimized by using special alloys for the material of coil.