Chapter = 14

Magnetism and Electromagnetism

Electromagnetism:

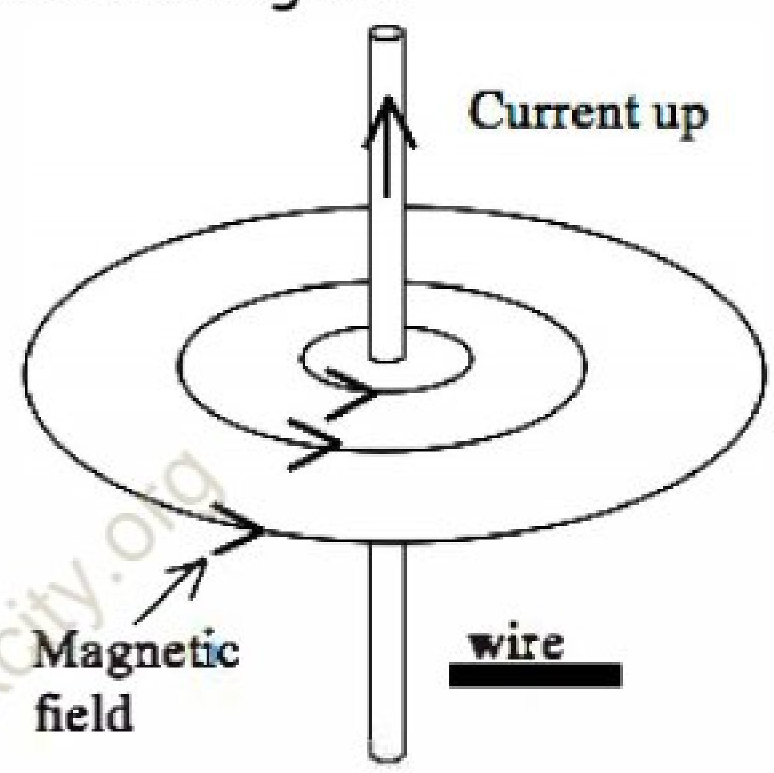
Electromagnetism is the branch of physics which relates the electricity and magnetism.

Introduction:

In 1819 Christian Orested discovered that magnetic field is generated around wire when current is passing through it, this wire treated as electromagnet. In 1829 Ampere's observed that two current carrying wires exerts force on each other and suggest that the magnetic forces are produced due to the currents passing through the wires.

Electromagnet:

When charges flow in a wire, magnetic field is produced around the wire which is called electromagnet.



Right-hand grip rule

Magnetic Field:

The region around magnet in which it can experiences force on another magnet or moving charge particle is called magnetic field. The S.I unit of magnetic field is Tesla. It is a vector quantity.

Direction of Magnetic Field:

The direction of magnetic field is given by right hand grip rule in which if the thumb represents current the fingers will represent the direction of magnetic field.

Magnetic Force:

When charge particle is moving in magnetic field making some angle with the field then it experiences force known as magnetic force.

Force on a charge moving in uniform magnetic field:

Consider a charge particle of magnitude 'q' is moving in a magnetic field '$\vec{B}$' with velocity '$\vec{v}$'. Let the charge particle makes an angle 'θ' with the field. Charge particle experiences magnetic forces "$\vec{F}$" when it is moving in a uniform magnetic field at some angle with the field. This magnetic force is directly proportional to the

1. Magnitude of charge 'q'
2. Magnitude of velocity of charge particle 'v'

3. Strength of the magnetic field $'B'$

4. Sine of the angle between the velocity of charge particle and field $'Sin\theta'$

Mathematically:

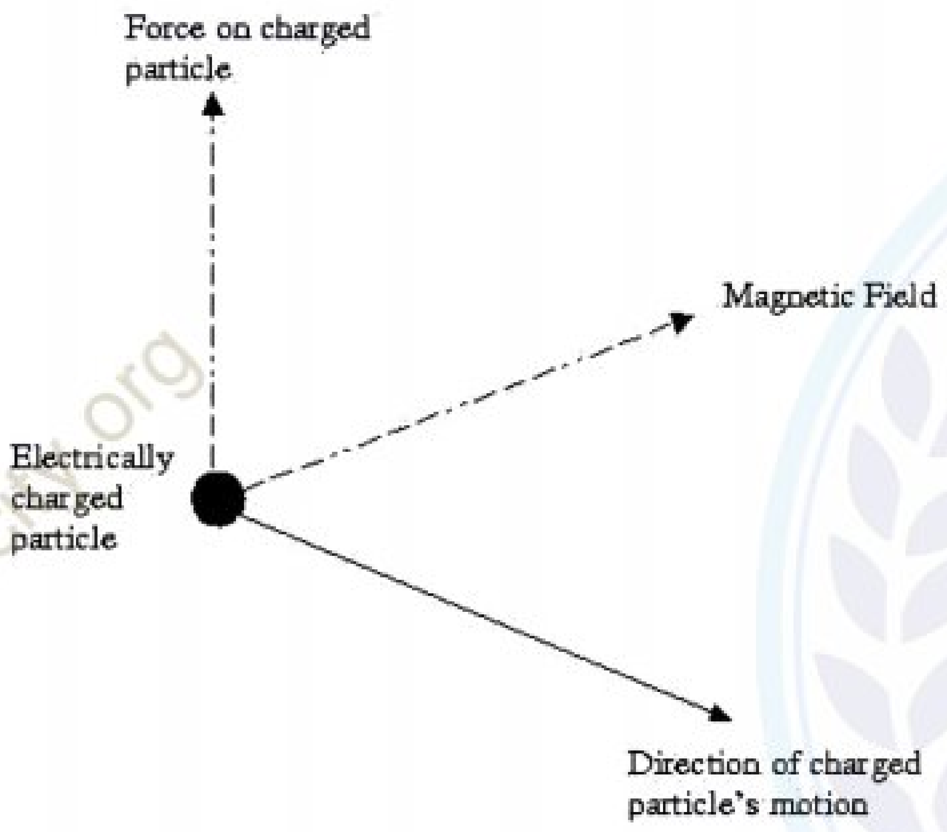
$$F \propto q$$
$$F \propto v$$
$$F \propto B$$
$$F \propto sin\theta$$

Comparing above expressions, we get

$$F = qvBsin\theta$$

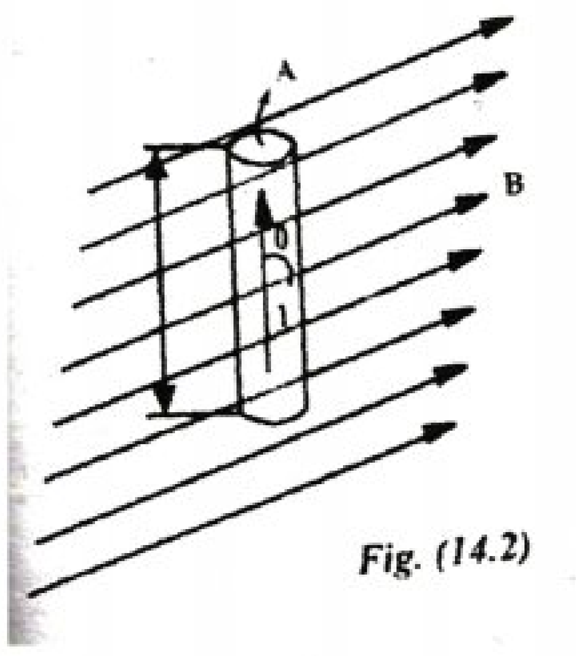
In vector form

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



Force on a current carrying conductor in uniform magnetic field

Consider a current carrying conductor placed in a uniform magnetic field '$\vec{B}$'. Let some electric current 'I' is passing through the conductor. The current carrying conductor experiences magnetic force $'\vec{F}'$ if the conductor is placed at some angle 'θ' with the field.



Since we know that the magnetic force on a charge particle when it is moving in uniform magnetic field is given by

Let $\vec{F} = q(\vec{v}\, x\, \vec{B}) \; ----(1)$

$L = length\ of\ conductor$

$n = Total\ number\ of\ charges\ per\ unit\ volume$

$A = Area\ of\ cross-section\ of\ conductor$

$e = charge\ on\ single\ electron$

The total charge $q = Ne \; --- \; (2)$

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

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

$$N = nAL$$

Substitute this value in equation (2), we get

$$q = nALe$$

Substitute this value in equation (1), we get

$$\vec{F} = nALe\,(\vec{v} \times \vec{B}) \; ----(3)$$

Consider a unit vector $\vec{u}$ in the direction of velocity and length since both vectors contain same directions, therefore

$$\vec{u} = \frac{\vec{v}}{v} \quad or \quad \vec{u} = \frac{\vec{L}}{L}$$

$$\vec{v} = \vec{u}v$$

Substitute this value in equation (3), we get

$$\vec{F} = nALe\,(\vec{u}v \times \vec{B})$$

$$\vec{F} = nALe\,(\vec{u}v \times \vec{B})$$

$$\vec{F} = nALev\,(\vec{u} \times \vec{B})$$

Now substitute $\vec{u} = \frac{\vec{L}}{L}$ in above equation, we get

$$\vec{F} = nALev\,(\frac{\vec{L}}{L} \times \vec{B})$$

$$\vec{F} = nAev\,(\vec{L} \times \vec{B})$$

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

Since we know that $= nALe$, therefore above equation will becomes

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

In magnitude form

$$F = ILBsin\theta$$
$$\boldsymbol{F = BILsin\theta}$$

Force on a current carrying rectangular coil in uniform magnetic field:

Consider a current carrying rectangular coil 'ABCD' suspended in a uniform magnetic field '$\vec{B}$' such that the plane of the coil is parallel to the magnetic field. Let current 'I' is passing through the coil or loop in clockwise direction as shown in figure

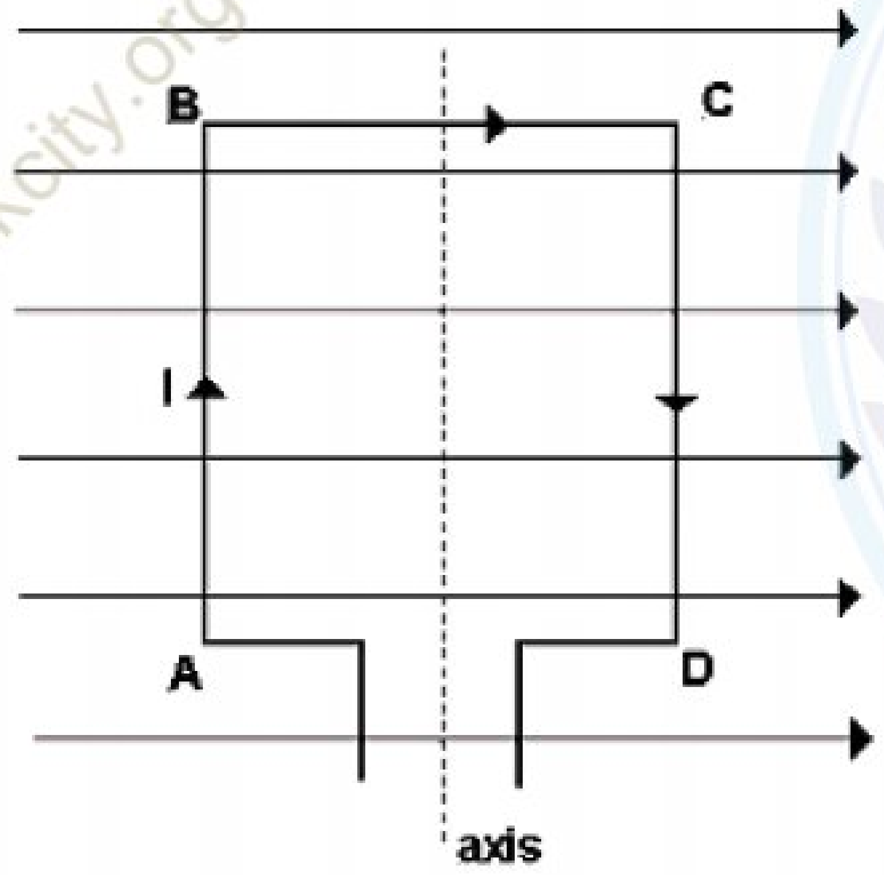
Let

L = Length of rectangular coil

b = width of the rectangular coil

A = b x L = area of the rectangular coil

N = number of turns in the coil



Since we know that the magnetic force on a current carrying conductor in uniform magnetic field

$$F = BILsin\theta$$

The sides of the rectangular loop can be treated as the current carrying conductors. The vertical sides of the rectangular loop experiences magnetic force as these sides are perpendicular to the field.

$$F = BILsin90°$$
$$F = BIL(1)$$
$$F = BIL$$

The horizontal sides of the loop experiences no magnetic force as these sides are either parallel or anti parallel to the field because $\theta = 0° \, or \, 180°$ and $sin0° = 0 \, and \, sin180° = 0$

$$F = 0$$

The magnetic forces on two vertical sides of the conductor are identical in magnitude but opposite in direction due to the currents flowing in opposite direction in vertical sides. The two forces constitute a torque of couple about axis of rotation such that the width of rectangular coil 'b' becomes the arm of the couple. Mathematically it is given by

Torque of Couple = (Magnitude of force) x (Arm of couple)

$$\tau = BIL \, x \, b$$

$$\tau = BI(L \, x \, b)$$

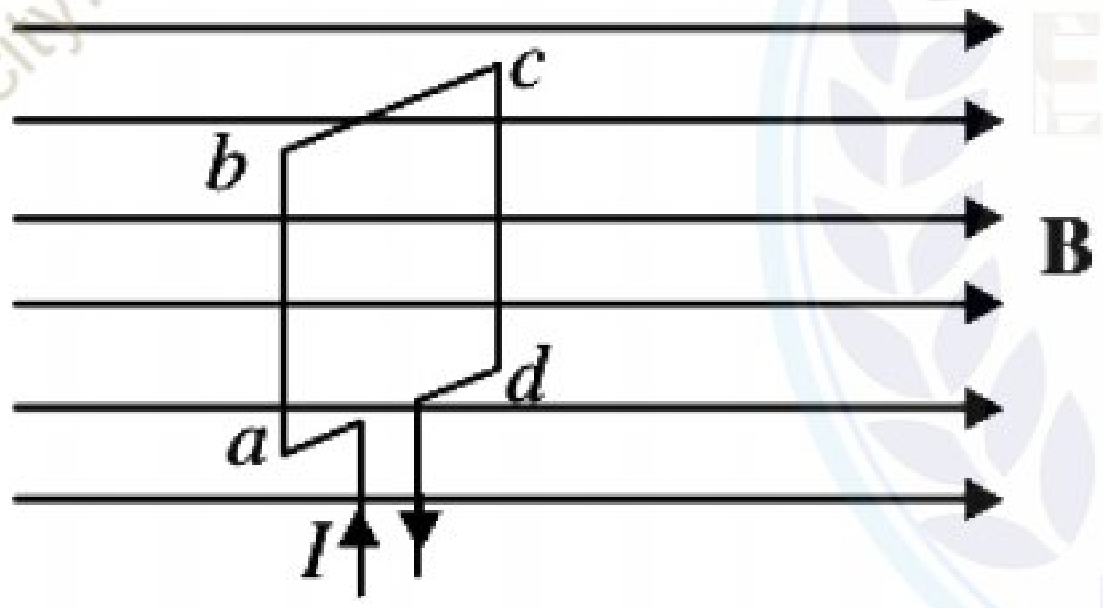
$$\tau = BIA$$

For 'N' number of turns, we have

$$\tau = BIAN$$

$$\tau = BINA$$

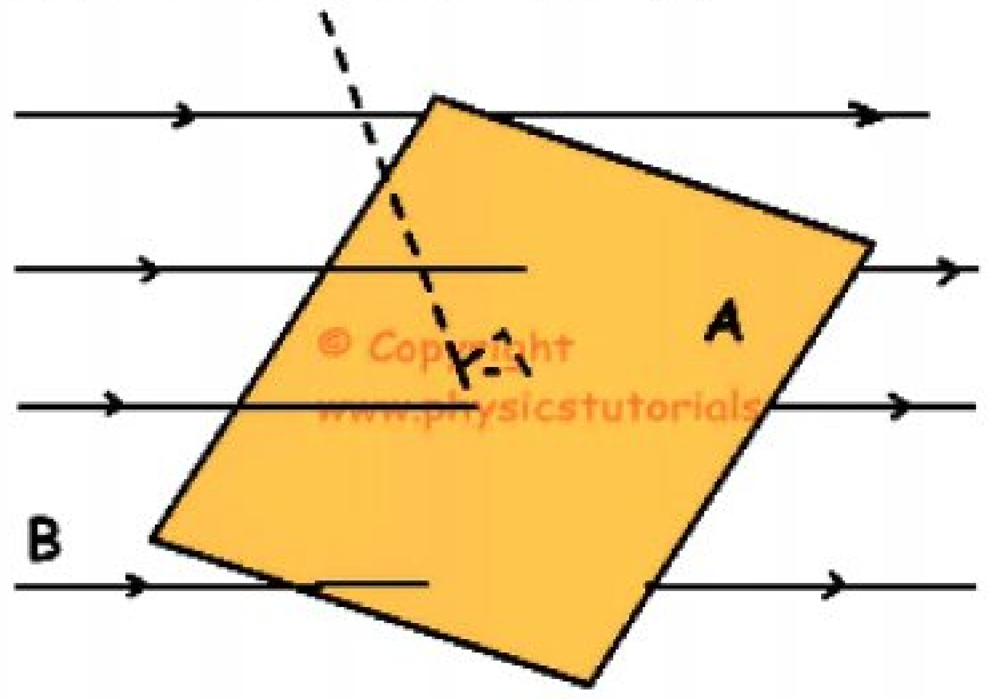
If the plane of the rectangular coil makes an angle α with the field then



$$\tau = BINA\cos\alpha$$

<u>Magnetic Flux</u>

The number of magnetic lines of forces passing through the surface normally is called magnetic flux. It is denoted by φ_B.



Mathematically:

It is the dot product of magnetic field "$\vec{B}$" and area vector "$\overrightarrow{\Delta A}$".

$$\varphi_B = \vec{B} \, . \, \overrightarrow{\Delta A}$$
$$\varphi_B = B\Delta A cos\theta$$

Unit:

The S.I unit of magnetic flux is Weber. It can be defined as "if magnetic field of 1 Tesla passing through the surface area of 1 m^2 normally, then magnetic flux will be 1 Weber."

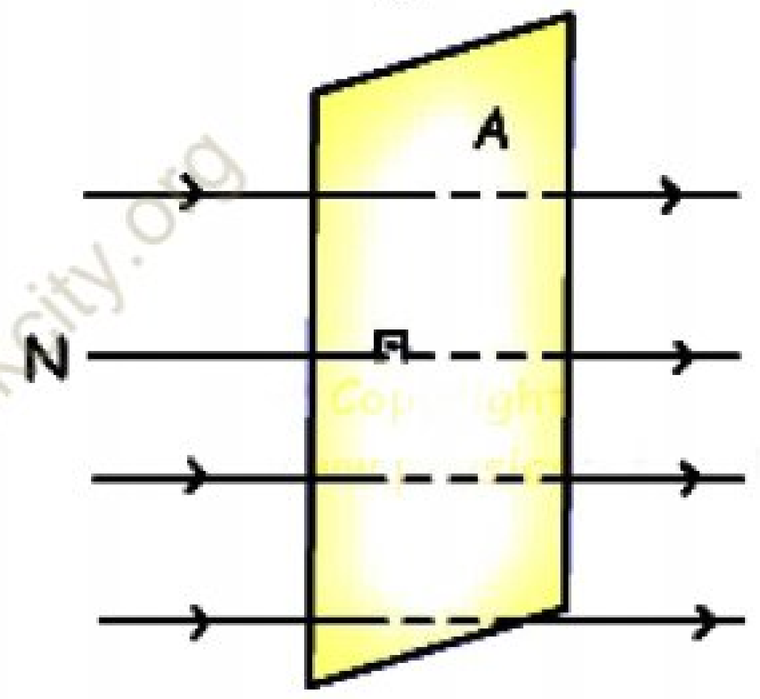
$$\varphi_B = B\Delta A cos\theta$$

Substituting S.I units in above equation

Weber = Tesla m^2

Maximum Flux

The magnetic flux will be maximum if the angle between the magnetic field is parallel to area vector i.e. magnetic lines of forces crossing the surface normally. $\theta = 0°$

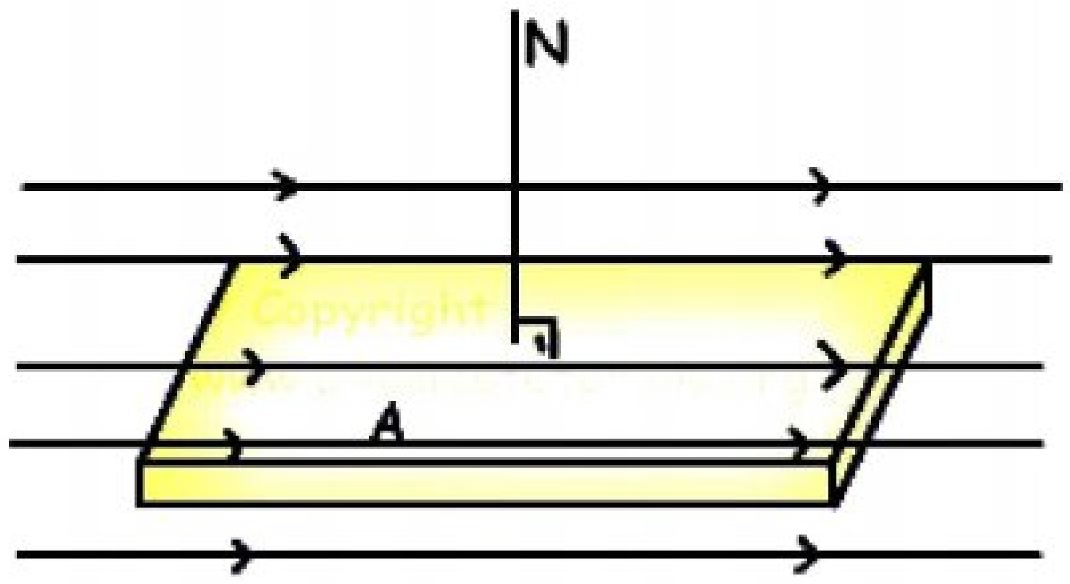


$$\varphi_B = B\Delta A cos\theta$$
$$\varphi_B = B\Delta A cos0°$$
$$\varphi_B = B\Delta A(1)$$
$$\varphi_B = B\Delta A$$

Minimum Flux

The magnetic flux will be minimum if the angle between the magnetic lines of forces and area vector is $90°$ i.e. no magnetic line of force passing through the surface as shown in figure

$$\varphi_B = B\Delta A cos\theta$$
$$\varphi_B = B\Delta A cos90°$$
$$\varphi_B = B\Delta A(0)$$
$$\varphi_B = 0$$



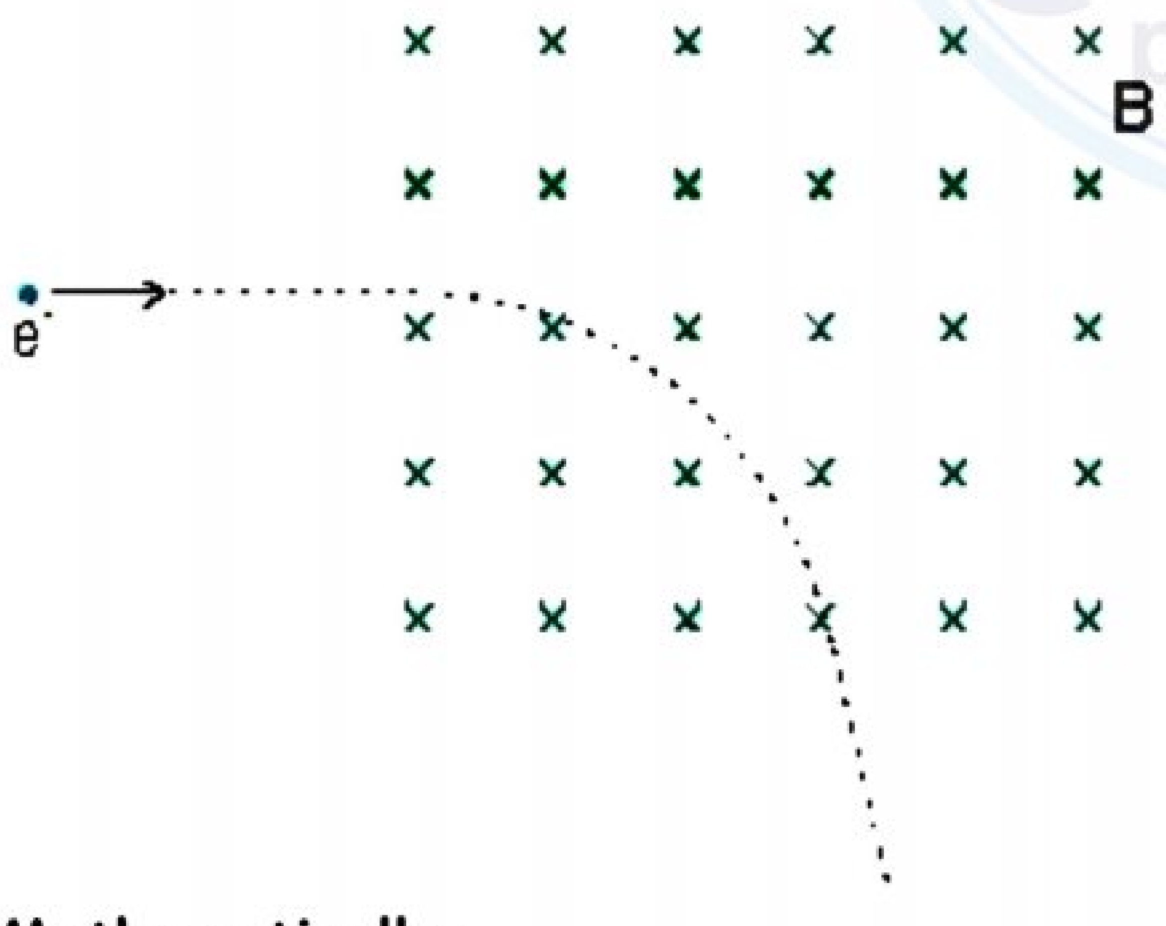
Negative Flux

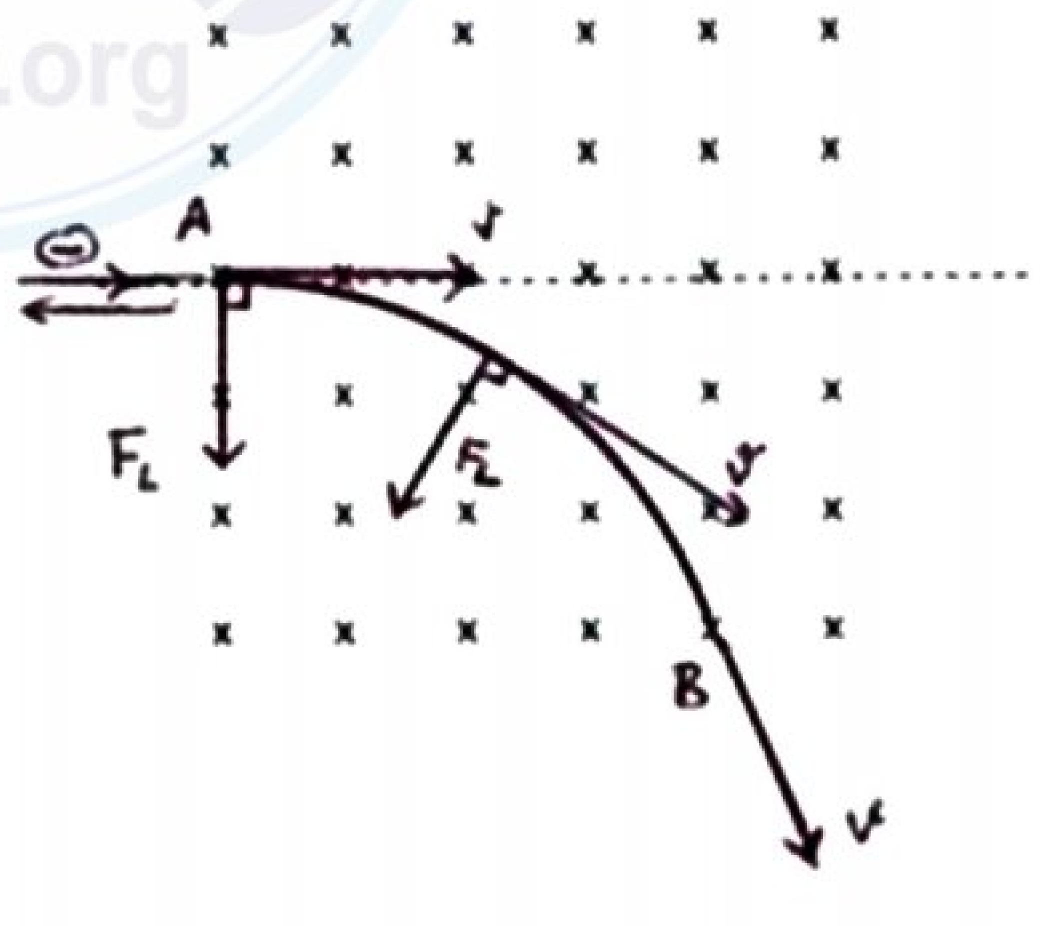
The magnetic flux will be minimum if the magnetic lines of forces are opposite to area vector i.e. $\theta = 180°$

$$\varphi_B = B\Delta A cos\theta$$
$$\varphi_B = B\Delta A cos 180°$$
$$\varphi_B = B\Delta A(-1)$$
$$\varphi_B = -B\Delta A$$

Motion of a charged particle in uniform magnetic field:

Consider a charge particle "q" with mass "m" moving in uniform magnetic field "B" with velocity "v". The charge particle experiences magnetic force as it enters the field and in the result moves in a curve path. The magnitude of velocity remain unchanged but its direction changes from point to point and finally the charge particle moves in a circular path. The magnetic force which is acting towards the centre of circle at any position on the circle provides the necessary centripetal force to the charge particle.





Mathematically:

Let "r" is the radius of circle and "θ" is the angle at which charge particle enters the field, then

$$Magnetic\ force\ =\ Centripetal\ force$$

$$qvBsin\theta = \frac{m(v_{perpendicular})^2}{r}$$

$$vsin\theta = perpendicular\ component\ of\ velocity$$

$$qvBsin\theta = \frac{m(vsin\theta)^2}{r}$$

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

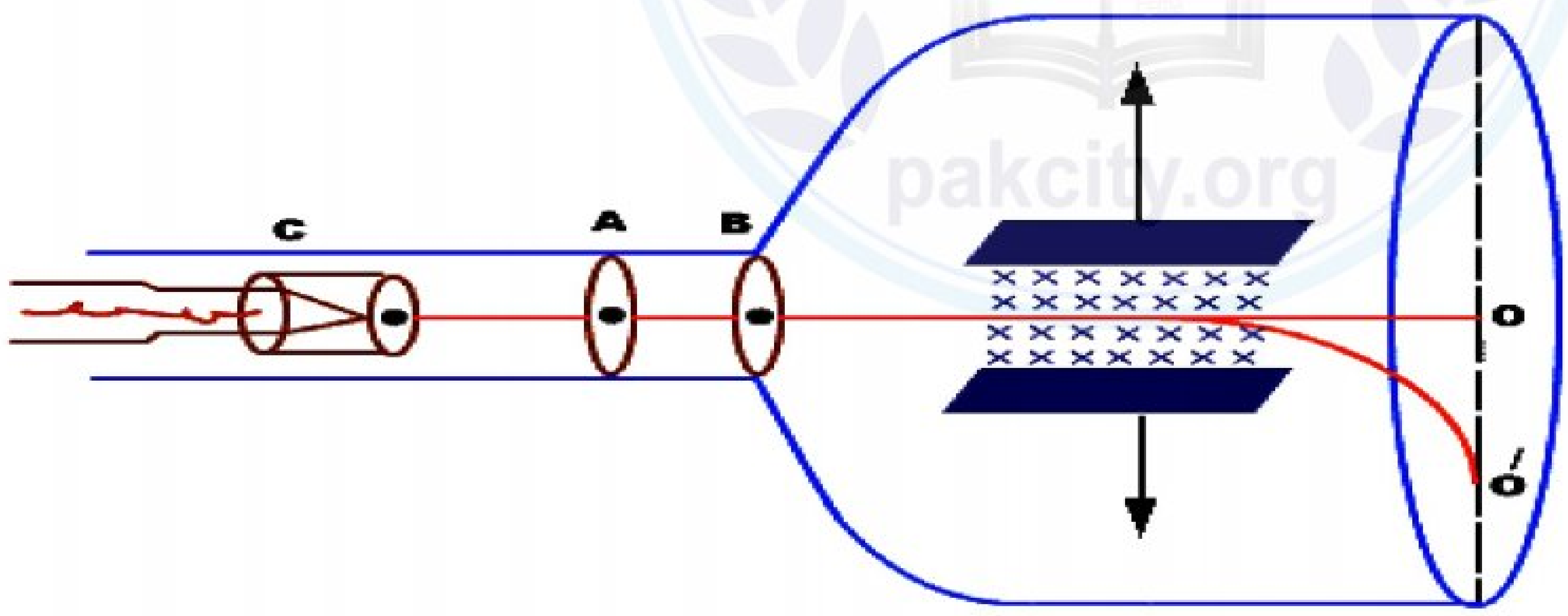
$$eB = \frac{mvsin\theta}{r}$$

$$r = \frac{mvsin\theta}{eB}$$

The e/m ratio of electron by J.J. Thomson method:

Introduction:

The e/m ratio of electron was found by Sir J.J. Thomson. In his method electrons are produced by heating a tungsten filament by passing a current through it. The electrons moving sideways are also directed towards the screen by applying negative potential on a hollow cylinder open on both sides surrounding a filament. The electrons are then accelerated by applying high potential positive voltage to disks A and B. The electron beam produced travels in a straight path and produced the spot on the screen at point o.



Velocity of electron:

If "V" is the total potential difference applied and "v" is the velocity of electron then loss in potential energy is equal to the gain in kinetic energy of electron. The energy equation is given by

Loss in Potential Energy=Gain in Kinetic energy

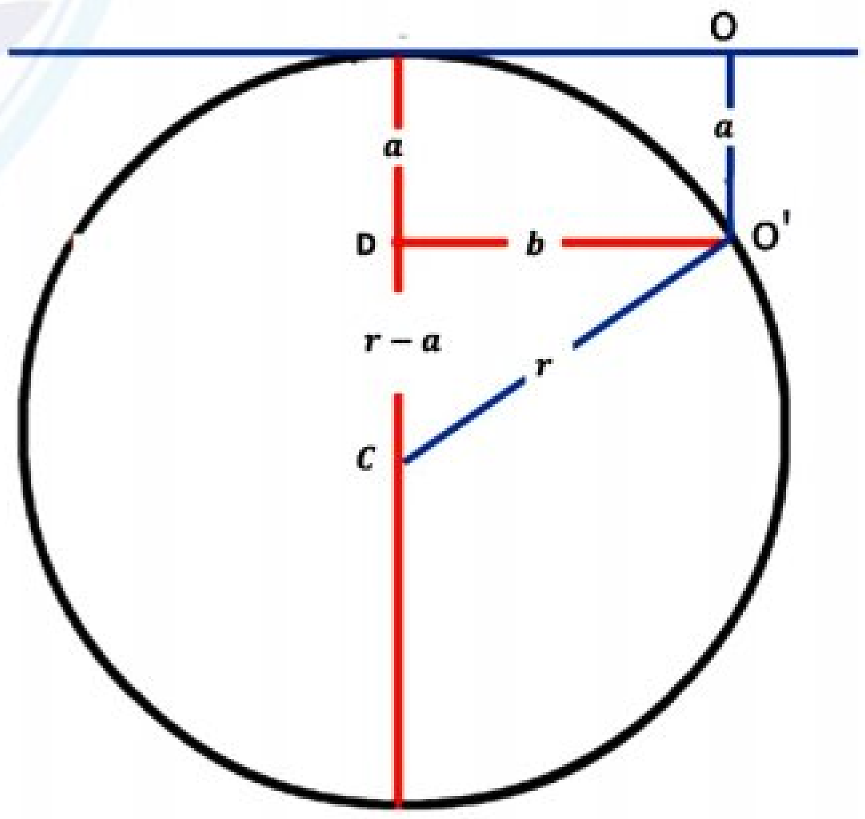
$$qV = \frac{1}{2}mv^2$$
$$eV = \frac{1}{2}mv^2$$
$$v^2 = \frac{2eV}{m}$$
$$v = \sqrt{\frac{2eV}{m}}$$

e/m ratio of electron:

If there is a magnetic field "$\vec{B}$" present b/w the plates directed inside to the page as shown in figure the electron deviated from its straight path and moves in a curve path. The force due to magnetic field on moving electrons makes them move in a circular path a the light spot shifts from o to o' on the screen. The magnetic force on electron provides the necessary centripetal force and

$$evB = \frac{mv^2}{r}$$
$$eB = \frac{mv}{r}$$
$$e/m = \frac{v}{rB}$$

Radius of circular path:



In figure

$a = shift\ of\ electron\ from\ o\ to\ o'$

$b = distant\ travelled\ in\ magnetic\ fields$

$r = radius\ of\ circle$

Applying Pythagoras theorem in right angle triangle ΔO'CD

$Hypotenuse^2 = Base^2 + Perpendicular^2$

$r^2 = (r-a)^2 + b^2$

$r^2 = r^2 - 2ar + a^2 + b^2$

$Since\ a\ is\ very\ small, therefore\ neglecting\ a^2$

$r^2 = r^2 - 2ar + b^2$

$b^2 = 2ar$

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

Neutral Condition:

By applying potential difference between the two horizontal plates electric field is produced to apply electric force on electron in a direction opposite to the direction of magnetic force. The potential difference is adjusted so that the two forces neutralize each other and electron beam pass through the region of electric and magnetic fields without deviation. In this condition

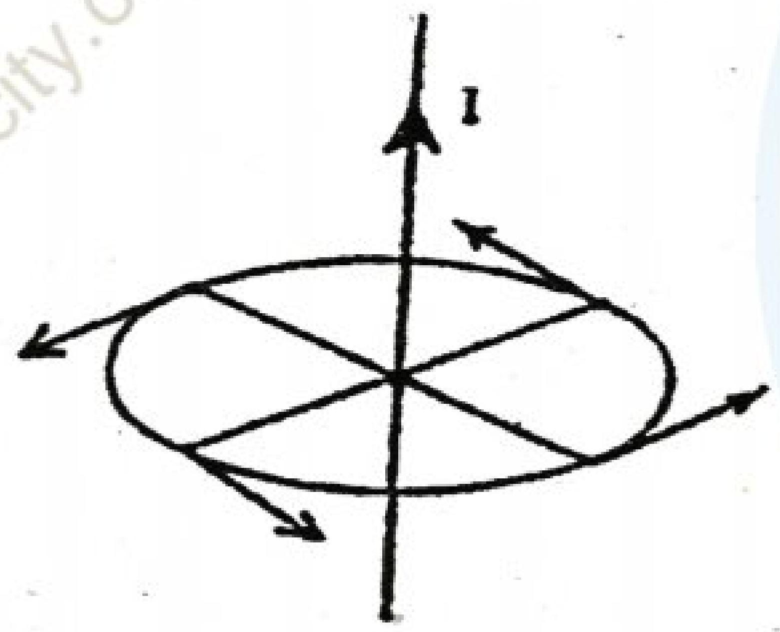
Electric force = Magnetic force

$$qE = qvB$$
$$E = vB$$
$$v = \frac{E}{B}$$

Biot and Savart law:

Statement:

"The magnitude of magnetic field around a straight current carrying conductor is directly proportional to the twice of current and inversely proportional to the distance from the conductor."



Mathematically:

Consider a long straight wire carrying a current "I" in the direction as shown in figure. The magnetic field at all the points on the curve taken in form a circle round the wire is tangential and of the same magnitude.

$$B \propto 2I$$
$$B \propto \frac{1}{r}$$

Comparing both expressions, we get

$$B \propto \frac{2I}{r}$$
$$B = (constant)\frac{2I}{r}$$

$$Here\ constant = \frac{\mu_0}{4\pi}$$

$$where\ \mu_0 = permeiability\ of\ free\ space$$

Substitute the value of constant in above equation, we get

$$B = \left(\frac{\mu_0}{4\pi}\right)\frac{2I}{r}$$

$$B = \frac{\mu_0 I}{2\pi R}$$

Ampere's law:

Statement:

"The sum of the products of the tangential components of magnetic field of induction and the length of an element of a closed taken in the magnetic field is μ_0 times the current which passes through the area bounded by this curve."

Mathematically (Proof):

Consider a long straight wire carrying a current "I" in the direction as shown in figure. The magnetic field at all the points on the curve taken in form a circle round the wire is tangential and of the same magnitude.

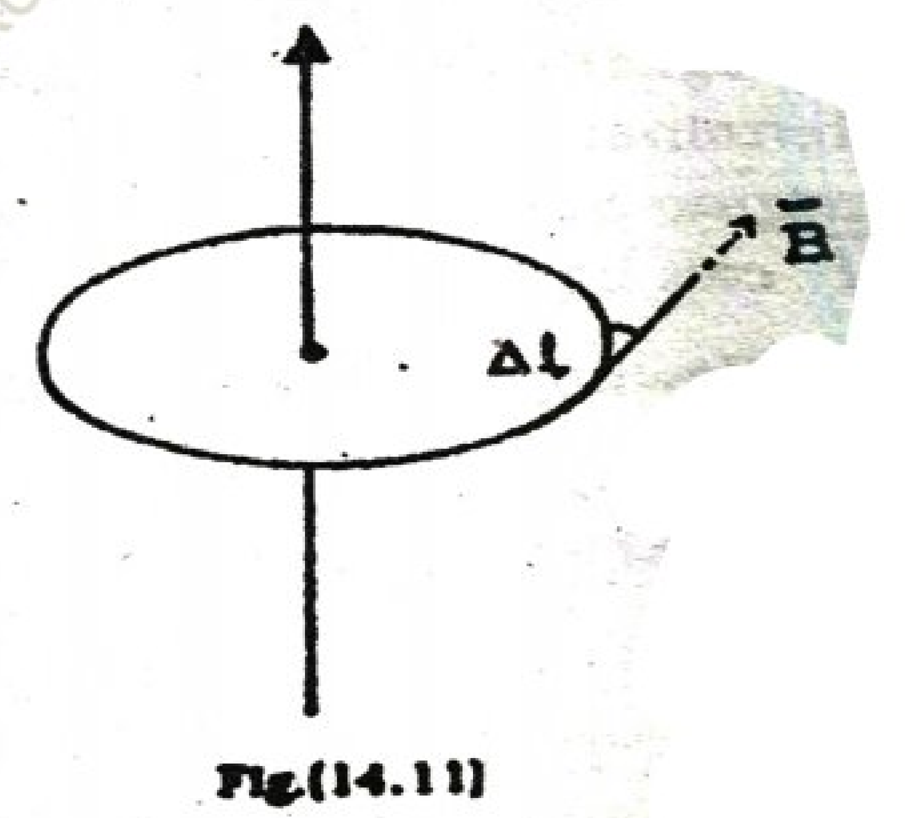


Fig.(14.11)

Let the circle be divided into small elements each of length Δl, such that at all elements the angle between the field and length element is $0°$.

Since we know that

$$\vec{B}.\overrightarrow{\Delta l} = B\Delta l cos\theta$$

$$\vec{B}.\overrightarrow{\Delta l} = B\Delta l cos 0°$$

$$\vec{B}.\overrightarrow{\Delta l} = B\Delta l$$

The sum of these products for all the elements

$$\sum(\vec{B}\,.\overrightarrow{\Delta l}) = \sum B\Delta l cos0^\circ$$

$$\sum(\vec{B}\,.\overrightarrow{\Delta l}) = B\sum \Delta l$$

$$\sum \Delta l \ = sum\ of\ the\ lengths\ of\ all\ elements = circumference\ of\ the\ circle = 2\pi r$$

$$\sum(\vec{B}\,.\overrightarrow{\Delta l}) = B\,(2\pi r) - - - - - (1)$$

According to Ampere's law

$$\sum(\vec{B}\,.\overrightarrow{\Delta l}) = \mu_0 I - - - - - (2)$$

Comparing (1) and (2), we get

$$B\,(2\pi r) = \ \mu_0 I$$

$$B \ = \frac{\mu_0 I}{2\pi r}$$

Applications of Ampere's law:

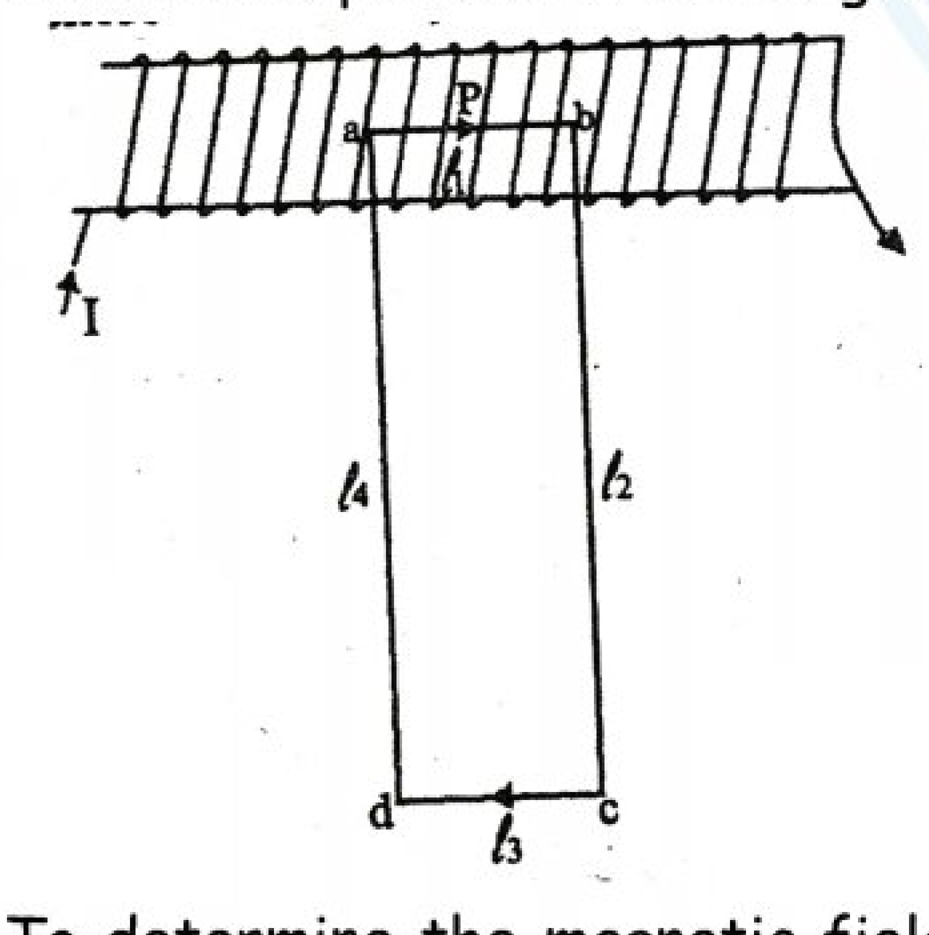
Ampere's law is used to calculate the magnetic field of solenoid and toroid.

Solenoid:

Solenoid is a coil of insulated copper wire wound on a long cylindrical with close turns.

Magnetic field of a Solenoid:

Consider a long solenoid with "N" number of turns. Let current "I" is passing through the solenoid and strong magnetic field is generated inside the solenoid. According to right hand rule the field is parallel to the length of solenoid.



To determine the magnetic field of solenoid consider an imaginary rectangular loop abcd with the side ab on the axis and the side cd far away where the field is zero as shown in figure. The rectangular loop is divided into four elements $l_1, l_2, l_3\ and\ l_4$.

The total magnetic flux of a closed rectangular loop is given by

$$\sum(\vec{B}.\vec{l}) = (\vec{B}.\vec{l_1}) + (\vec{B}.\vec{l_2}) + (\vec{B}.\vec{l_3}) + (\vec{B}.\vec{l_4}) - - - (1)$$

$(\vec{B}.\vec{l_1})$:

$$\vec{B}.\vec{l_1} = Bl_1 cos\theta$$

Since side $\vec{l_1}$ is parallel to the magnetic field $\vec{B}$, therefore magnetic flux is maximum for side ab

$$\vec{B}.\vec{l_1} = Bl_1 cos0°$$

$$\vec{B}.\vec{l_1} = Bl_1(1)$$

$$\vec{B}.\vec{l_1} = Bl_1$$

$(\vec{B}.\vec{l_2})$ and $(\vec{B}.\vec{l_4})$:

Since both sides $\vec{l_2}$ and $\vec{l_4}$ are perpendicular to the magnetic field $\vec{B}$ i.e. $\theta = 90°$, $cos90° = 0$
Therefore the magnetic flux is zero for both perpendicular side bc and ad.

$$\vec{B}.\vec{l_2} = 0$$

$$\vec{B}.\vec{l_4} = 0$$

$(\vec{B}.\vec{l_3})$:

Since side cd is far away from solenoid where the field is very small. It can be neglected and put equal to zero.

$$B = 0$$

Therefore

$$\vec{B}.\vec{l_3} = 0$$

Substituting all values in (1), we get

$$\sum(\vec{B}.\vec{l}) = Bl_1 + 0 + 0 + 0$$

$$\sum(\vec{B}.\vec{l}) = Bl_1$$

In general,

$$\sum(\vec{B}.\vec{l}) = Bl - - - (2)$$

According to Ampere's law the total magnetic flux around closed loop abcd

$$\sum(\vec{B}.\vec{l}) = \mu_0 I$$

For N number of turns

$$\sum(\vec{B}.\vec{l}) = \mu_0 NI - - - (3)$$

Comparing equations (2) and (3), we get

$$Bl = \mu_0 NI$$

$$B = \mu_0 \frac{N}{l} I$$

$$\frac{N}{l} = n = number\ of\ turns\ per\ unit\ length$$

$$B = \mu_0 nI$$

The magnetic field is independent of the position within the solenoid which shows that the field is uniform within a long solenoid. The direction of magnetic field is along the axis of the solenoid.

Toroid:

Toroid is a coil of insulated copper wire wound on a circular core with close turns. It is also called circular solenoid.

Magnetic field of a Toroid:

Consider a toroid with "N" number of turns. Let current "I" is passing through the toroid winding and strong magnetic field is generated inside the core of toroid.

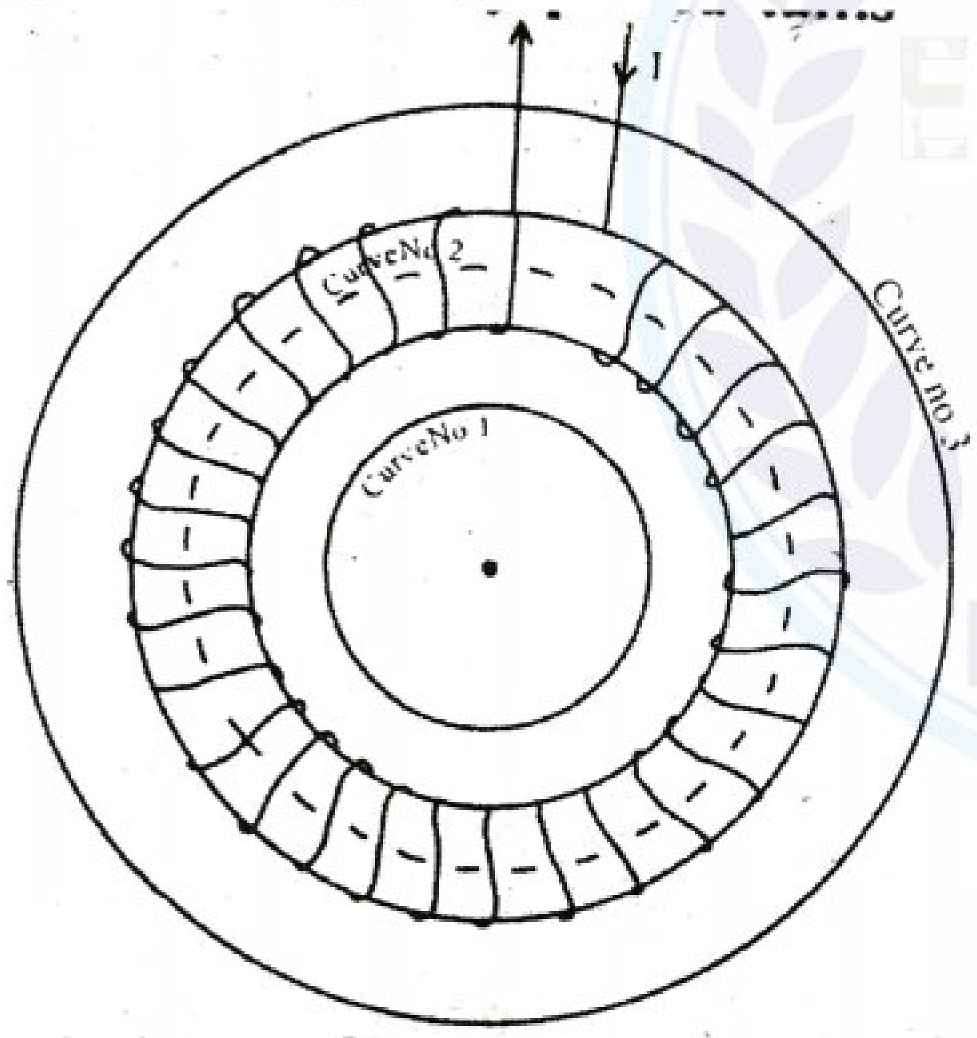


Fig.

To calculate the magnetic field of toroid consider three imaginary curves as shown in figure. Consider the following cases:

1. If the circular path (curve 1) is outside the core on the inner side of the toroid it encloses no current, therefore the magnetic field is zero at curve 1.

$$B = 0$$

2. If the circular path (curve 2) is within the core the area bounded by the curve will be threaded by N turns each carrying a current I. It is evident from symmetry that the field at all points of the curve must have the same magnitude and it should be tangential to the curve at all points. The sum of these products for all the elements

$$\sum(\vec{B}.\vec{\Delta l}) = \sum B\Delta l cos0°$$

$$\sum(\vec{B}.\vec{\Delta l}) = B\sum \Delta l$$

$$\sum \Delta l = Sum\ of\ the\ lengths\ of\ all\ elements = Circumference\ of\ the\ circle = 2\pi r$$

$$\sum(\vec{B}.\vec{\Delta l}) = B\ (2\pi r)$$

3. If the circular path (curve 3) is outside of the core on the outer side of toroid the area bounded by the curve will be threaded by each turns twice but in opposite directions and the algebraic sum of all the currents is zero.

$$B = 0$$

Therefore the magnetic flux at curve 1 and curve 3 is zero and the total magnetic flux of toroid is the magnetic flux at curve 2 i.e.

$$\sum(\vec{B}.\vec{\Delta l}) = B\ (2\pi r) - - - (1)$$

According to Ampere's law

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

Comparing (1) and (2), we get

$$B\ (2\pi r) = \mu_0 NI$$

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

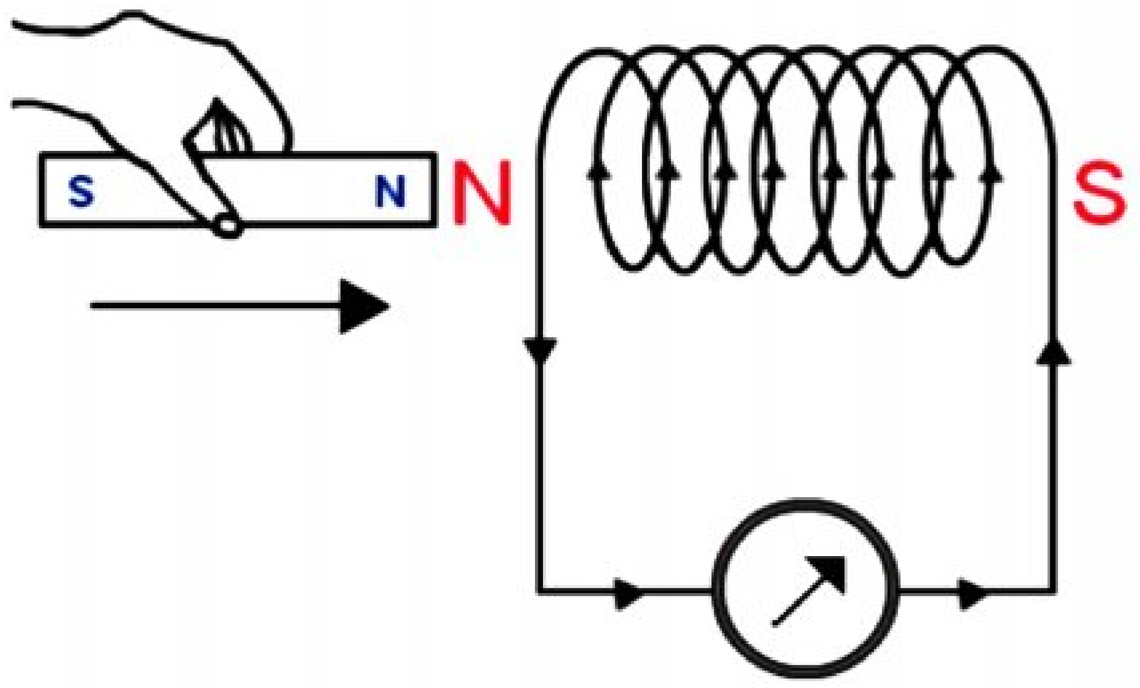
A toroid, therefore, produced a uniform magnetic field of induction which is confined in the space occupied by the core.

Electromagnetic Induction:

Electromagnetic induction is a process in which conductor placed in a magnetic field causes the production of a voltage across the conductor.

Introduction:

In 1830 Joseph Henry in the United States and a year later Faraday in England independently observed that an emf is setup in a coil placed in a magnetic field whenever the flux through the coils changes. This effect is called electromagnetic induction and if the coil forms a part of a closed circuit, the induced emf causes a current to flow in the circuit.



Faraday's law of induction:

Statement:

"The induced emf in a coil is directly proportional to the rate at which magnetic flux is changing and the number of turns in the coil."

Mathematically:

$$\xi \propto \frac{d\varphi_B}{dt}$$

$$\xi \propto N$$

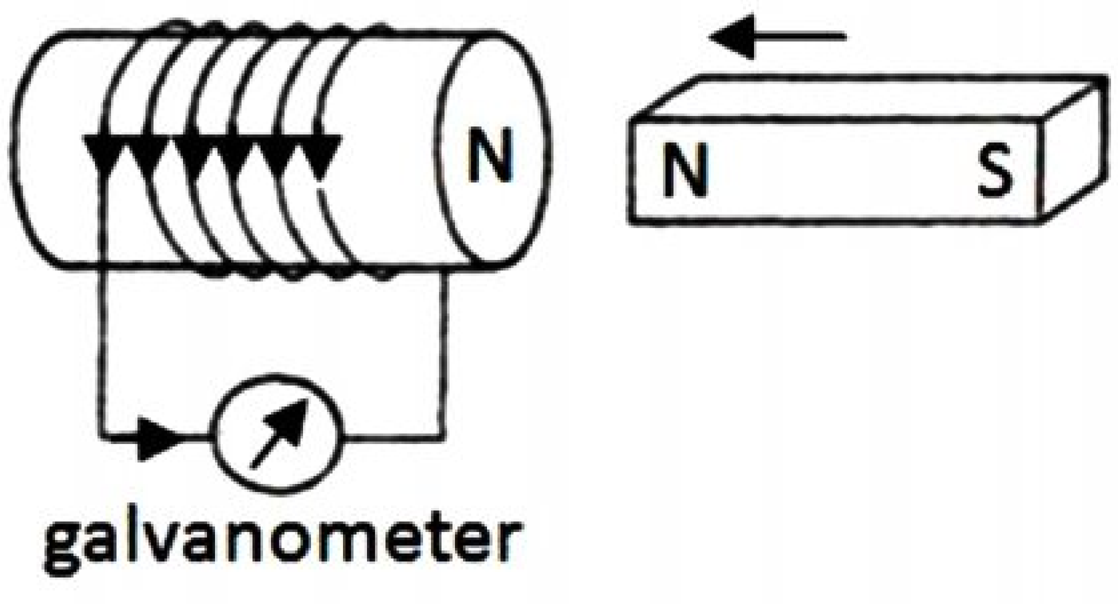
Comparing both expressions, we get

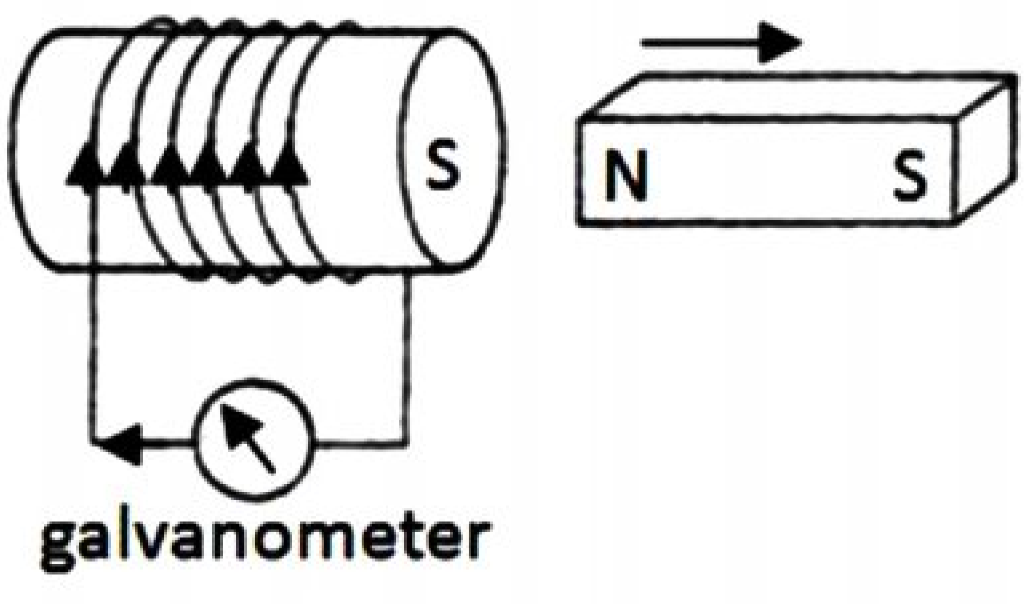
$$\xi = N\frac{d\varphi_B}{dt}$$

Lenz's law:

Statement:

"The induced current always flows in such a direction as to oppose the change which is giving rise to it."



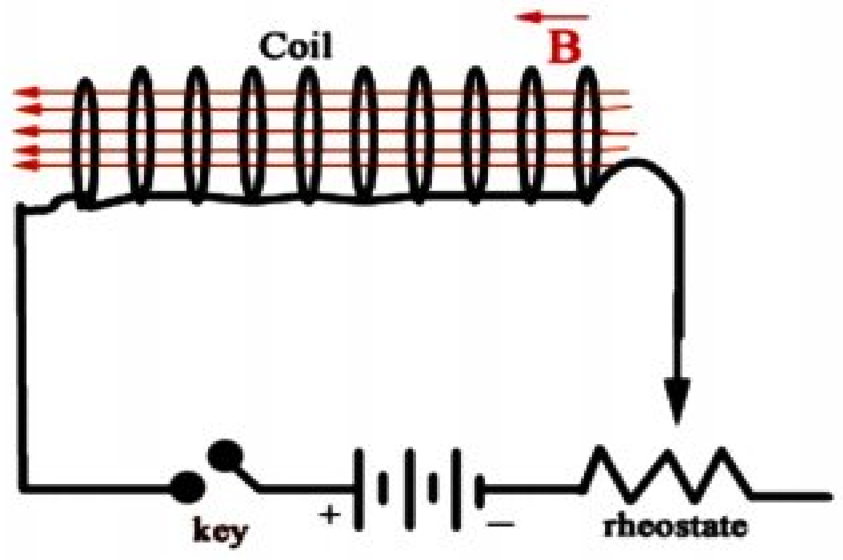


Mathematically:

$$\xi = -N\frac{d\varphi_B}{dt}$$

Self Induction:

When a magnetic flux changes through the coil and emf induces in the same coil then this phenomenon is called self induction.



Mathematically:

A coil through which a current is flowing has an associated magnetic field. If the current changes then magnetic flux does also changes and an emf is induced in the coil. This induced emf is directly proportional to the rate at which magnetic flux is changing

$$\xi \propto \frac{dI}{dt}$$

$$\xi = (constant)\frac{dI}{dt}$$

$$Here, constant = L = Self\ Inductance\ of\ the\ coil$$

$$\xi = L\,\frac{dI}{dt}$$

If the current is increasing, the back emf opposes the increase, if the current is decreasing, it opposes the decrease. Therefore using the concept of Lenz's law

$$\xi = -L\,\frac{dI}{dt} --- (1)$$

According to Faraday's law of induction the induced emf in the coil

$$\xi = -N\,\frac{d\varphi}{dt} --- (2)$$

Comparing (1) and (2), we get

$$-L\,\frac{dI}{dt} = -N\,\frac{d\varphi}{dt}$$

$$LdI = N\,d\varphi$$

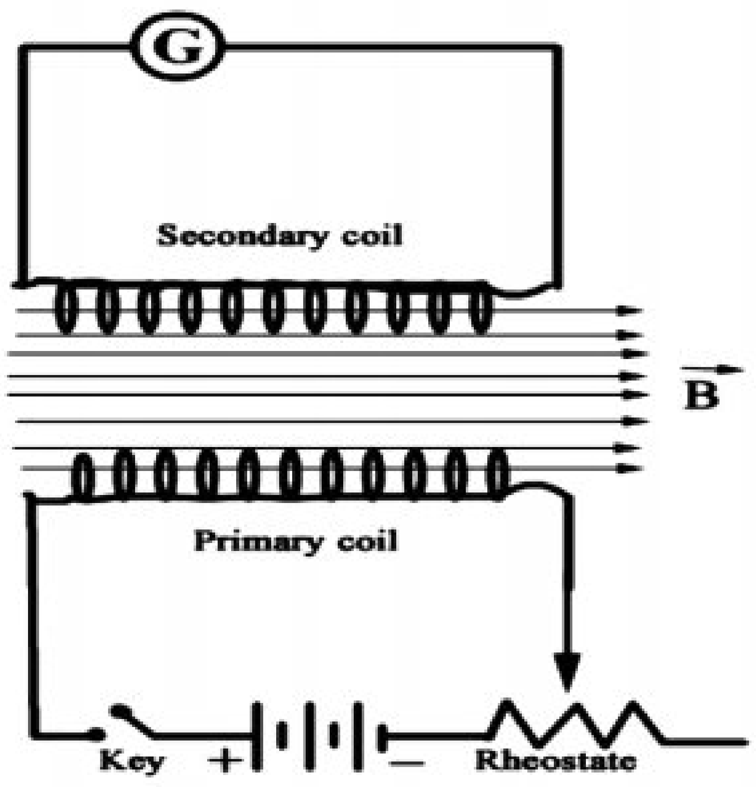
$$d(LI) = d(N\varphi)$$

$$LI = N\,\varphi$$

The self inductance of the coil depends on the dimensions of the coil, the number of turns and the permeability of the core material. The S.I unit of self inductance is Henry.

Mutual Induction:

It two coils are close together, then changing magnetic flux in one coil (primary coil) setup a changing magnetic flux in secondary coil and hence produces an induced emf in secondary coil. This phenomenon is called mutual inductance.



Mathematically:

The induced emf in the secondary coil is directly dependent on the rate at which magnetic flux is changing in the primary coil.

$$\xi_s \propto \frac{dI_p}{dt}$$

$$\xi_s = (constant)\frac{dI_p}{dt}$$

$$Here, constant = M = Mutual\ Inductance\ of\ the\ coil$$

$$\xi_s = M\ \frac{dI_p}{dt}$$

The S.I unit of mutual inductance is Henry. It depends upon the dimensions of the coil, number of turns and permeability of the core material. According to Lenz's law the induced emf always oppose the change which causes this emf, therefore

$$\xi_s = -M\ \frac{dI_p}{dt} --- (1)$$

Since we know that the Faraday's law of induction for induced emf in a secondary coil

$$\xi_s = -N_s\frac{d\varphi_s}{dt} --- (2)$$

Comparing (1) and (2), we have

$$-N_s \frac{d\varphi_s}{dt} = -M \frac{dI_p}{dt}$$
$$N_s d\varphi_s = M\, dI_p$$
$$d(N_s\varphi_s) = d(MI_p)$$
$$N_s\varphi_s = MI_p$$

Motional EMF:

When a conductor is moved across a magnetic field, a potential difference appears across the ends. This potential difference is known as motional emf.

Derivation:

Consider a wire of length "l" moving across the magnetic field of induction "B" with a velocity "v" as shown in figure. Each free electron of the conductor is moving with the conductor and thus experiences a force which is give by

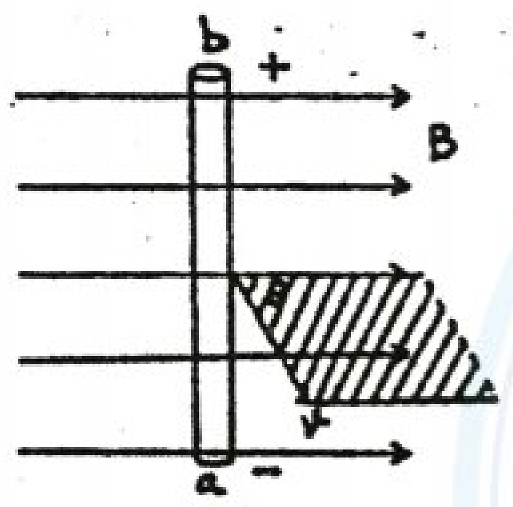


fig.(14.19.)

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

The electrons are flows toward end a leaving the end b with positive charge till the force of electric field balance the force due to the motion of conductor. Thus a potential difference is setup b to a

Potential difference = work done by unit charge

$$V = \frac{W}{q}$$
$$V = \frac{Force\ x\ distance}{q}$$
$$V = \frac{qvB\sin\theta\ x\ l}{q}$$
$$V = vBL\sin\theta$$

If the conductor is moving at right angles to the field i.e. $\theta = 90°$.

$$V = vBL\sin 90° = vBL(1)$$
$$V = vBL$$

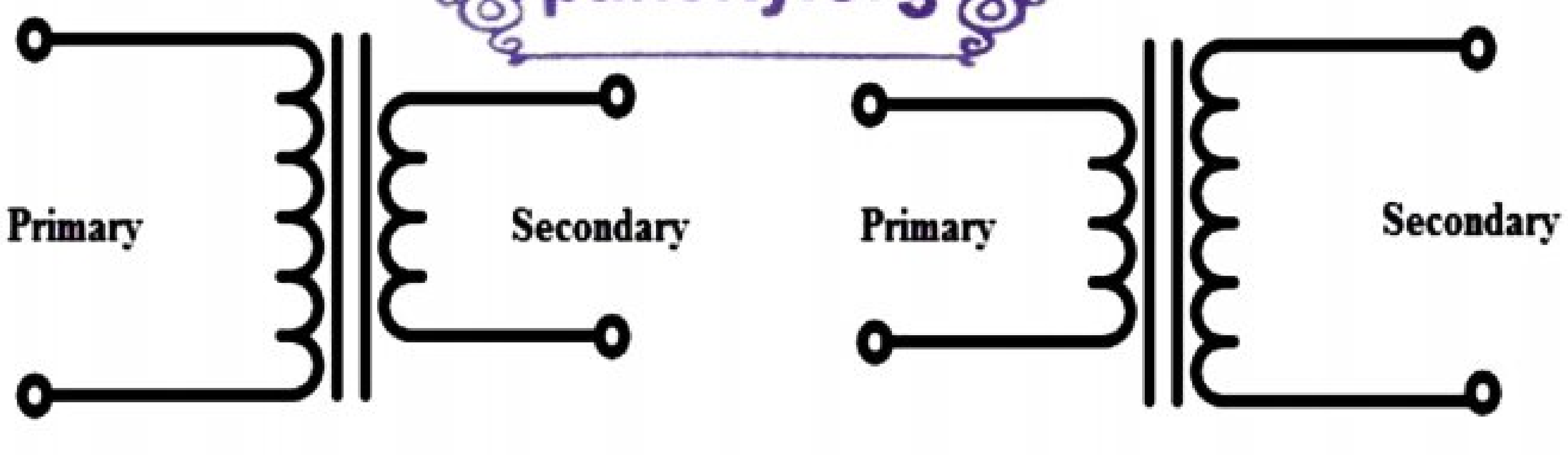
Transformer:

Definition:

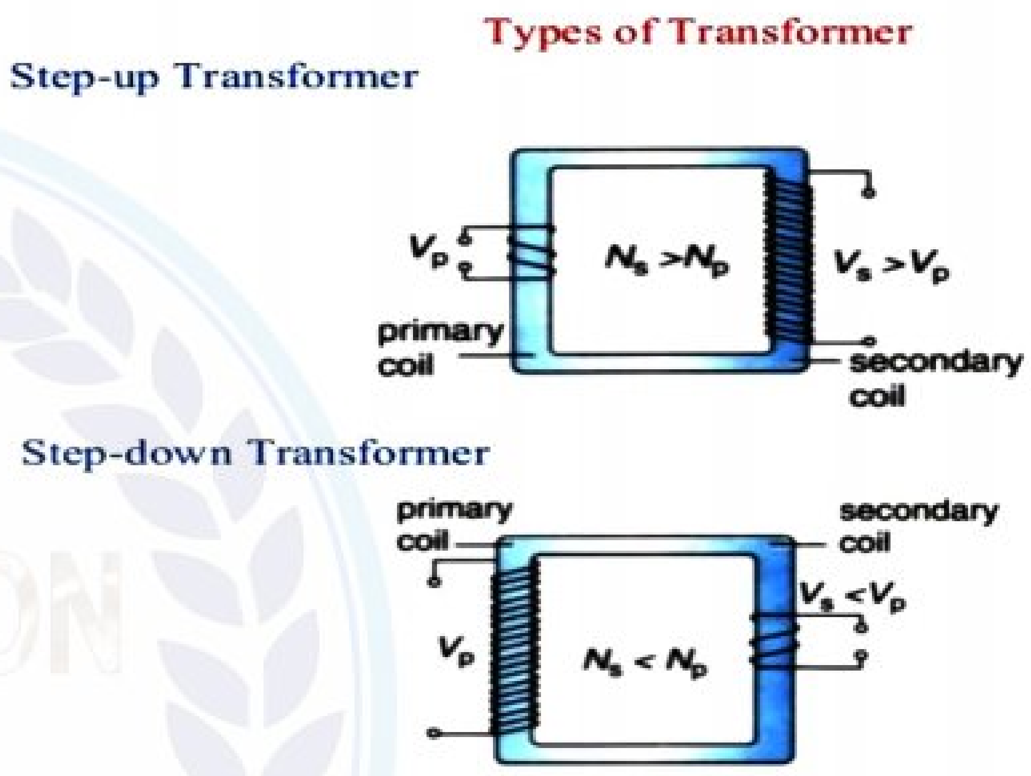
Transformer is a device which is used to step up or step down an alternating emf.

Principle:

It works on the principle of mutual induction and explained on the basis of Faraday's law of electromagnetic induction.



Step-down Transformer



Types of Transformer

There are two types of transformers based on the ratio of output to the input voltage.

1. Step-up Transformer
2. Step-down Transformer

Step up Transformer:

In step-up transformer the number of turns in secondary coil is greater than the number of turns in primary coil.

$$N_S > N_P$$

Step down Transformer:

In step-down transformer the number of turns in secondary coil is less than the number of turns in primary coil.

$$N_S < N_P$$

Construction:

Two coils of insulated copper wire, the primary and secondary, are wound, one on top of the other, on a laminated soft iron core and thus theses are linked magnetically. The presence of the soft iron ensures that all the flux associated with primary coil also passes through the secondary coil.

Working:

Suppose that an alternating emf V_p is applied to the primary coil. Since the input voltage is A.C. i.e. varying current is flowing in primary coil therefore magnetic flux is changing in primary coil.

The changing flux associated in the primary coil also passes through the secondary coil and induces emf in the secondary coil.

Ratio of Output to the input voltage:

According to Faraday's law of inductance the voltage V_p in primary coil is given by

$$V_p = N_p \frac{d\varphi}{dt} --- (1)$$

Let V_s is the voltage induced in the secondary coil then Faraday's law of induction for secondary coil is given by

$$V_s = N_s \frac{d\varphi}{dt} --- (2)$$

Divide equations (1) and (2), we get

$$\frac{V_S}{V_P} = \frac{N_S}{N_P}$$

Efficiency of Transformer:

When a load (resistance) is connected across secondary, a current I_s flows in the secondary. Suppose that the current in the primary is I_p. If the transformer is 100% efficient.

Power output = Power input

$V_s I_s = V_P I_P$

Efficiency of a transformer, $\eta = \frac{Power\ Output}{Power\ Input}$

$$\eta = \frac{V_S I_S}{V_P I_P}$$

In terms of percentage

$$\eta\% = \frac{V_S I_S}{V_P I_P} \times 100$$

Power losses in Transformer:

There are four types of power losses in transformer

- Eddy current losses
- Hysteresis losses
- I^2R losses
- Flux leakage losses

1. **Eddy Current losses (Circulating Current losses):**

   In transformer A.C. voltage is supplied to the primary windings which produce alternating emf in secondary winding. When changing flux in primary coil links with secondary at the same time some part of this flux also get linked with some other parts of the transformer (e.g. soft iron core) which results small circulating current in them. This current is called eddy current. This current produce heating effect in the core of the transformer.

   Correction method:

   To reduce eddy losses the core is laminated i.e. made up of thin sheets of soft iron each separated from the next by a layer of insulating varnish. These very nearly eliminate eddy current losses.

2. **Hysteresis losses (Core losses):**

   Each time the direction of magnetization of the core is reversed, some energy is wasted in overcoming in internal friction. This is known as hysteresis losses or core losses and it produce heating in the core.

   Correction method:

   It is minimized by using core of high permeability.

3. **I^2R losses (Copper losses):**

   Some energy is dissipated as heat in the primary and secondary coils of transformer which is called copper losses or I^2R losses.

   Correction method:

   This is reduced by using suitably thick wire.

4. **Flux Leakage losses (Stray losses):**

   Some loss of energy occurs because a small amount of the flux associated with the primary coils fails to pass through the secondary coil and this small flux passes through winding insulation and transformer insulating oil.

   Correction method:

   Flux leakage losses can be reduced by making some special designs of core for primary and secondary windings.

Dynamo:

Dynamo is a device which converts either mechanical energy into electrical energy or electrical energy into mechanical energy e.g. generator or motor.

Generator:

An electric generator is a device which converts mechanical energy into electrical energy.

A.C. Generator;

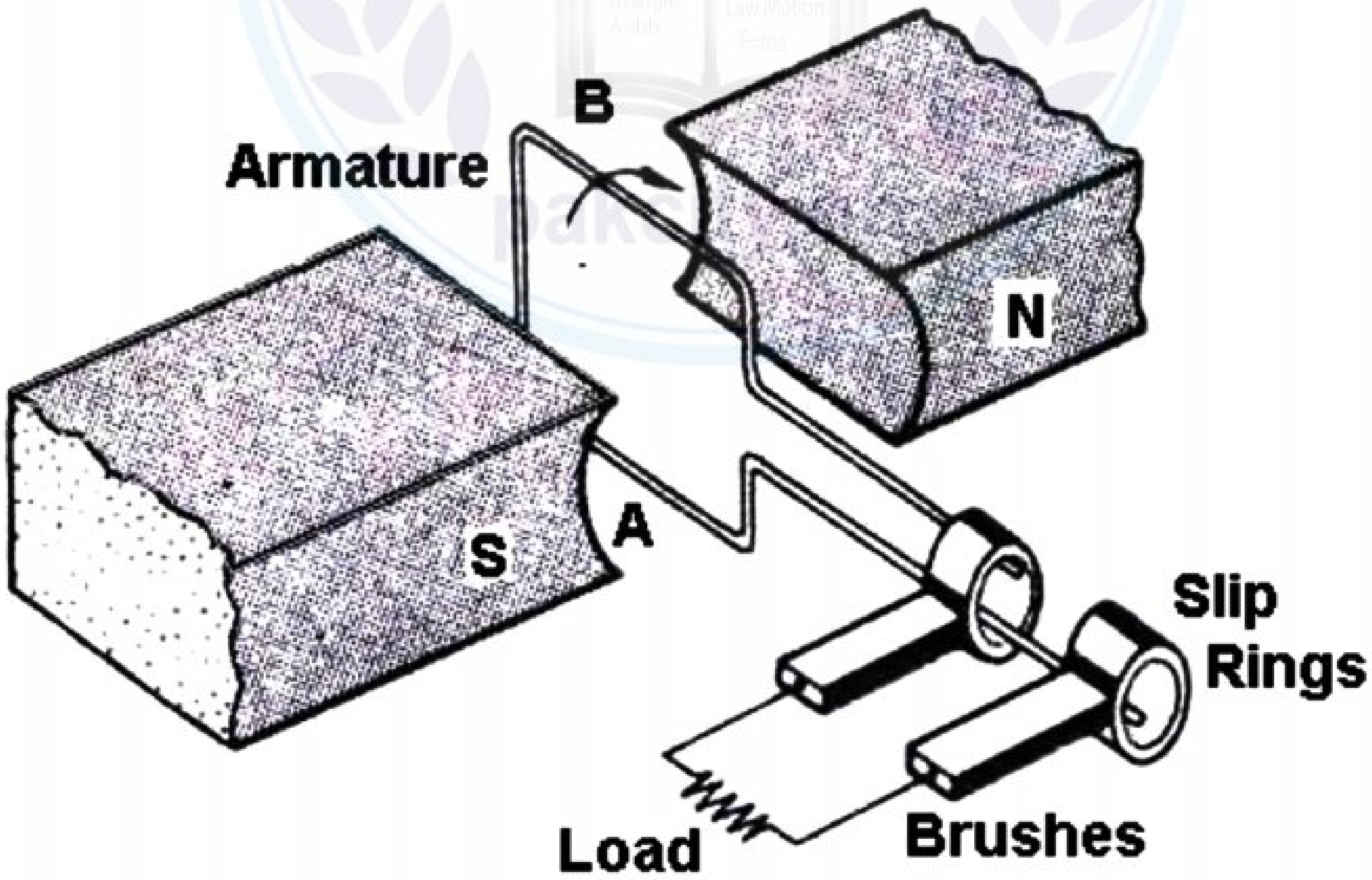
AC generator is a device which converts mechanical energy into alternating current.

Principle:

The principle of the generator is that an emf is induced in the coil due to changing magnetic flux.

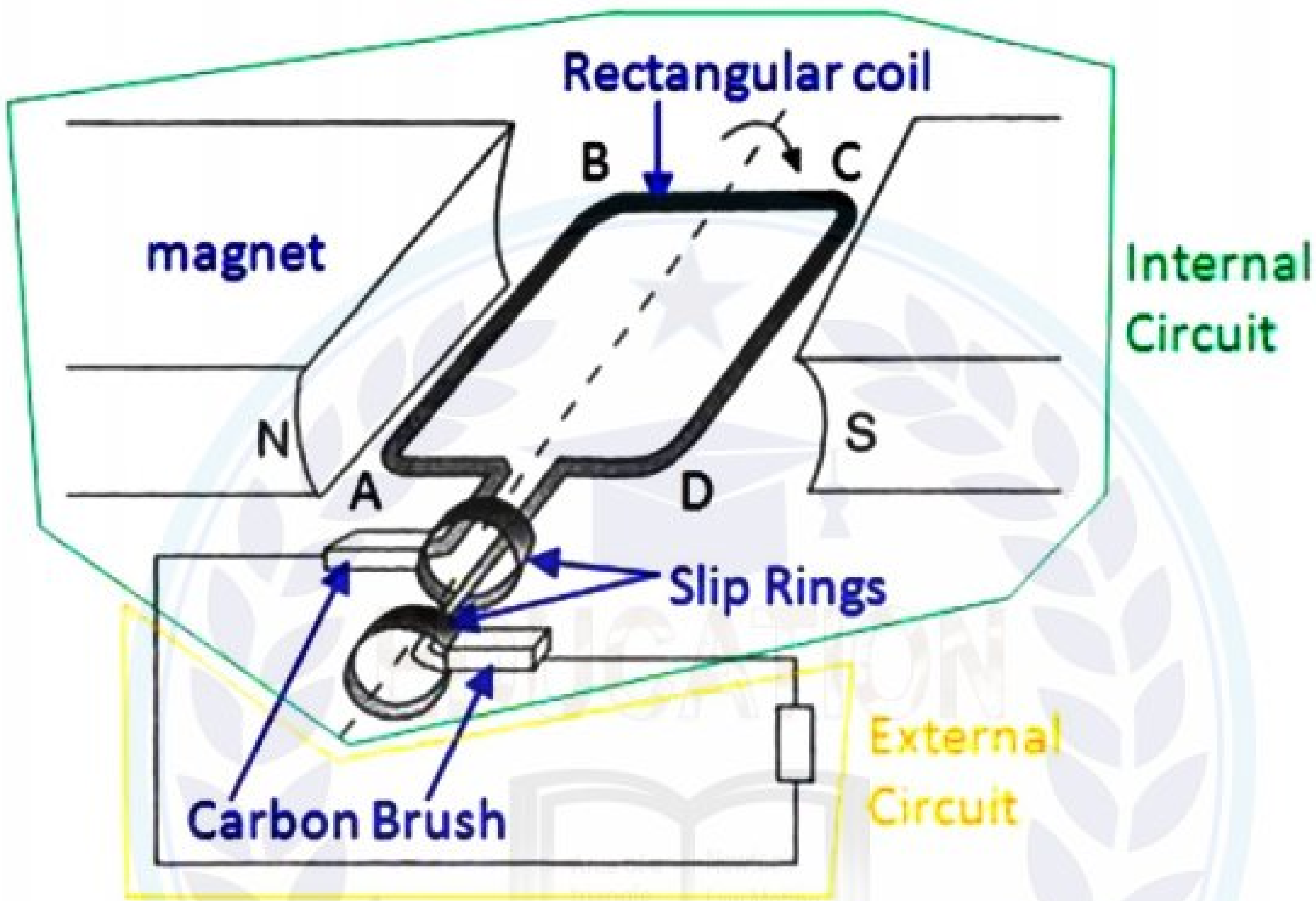
Construction:

1. **Field Magnet:** It is a strong magnet to produce a strong and uniform magnetic field $\vec{B}$.
2. **Armature:** Armature of the coil consists of a large number of turns of insulated copper wire wound on a laminated soft iron core.
3. **Slip rings and** The ends of the coil are joined to two separate copper rings fixed on the axle. These slip rings rotates along with the armature.
4. **Collecting Brushes:** Carbon brushes make contact between the armature and external circuit. These brushes remain pressed against each of the rings which form the terminals of the external circuit.



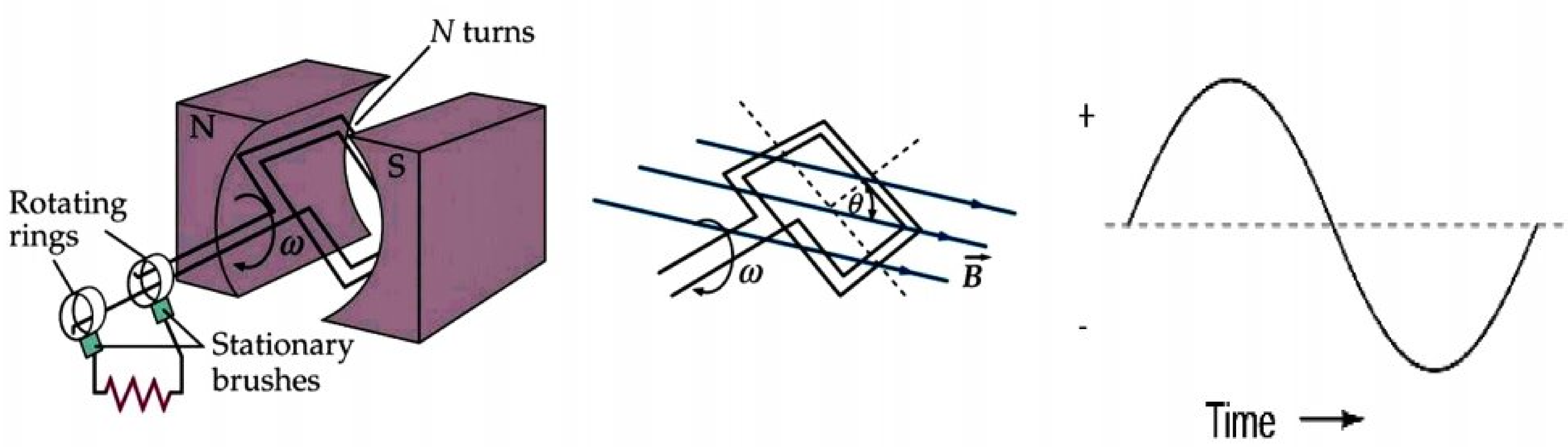
Working:

As the coil rotates clockwise, one side of the rectangular coil moves inward and other side outward. Therefore changing magnetic flux induces emf and current flows in the coil. The slip ring also rotates with the coil and sliding over carbon brushes. Carbon brushes are used to provide stationary contacts between external circuit and rectangular coil. The induced current thus flows in the external circuit through stationary carbon brushes. As the face of the coil changes from one side to another the magnetic flux changes in the reverse direction and the direction of current becomes reverse. We therefore see that the induced current in the external circuit changes direction after every half rotation of the coil.



Derivation:

A motional emf is setup in each of the two sides AB and CD in opposite directions when the coil is rotated because these sides are moving in opposite sense with respect to the magnetic field. Since the other two sides AD and BC are moving in the same sense with respect to field. The emfs are induced in the same direction and cancel each other.



Let

$v = linear\ velocity$

$B = Magnetic\ field\ of\ induction$

$N = Number\ of\ turns$

$l = length\ of\ the\ verticla\ side\ of\ the\ coil$

$\xi = emf\ produced\ in\ the\ coil$

$\omega = angular\ velocity$

$b = width\ of\ the\ coil$

$A = area\ of\ the\ rectangular\ coil$

$The\ motional\ emf\ produced\ in\ the\ two\ sides\ of\ the\ coil\ is\ given\ by$

$$\xi = 2vBNl\sin\theta - - - - - (1)$$

$Since\ we\ know\ that\ angular\ velocity, \omega = \frac{\theta}{t}$

$Therefore, \theta = \omega t, substitute\ this\ value\ in\ equation\ (1), we\ get$

$$\xi = 2vBNl\sin\omega t - - - -(2)$$

$The\ relation\ between\ linear\ velocity\ and\ angular\ velocity$

$$v = r\omega - - - - - - -(3)$$

$Since\ each\ particle\ of\ the\ both\ side\ rotates\ in\ a\ circle\ of\ radius\ half\ of\ the\ width\ of\ the\ rectangular\ coil, therefore$

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

$Substitute\ this\ value\ in\ (3), we\ get$

$$v = \left(\frac{b}{2}\right)\omega$$

$Put\ this\ value\ in\ equation\ (2), we\ get$

$$\xi = 2\left(\frac{b}{2}\right)\omega BNl sin\omega t$$

$$\xi = b\omega BNl sin\omega t$$

$$\xi = (bl)\omega BN sin\omega t$$

$$\xi = (A)\omega BN sin\omega t$$

$$\xi = N\omega AB sin\omega t$$

$Since\ we\ know\ that\ \omega = 2\pi f, therefore$

$$\xi = N\omega AB sin 2\pi ft$$

This equation shows that the alternating emf changes with the time.

Problem 14.14:

A 100 turns coil in a generator has an area of 500 cm^2 rotates in a field with B = 0.06 Weber / m^2. How fast must the coil rotated in order to generate a maximum voltage of 150 volts.

Ans.

Given Data

N = 100

A = 500 cm^2 = 500 x 10^{-4} m^2

B = 0.06 Weber / m^2

How fast must the coil rotated, ω = ? (angular speed)

Maximum voltage, $\xi = 150\ volts$

Solution:

Since we know that

$\xi = N\omega AB sin\omega t$

$\xi_{max} = N\omega AB$

$150 = (100)(\omega)(500 \times 10^{-4})(0.06)$

$150 = (0.3)(\omega)$

$\frac{150}{0.3} = \omega$

$\omega = 150\ rad/second$

Magneto:

A small generator employing a permanent magnet is called magneto and it is used in ignition system of petrol engines, motor bikes and motor boats etc.

Alternators:

The field magnets of large generators are electromagnets and these generators are called alternators.

Stator and Rotor:

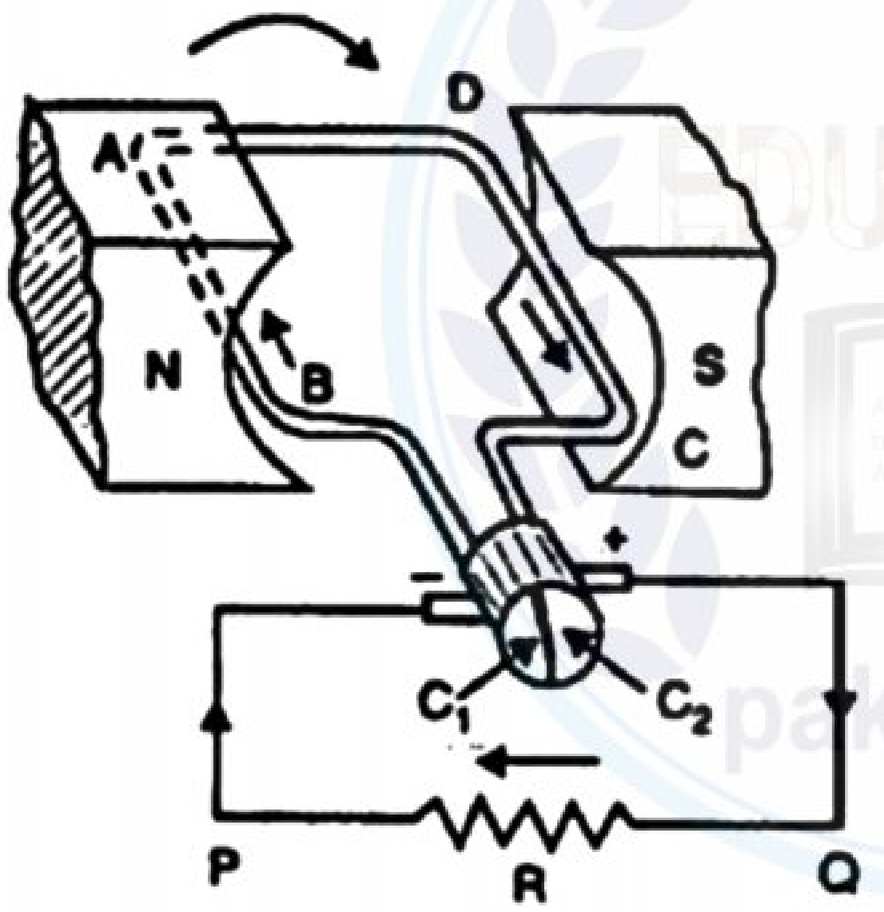
When the armature is stationary and the field magnet rotates around the armature then this is called stator and rotating magnet is called rotor.

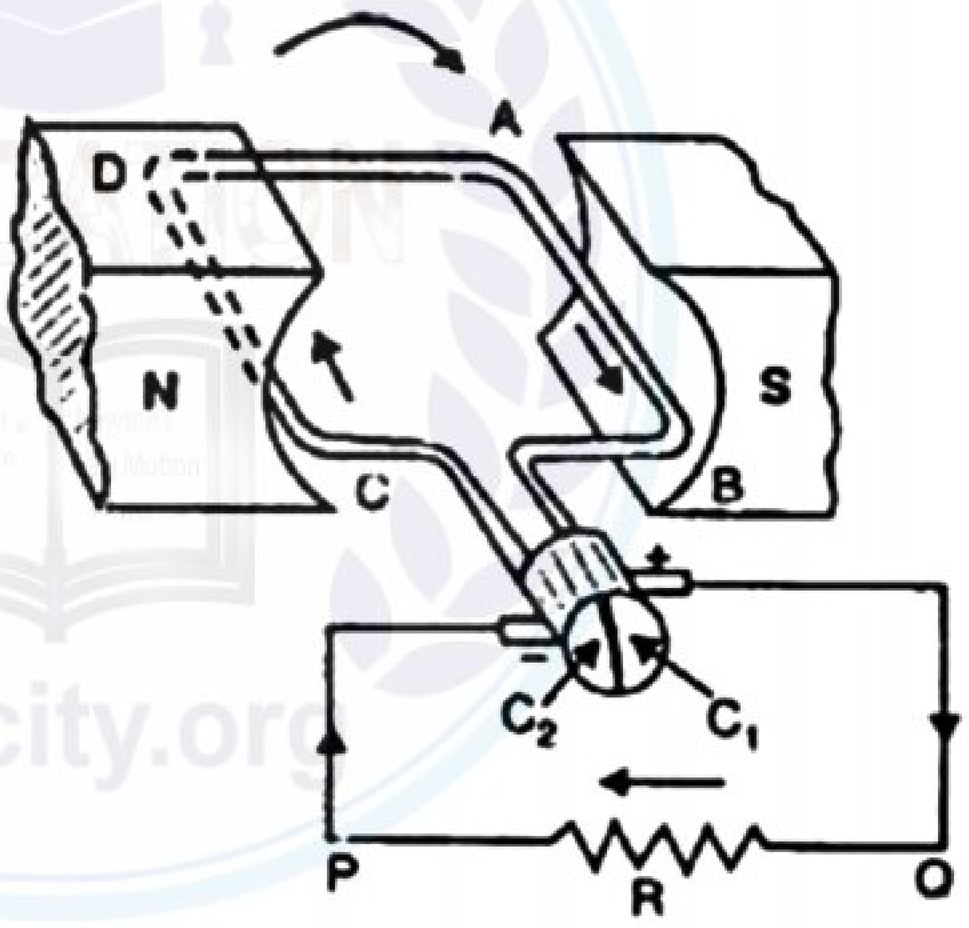
D.C. Generator:

DC generator is a device which converts mechanical energy into direct current.

Commutator:

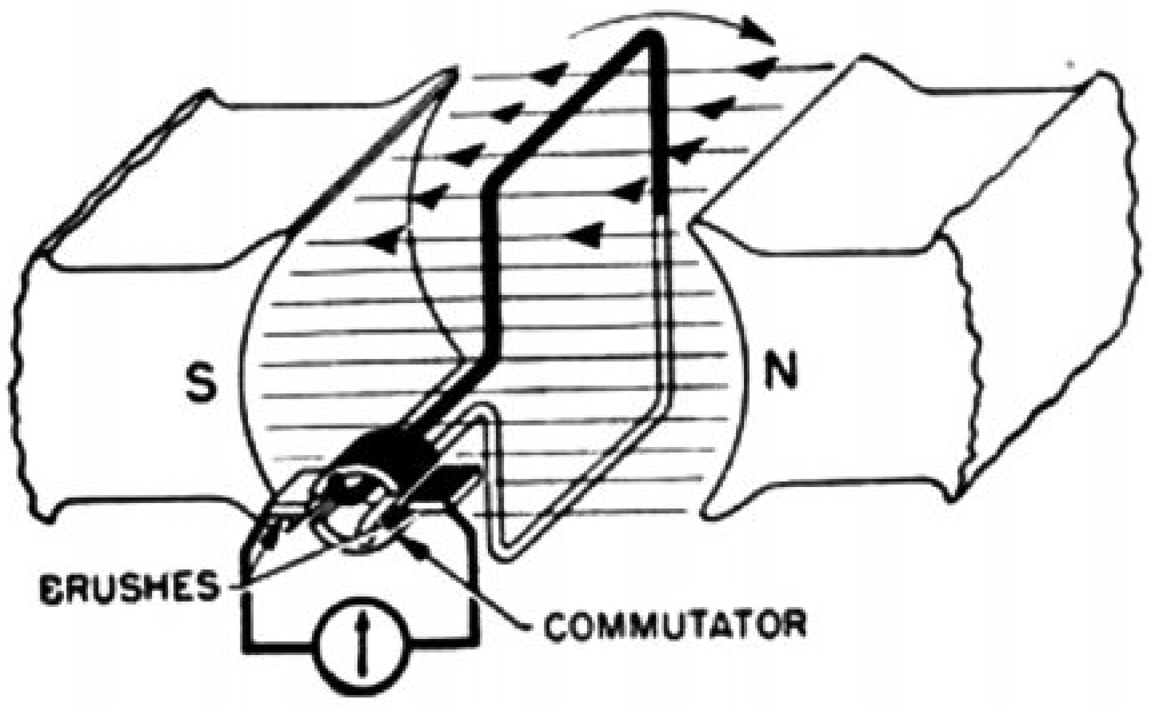
By replacing the slip rings of an A.C. generator by split ring, or Commutator, the generator can be made to produce a direct current through the external circuit.





Working of Commutator or D.C. Generator:

As the coil rotates past its next vertical position, an emf is induced in the coil in the reverse direction. At the same time the two halves of the split rings exchange their contacts with the external i.e. carbon brushes so that the direction of induced emf in the external circuit remains unchanged.



Electric Motor:

An electric motor is a device which converts electrical energy into mechanical energy.

D.C. Motor:

A simple D.C. motor convert electrical energy into mechanical energy when direct current is applied to it.

Working:

When a current is passed through a coil capable of rotation in a magnetic field of induction then it experiences a couple which is given by

$$\tau = BINA\cos\alpha$$

This couple rotate the coil in anticlockwise direction. The couple becomes zero when the face of the coil is perpendicular to the field. As the coil complete half rotation the Commutator reverse the direction of the current. It follows that the current in the rectangular loop always flow in the same direction i.e. clockwise and therefore the coil rotates in anticlockwise direction.