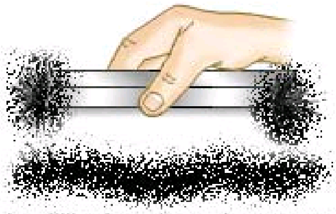
UNIT -18 MAGNETIC FIELDS

MAGNETISM

Magnets have been known to humans for over two to three thousand years. Magnets attract some other substances and are generally made up of iron. Nickel also shows magnetic behavior sometimes. Alloys of Fe-Ni and a few different elements added to them show magnetism.

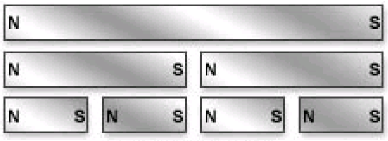
PROPERTIES OF MAGNETS

If you bring iron filings or iron nails close to a magnet, the filings or nails will get attracted to the magnetic poles. The centre of the magnet does not attract the filings or the nails.



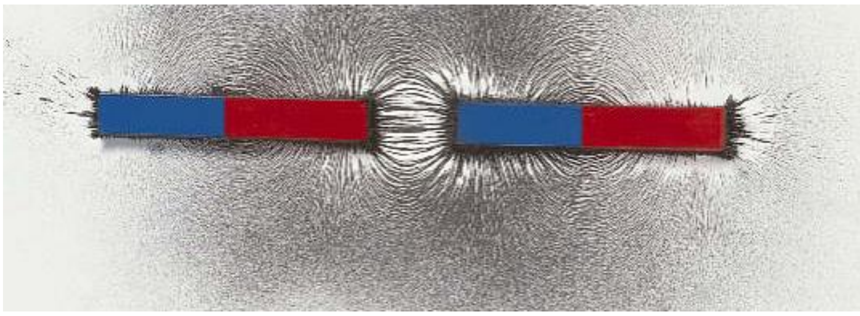
Iron filling form dense clusters near the ends of the magnet

If you break up a magnet, new north and south poles will form immediately. A magnetic pole cannot be isolated.



Breaking a Magnet

If you spread iron filings around a magnet, they will align along the lines in a curved fashion, starting from one pole and ending on the next. These lines are called lines of force of the magnet.



THE MAGNETIC FIELD

We begin our study of magnetism with a few general observations regarding magnets and the fields they produce. These observations apply over a wide range of scales—from the behavior of small, handheld bar magnets to the global effects associated with the Earth's magnetic field.

(a) Opposite poles attract (b) Like poles repel

UNIT -18 MAGNETIC FIELDS

INTRODUCTION:

A magnetic field is a fundamental concept in physics that describes the region around a magnet or a current-carrying conductor where magnetic forces are exerted on other magnets, conductors, or charged particles.

Permanent magnets, such as iron magnets, have their intrinsic magnetic fields due to the alignment of their magnetic domains.

Magnetic fields have numerous practical applications, including:

Electric motors
Transformers
MRI machines (Magnetic Resonance Imaging)
Magnetic levitation trains
Magnetic compasses
Magnetic data storage (hard disk drives)

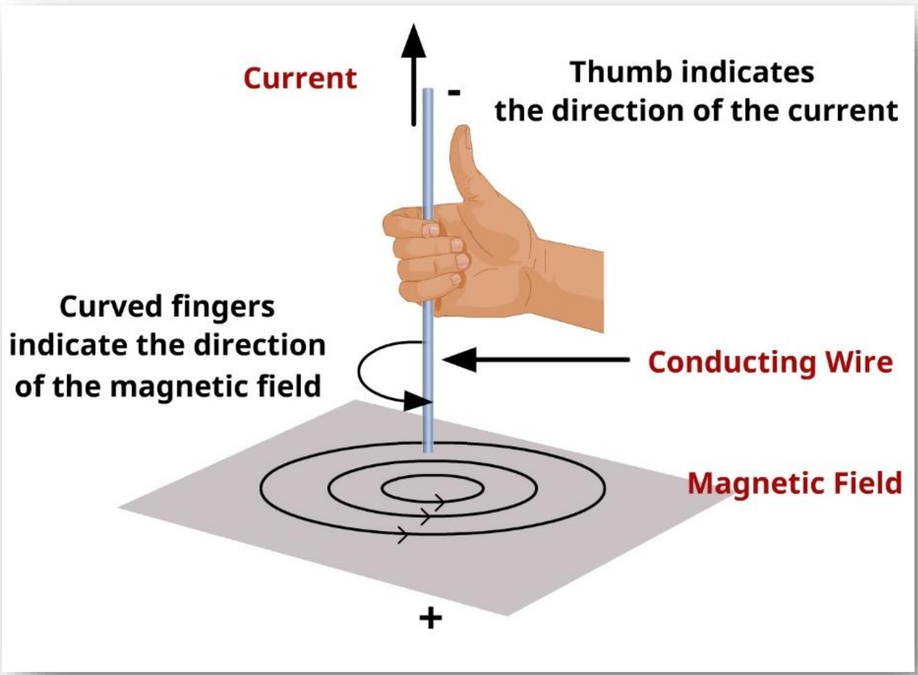
MAGNETIC FIELDS:

The magnetic field can be defined as "***An area around a permanent magnet or a current-carrying conductor, where they generate a magnetic force***." Unlike in electrostatics, where electric charges create an electric field and exert electric forces on other charges, the magnetic field lacks a direct counterpart due to the absence of magnetic monopoles.

The magnetic field can be generated through two primary methods:

From permanent magnets.

From current carrying conductors, also known as electromagnets

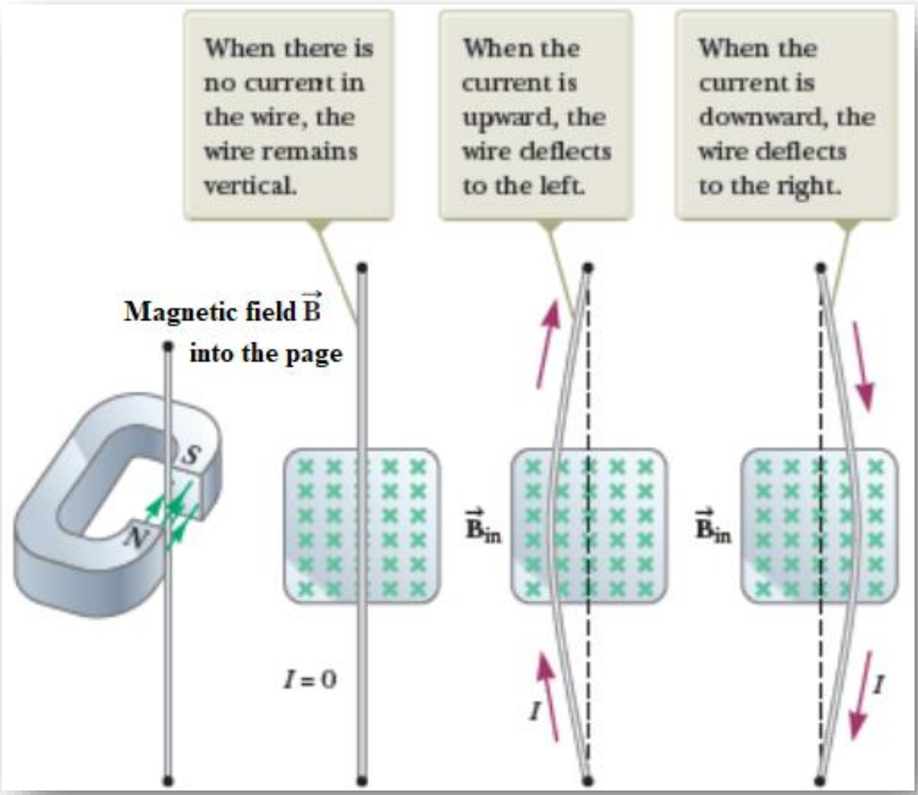


In 1819, Hans Christian Oersted made a significant discovery that revealed how a current The carrying conductor generates a magnetic field.

When current is passed through a straight current-carrying conductor, a magnetic field is produced around it, the field lines are concentric circles at every point of the current-carrying conductor. The direction of the magnetic field about the direction of electric current through a straight conductor can be depicted by using the Right-Hand Thumb Rule, also called the Maxwell Corkscrew Rule.

MAGNETIC FORCE ON CURRENT-CARRYING CONDUCTOR

When we place a current-carrying conductor within a uniform external magnetic field, the interaction between the magnetic field produced by the conductor and the external magnetic field gives rise to external force, denoted as F, acting on the conductor, as illustrated in the figure.



Factors on which the force acting on current carrying conductor in a magnetic field:

The force acting on a current-carrying conductor depends on several factors, such as, length, current, and the strength of the external magnetic field

The force (F) is directly proportional to the length of the conductor (L) that lies within the magnetic field

$$F \propto L \quad \ldots\ldots (i)$$

The force is also directly proportional to the current (I) passing through the conductor.

$$F \propto I \quad \ldots\ldots (ii)$$

Similarly, the force is directly proportional to the strength of the external magnetic field (B).

$$F \propto B \quad \ldots \ldots (iii)$$

Combining these factors, we will obtain the following relationship:

$$F \propto BIL$$

$$F = (k)\, BIL$$

Here, 'k' is the proportionality constant, and its value equals 1 in the SI unit system.

$$F = BIL$$

We can write this expression in a more convenient vector form

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

where $\vec{L}$ is a vector that points in the direction of the current I and has a magnitude equal to the length L of the segment.
The magnitude of this force is given by

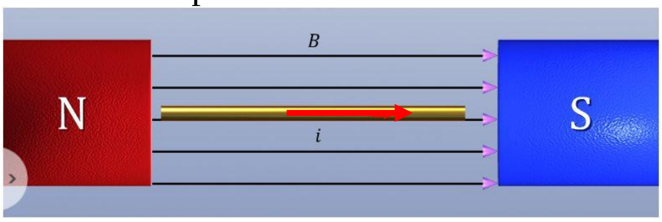
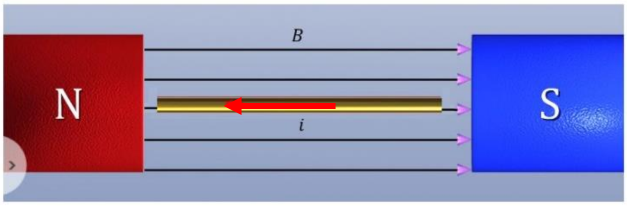
$$F = BIL \sin\theta$$

Where 'θ' is the angle between vector length $(\vec{L})$ and magnetic field $(\vec{B})$

SPECIAL CASES

ZERO FORCE:

If the current-carrying conductor is parallel to the field, the force is zero
When $\theta = 0^o$ or 180^o

$F = BIL\sin\theta$ $\theta = 0^0$ $F = BIL\sin 0$ $F = BIL(0)$ $F = 0$ A conductor will experience no force when its current is parallel to $\vec{B}$.  	$F = BIL\sin\theta$ $\theta = 180^0$ $F = BIL\sin 180$ $F = BIL(0)$ $F = 0$ A conductor will experience no force when the current is anti-parallel to $\vec{B}$. 

MAXIMUM FORCE:

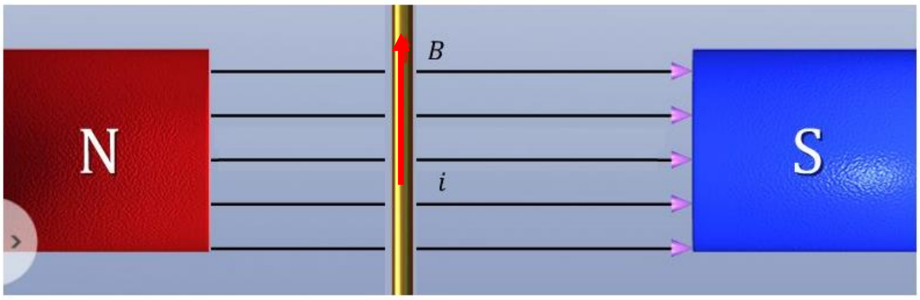
The current carrying wire has been positioned at 90^0 to the magnetic field. The maximum force acting on the wire due to the magnetic field

$$F = BIL\sin\theta$$

$$\theta = 90^0$$

$$F = BIL\sin 90$$

$$F = B\,I\,L\,(1)$$
$$F = B\,I\,L$$



MAGNETIC FLUX:

Definition 1

Magnetic flux is the number of magnetic lines passing through an area held perpendicular to it.

Definition 2

Magnetic flux is the dot product between the magnetic field and vector area.

Mathematically

$$\Phi = \vec{B}\,.\,\vec{A}$$
$$\Phi = B\,A\,\cos\theta$$

where

B is the magnitude of the magnetic field (having the unit of Tesla, **T,** or **web/m^2**),

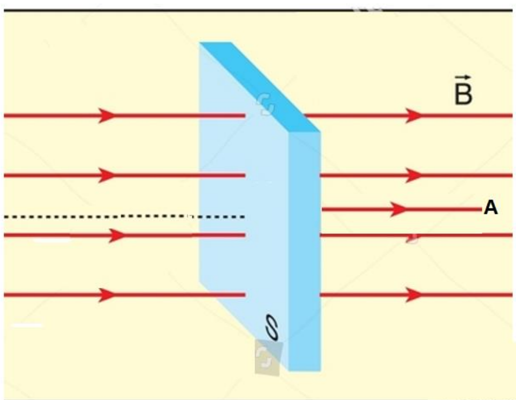
A is the surface area through which magnetic field lines project in meters squared (m^2)

θ is the angle between the magnetic field lines and the standard (perpendicular) to area **A**

Maximum Magnetic Flux:

The magnetic flux will be maximum when the angle between magnetic field B and area vector A is zero, i.e., =0°, and the surface is perpendicular to the magnetic lines.

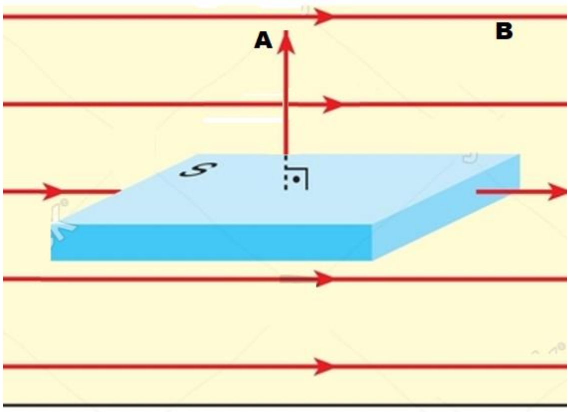
$$\Phi = B\,A\,\cos\theta$$
$$\Phi = B\,A\,\cos 0^0$$
$$\Phi = B\,A\,(1)$$
$$\Phi_{max} = B\,A$$



This case is shown in the figure.

Minimum Magnetic Flux:

When the angle between the area vector and magnetic field is 90°, then lines of force do not pass through the surface, and magnetic flux will be minimum



$$\Phi = B\,A\cos\theta$$
$$\Phi = B\,A\cos 90^0$$
$$\Phi = B\,A\,(0)$$
$$\Phi_{min} = 0$$

Unit of Magnetic Flux:
The SI unit of magnetic flux is Weber (Wb).

$$1\,Web = 1\,\frac{N\,m}{A}$$

MAGNETIC FLUX DENSITY:
Magnetic flux density can be defined as:
The magnetic flux density at a specific point in space is the force experienced per unit length along a straight conductor carrying unit current placed perpendicular to the field at that particular location.

$$\mathbf{B} = \frac{\mathbf{F}}{\mathbf{I\,L}}$$

Unit of Magnetic Flux Density:
The SI unit of magnetic flux density is Tesla (T), named after the Serbian-American inventor Nikola Tesla.

$$1T = \frac{N}{A\ m}$$

ONE TESLA:

One Tesla is defined as follows: If a conductor having a length of 1 m and carrying a current of 1 A placed perpendicularly to the magnetic field experiences a force of one Newton, then the magnetic flux density will be 1 Tesla.

THE BIOT – SAVART LAW
This law is a mathematical relation between magnetic induction ‘B’ at a point due to a current-carrying conductor and current 'I.'

MATHEMATICAL EXPRESSION:

Magnetic induction ‘B’ at a point due to a straight current-carrying conductor is directly proportional to twice the current value through the conductor and inversely proportional to the distance from the conductor.

$$B \;\alpha\; \frac{2I}{r}$$

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

$$B = \frac{\mu_0}{4\,\pi} \times \frac{2I}{r}$$

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

Where μ_0 is called the permeability of free space.
Its value is $4\pi \times 10^{-7}\; T.m/A$

CONCLUSION:

1. It is clear from the above equation that the magnitude of ‘B’ at any point on the circle of radius ‘r’ is constant if a current-carrying conductor is placed at its center.
2. The direction at any point on the circle is along the tangent. Such a field is usually known as a tangential magnetic field.

AMPERE’S LAW

This law is the relation between the tangential component of the magnetic field of induction at a point on a closed curve and the net current ‘I’ through the area bounded by the curve.

STATEMENTS

The law states that the sum of the products of the tangential component of the magnetic field of induction and the length element of a closed curve taken in the magnetic field is μ_o times the current, which passes through the area, bounded by this curve.

MATHEMATICAL EXPRESSION:

$$\sum_{N}\left(\vec{B}.\,\Delta\vec{L}\right)_n = \mu_o \text{ (current enclosed)}$$

Where μ_o is called the permeability of free space, its value is $4\pi \times 10^{-7}$ T.m/A.

PROOF:

Consider a long straight conductor carrying a current 'I.' The magnetic lines of induction will be concentric circles, and the magnetic field will be along the tangent at any point. Draw a circle of radius 'r' with its center at the conductor. The magnitude of B at any point on the circle is given by the Biot-Savant law.

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

Suppose break the whole circle path into small elements each of length Δl (i.e., Δl_1 Δl_2 ………, Δl_n). Multiply each element by the tangential component of the magnetic field (BCosθ). B will be parallel to small element Δl, then applying Ampere's law

$$(\vec{B}.\overrightarrow{\Delta l_1}) + (\vec{B}.\overrightarrow{\Delta l_2}) + (\vec{B}.\overrightarrow{\Delta l_3}) + \cdots \ldots \ldots \ldots \ldots + (\vec{B}\,.\,\overrightarrow{\Delta l_n}) = \mu_0 I$$

$$\sum_{i=1}^{n} (\vec{B} \cdot \overrightarrow{\Delta l})_i = \mu_0 I$$

$$\sum_{i=1}^{n} (\vec{B} \cdot \overrightarrow{\Delta l})_i = \mu_0(\text{current enclosed})$$

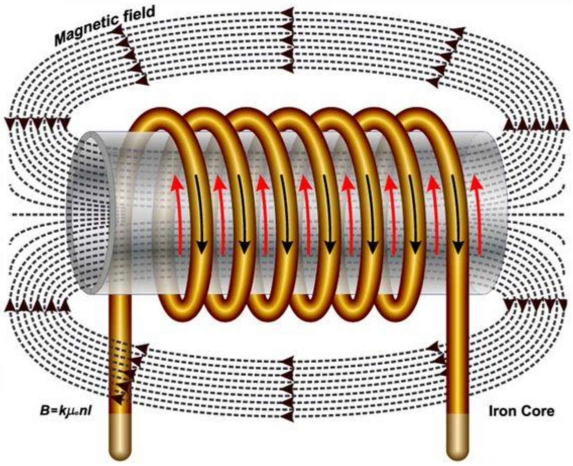
APPLICATIONS OF AMPERES'S LAW

SOLENOID

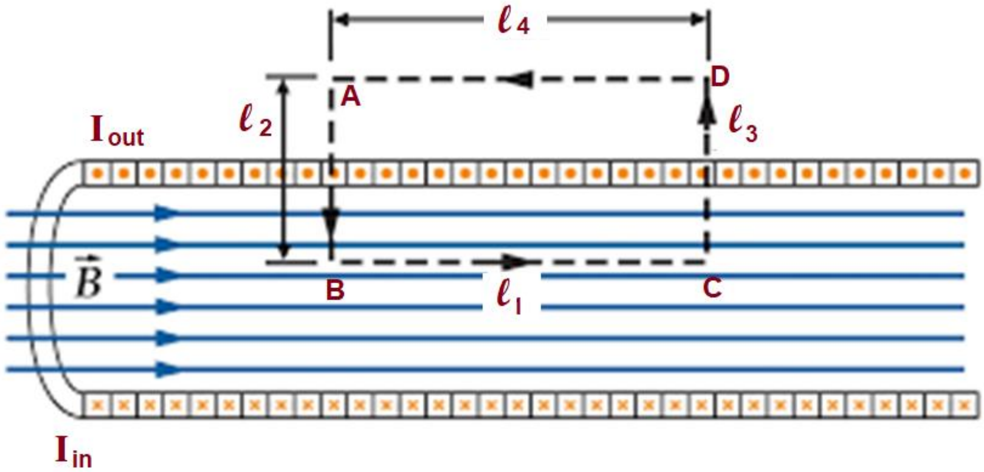
A long-insulated wire wound in a close-packed helix carrying a current is called a solenoid.

SOLENOIDAL FIELD:

A long coil of wire with many loops or turns, Each loop produces a magnetic field as was shown in Fig, and the total field inside the solenoid will be the sum of the fields due to each current loop as shown in Fig, for a few loops. If the solenoid has many loops and they are close together, the field inside will be nearly uniform and parallel to the solenoid axis except at the ends, as shown in Fig. Outside the solenoid, the field lines spread out in space, so the magnetic field is much weaker than inside.



Consider an Amperian loop ABCD with side AB along the axis to calculate' B' inside the solenoid. Now calculate the products of $\vec{B}$ and elements l_1 , l_2 , l_3 , *and* l_4.



(i) $\vec{B}.\vec{l_1} = B\, l_1 \cos\theta$ $\quad$ *B is parallel to* l_1, *then* $\theta = 0^0$

$\vec{B}.\vec{l_1} = B\, l_1 \cos 0^0$

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

(ii) $\vec{B}.\vec{\ell_2} = B\,\ell_2 \cos\theta$ $\quad$ *B is perpendicular to* ℓ_2, *then* $\theta = 90^0$

$\vec{B}.\vec{\ell_2} = B\,\ell_2 \cos 90^0 = B\,\ell_1(0)$

$\vec{B}.\vec{\ell_2} = 0$

(iii) $\vec{B}.\vec{\ell_3} = B\,\ell_3 \cos\theta$ $\quad$ *B is perpendicular to* l_3, *then* $\theta = 90^0$

$\vec{B}.\vec{\ell_3} = B\,\ell_3 \cos 90^0 = B\,\ell_3(0)$

$\vec{B}.\vec{\ell_3} = 0$

(iv) The field outside the solenoid is negligible compared to inside.

$\vec{B}.\vec{\ell_4} = 0$

Adding all these products, we get

$$\vec{B}.\vec{\ell_1} + \vec{B}.\vec{\ell_2} + \vec{B}.\vec{\ell_3} + \vec{B}.\vec{\ell_4} = B\,\ell_1 + 0 + 0 + 0$$

$$\sum_{i=1}^{4}(\vec{B}.\vec{\ell})_i = B\,\ell \quad \ldots\ldots\ldots\ldots(i)$$

Let

n $= \frac{N}{\ell}$ (no. of turns per unit length)

I = current in each turn,

Then n ℓ I = current enclosed by Amperian loop

From Ampere's Law:

$$\sum_{i=1}^{4}(\vec{B}.\vec{\ell})_i = \mu_0\,(current\ enclosed\ by\ amperian\ loop)$$

Substituting the value of current enclosed = n l I in the above equation, we get

$$\sum_{i=1}^{4}(\vec{B}.\vec{\ell})_i = \mu_0 (n \ell I) \ldots\ldots\ldots\ldots (ii)$$

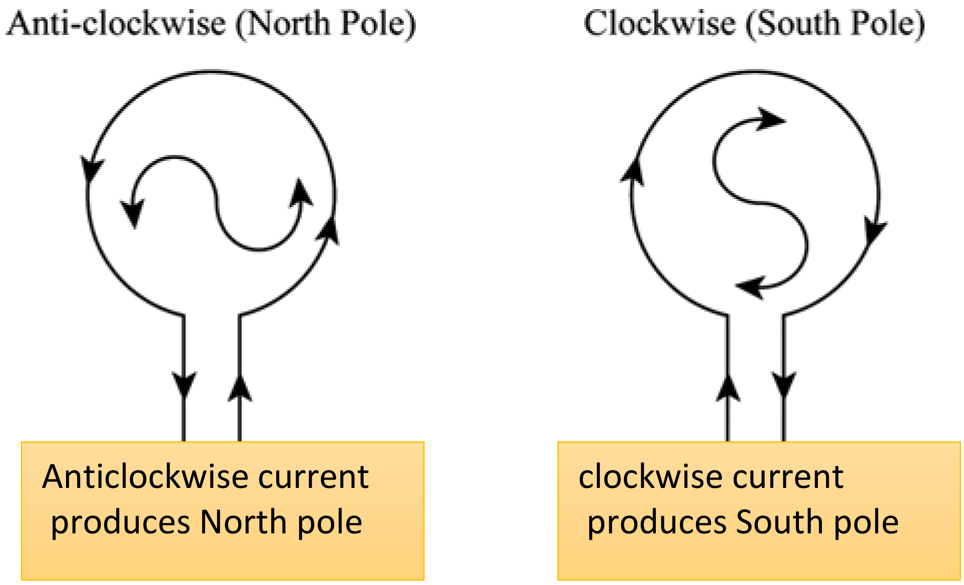
Comparing equations (i) and (ii), we get

$$B\ell = \mu_0 (n\ell I)$$

$$\boldsymbol{B = \mu_0 n I}$$

This is the magnetic field magnitude inside a solenoid. ***B*** depends only on the number of loops per unit length and the current *I*.

Note



TOROID

A Solenoid bent into the doughnut shape is called a toroid OR. A toroid is a coil of insulated copper wire wound on a circular core.

TOROID FIELD:

When a current is passed through a toroid field, it is strong, and lines of induction are concentric circles. The outside toroid field is negligible. To calculate 'B' inside the toroid, consider the Amperian loop in the form of a circle of radius 'r' concentric with the toroid. Divide the loop into small elements $\Delta\ell$ and calculate the product of $\vec{B}$ and $\overrightarrow{\Delta l}$ for each element.

$$\vec{B}.\overrightarrow{\Delta\ell} = B\,\Delta\ell\,\cos 0^0$$

$$\vec{B}.\overrightarrow{\Delta\ell} = B\,\Delta\ell$$

The sum of all these products will be

$$\sum_{i=1}^{n}\left(\vec{B}.\ \overrightarrow{\Delta\ell}\right)_i = B\sum_{i=1}^{n}(\Delta\ell)_i$$

$$\sum_{i=1}^{n}\left(\vec{B}.\ \overrightarrow{\Delta\ell}\right)_i = B\ (2\,\pi\,r)\ \dots\dots\dots(i)$$

For Ampere's law

$$\sum_{i=1}^{n}\left(\vec{B}.\ \overrightarrow{\Delta l}\right)_i = \mu_0\ (current\ enclosed)$$

$$\sum_{i=1}^{n}\left(\vec{B}.\ \overrightarrow{\Delta l}\right)_i = \mu_0\ (NI)\ \dots\dots\dots\dots\dots(ii)$$

Comparing equations (i) and (ii), we get

$$B\ (2\,\pi\,r) = \mu_0\ (\mathrm{N\,I})$$

$$B = \frac{\mu_0\ (\mathrm{N\,I})}{(2\,\pi\,r)}$$

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

This is known as the toroid magnetic field formula.

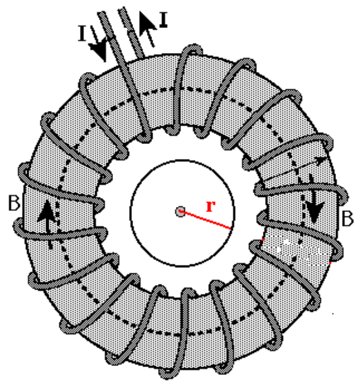
The result shows that the B varies as $\frac{1}{r}$ and, hence, is non-uniform in the region occupied by the toroid. However, if it is very large compared with the cross-sectional radius of the toroid, then the field is approximately uniform inside the toroid.

SPECIAL CASES

CASE - 1

If the Amerian circular loop is not within the toroid but on the inner side of the toroid, then it encloses no current (I = 0).

According to the Ampere's law:



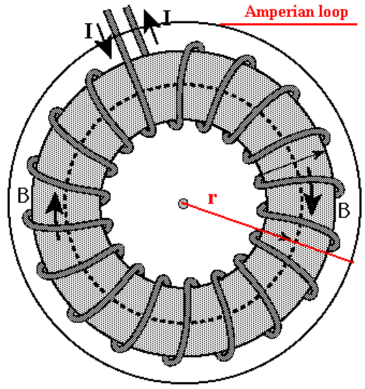
$$B = \frac{\mu_0\ \mathrm{N}\ (0)}{2\,\pi\,r}$$

$$B = 0$$

CASE – 2

Suppose the amperian circular loop is outside the toroid. In that case, this circular path encloses N turns, carrying a current in one direction and the same amount of current in the opposite direction. Hence, the net current bounded by this circular path is zero

According to the Ampere's law:



$$B = \frac{\mu_0 N(0)}{2\pi r}$$

$$B = 0$$

FORCE ON A CHARGED PARTICLE IN A UNIFORM MAGNETIC FIELD

It is found experimentally that a moving charge particle experiences a force in a magnitude field. This force is directly proportional to

1. The magnitude of charge "q"
2. The magnitude of velocity "v"
3. The magnetic induction "B"
4. The "sine" of "θ" between $\vec{v}$ and $\vec{B}$

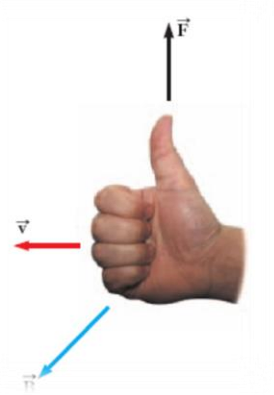
$$F \propto q V B \sin\theta$$

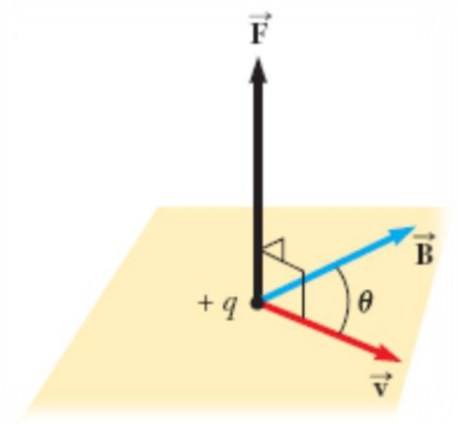
In SI system the unit of "B" is so adopted that the proportionality constant in above equation becomes one. Because $\vec{F}$, $\vec{V}$ and $\vec{B}$ are vectors, the force can be written as a vector product.

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

DIRECTION OF FORCE

You can determine the direction of the $(\vec{v} \times \vec{B})$vector by using the right-hand rule as for any cross product (for q is positive): orient;your right hand so that your outstretched fingers point along the direction of the motion of the particle (v), and when bend your fingers they point along the direction of B. then your thumb will point in the direction of the force. This is true only for positively charged particles; for negatively charged particles, the force is exactly in the opposite direction.





CHARACTERISTICS

1. A charge experiences zero force if the particle moves parallel or anti-parallel to the field lines ($\theta = 0^o$ or 180^o).
2. Magnetic force cannot change the magnitude of velocity $\vec{v}$
3. Work done by magnetic force on charge particle q is always zero.
4. Magnetic force cannot change the kinetic energy of **q**.

UNIT OF 'B'

Consider, $F = q\,V\,B\,\sin\theta$

$$B = \frac{F}{qV \sin\theta}$$

$$\text{Unit of B} = \frac{Newton}{coulomb\left(\frac{meter}{second}\right)}$$

$$\text{Unit of B} = \frac{\text{Newton}}{\text{coul / second . meter}}$$

$$\text{Unit of B} = \frac{\text{Newton}}{\text{ampere . meter}}$$

Unit of B = tesla (T).

A unit magnetic field of induction of 1 Tesla is said to exist at a point where the force experienced by a unit positive charge moving with 1 m /s perpendicular to the magnetic field is 1N.

CHARGE TO MASS RATIO OF ELECTRON:

Measuring an electron's charge-to-mass ratio (e/m) is a classic experiment in electromagnetism and particle physics, known as the "e/m experiment."

APPARATUS AND MATERIALS:

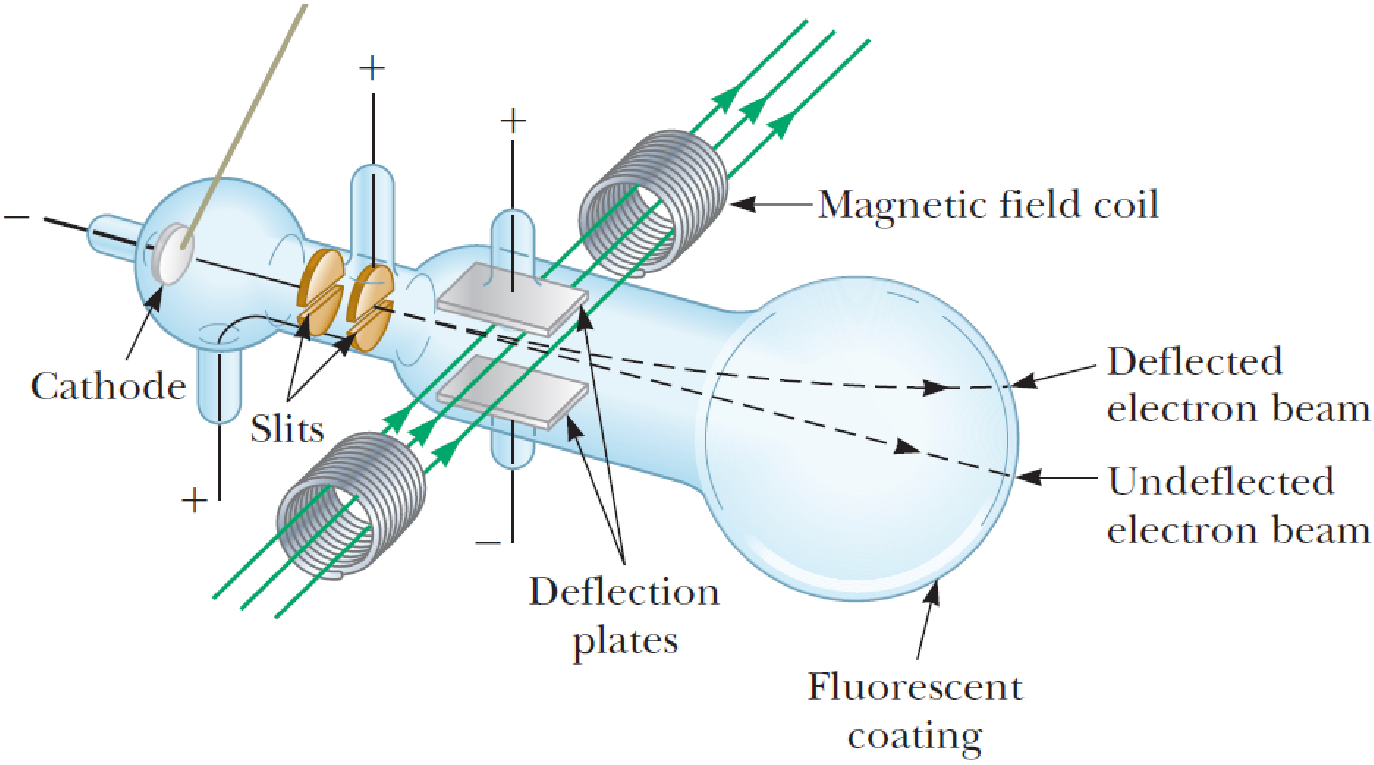
1. Cathode Ray Tube (CRT): This vacuum tube produces a beam of electrons. It consists of an electron gun, focus in, deflection plates, and a fluorescent screen, as shown in the figure

2. Magnetic Field Source: We'll need a strong and uniform magnetic field source, such as a Helmholtz coil or a solenoid.

3. Voltage Source: A variable voltage source to create an electric field.

4. Fluorescent Screen: A screen coated with a phosphorescent material to visualize the electron beam.

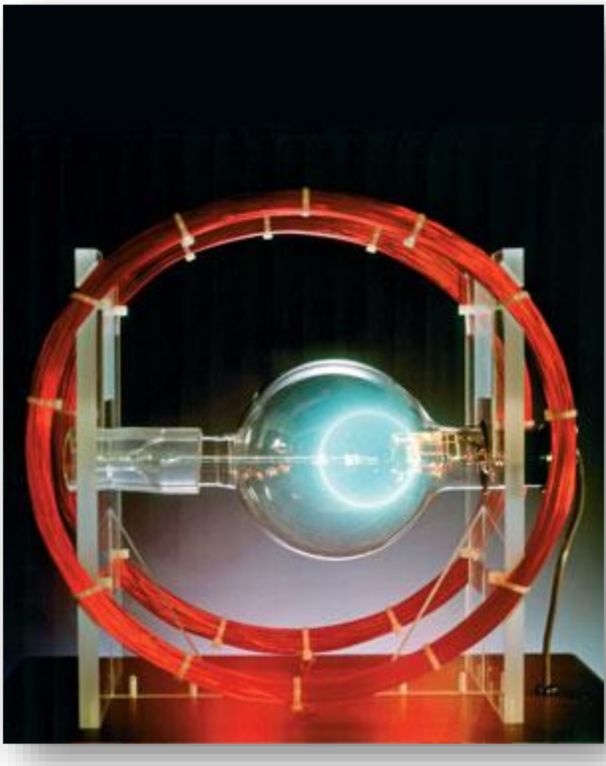
5. Rulers and Measurement Devices: To measure the radius of the electron beam's circular path and the electric Potential applied.



PROCEDURE:

1. Electrons are produced by heating the filament and focused toward the screen by applying negative Potential on the cylinder
2. Electrons are accelerated through a potential difference of 1000 volts between filament and disc.
3. A further potential of 500 volts is applied between slits to obtain a fine beam of electrons.
4. After passing through the middle of the plates, the beam strikes the screen coated with ZnS, and a light spot is produced at "O."
5. A magnetic field produced by two coils deflects the electron beam from "0" to $0^{/}$ on the screen.

6. An electric field is produced between two plates, such that the two fields cancel each other's effect and the spot comes back to 'O'.



The white ring inside the glass tube is the glow of a beam of electrons that ionize the gas molecules. The red coils of current-carrying wire produce a nearly uniform magnetic field, illustrating the circular path of charged particles in a uniform magnetic field.

CALCULATIONS

The magnetic field produced by Helmholtz coils is perpendicular to this velocity and produces a magnetic force that is transverse to both v and B: this provides the centripetal force that makes an electron move along the circular trajectory; the radius of this trajectory **r** can be found from

$$q\,v\,B = \frac{m\,v^2}{r}$$

$$e\,v\,B = \frac{m\,v\,v}{r}$$

$$e\;B = \frac{m\,v}{r}$$

$$\frac{e}{m} = \frac{v}{B\,r} \ldots\ldots\ldots\ldots\ldots (i)$$

DETERMINATION OF VELOCITY

Work- kinetics energy Method-1

When an electric field acts on a charge, the work done by the field is equal to the change in the charge's kinetic energy.

$$\frac{1}{2} m\, v^2 = qV$$

$$\frac{1}{2} m\, v^2 = eV$$

$$v = \sqrt{\frac{2\, eV}{m}} \quad \ldots\ldots\ldots.(ii)$$

VELOCITY SELECTOR METHOD II

An electric field is directed vertically downward, and the uniform magnetic field is applied in the direction perpendicular to the electric field. The two field forces on the electron are equal in magnitude, but opposite in direction (**e)** electron beam is passed through a crossed field region, then

$$e\, v\, B = e\, E$$

$$v = \frac{E}{B} \ldots\ldots\ldots(iii)$$

DETERMINATION OF RADIUS:

Using Pythagoras theorem

$(Hyp)^2 = (Base)^2 + (Perp)^2$

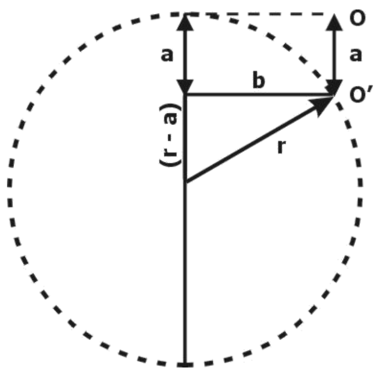
$r^2 = b^2 + (r - a)^2$

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

But "a" is very small; its square can be neglected.

$\therefore \quad 2ra = b^2$

$$r = \frac{b^2}{2a} \ldots\ldots\ldots\ldots\ldots(iv)$$



GALVANOMETER

DEFINITION

It is a device that detects (or measures) small electric currents.

CIRCUIT SYMBOL

In an electrical circuit diagram, the galvanometer is represented by 

TYPES

Two prevalent types of galvanometers are:

1. moving-coil galvanometer
2. moving magnet galvanometer.

MOVING -COIL GALVANOMETER

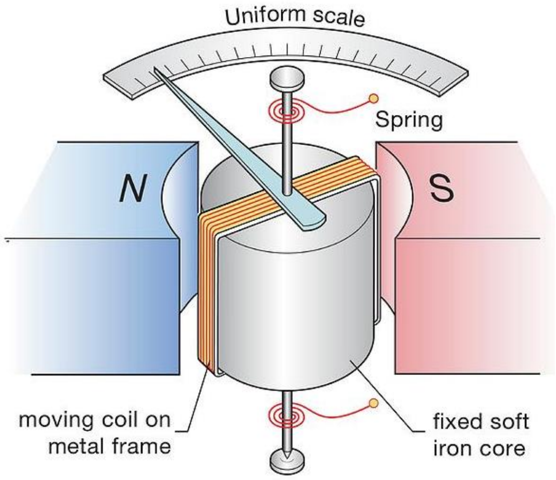
The French scientist D' Arsonval developed the original form of the galvanometer. The modern form of the moving coil galvanometer is the result of the work of Dr. Edward Weston, who improved the original form.

PRINCIPLE

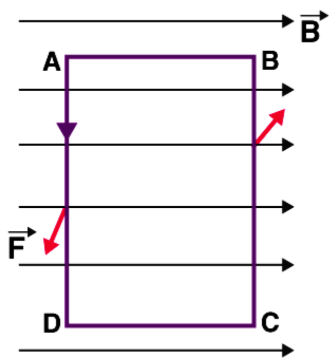
It works based on the principle of electromagnetic induction. When a coil carrying an electric current is positioned within an external magnetic field, it undergoes magnetic torque. The degree of deflection observed in the coil caused by this magnetic torque is directly proportional to the magnitude of the current flowing through the coil.

CONSTRUCTION:

1. **Coil:** The key component of a Galvano meter is a coil of wire (usually wound around as an iron core) suspended within a magnetic field. The coil is mounted on a spindle so that it can rotate freely.
2. **Magnet:** A permanent magnet or an electromagnet is placed around the coil. The magnetic field lines from the magnet pass through the coil.
3. **Spring:** A delicate torsion spring is attached to the coil, providing a restoring torque when the coil is deflected.
4. **Pointer:** A thin pointer or needle is attached to the coil, allowing for deflection measurement.



WORKING



When a small electric current flows through the coil, it generates a magnetic field around it. This magnetic field interacts with the external magnetic field (provided by the permanent magnet or electromagnet) to exert a torque on the coil.

The torque causes the coil to rotate, and the amount of rotation is proportional to the current passing through it. This rotation is indicated by the deflection of the pointer on a calibrated scale.

The coil continues to rotate until the restoring torque from the spring equals the torque due to the current-induced magnetic field. At this point, the pointer comes to rest, and its position on the scale indicates the magnitude of the current.

When a current passes through a galvanometer coil, it experiences a magnetic deflecting torque, which tends to rotate it.

$$Deflecting\ torque = BINA\ \cos\alpha$$

Where

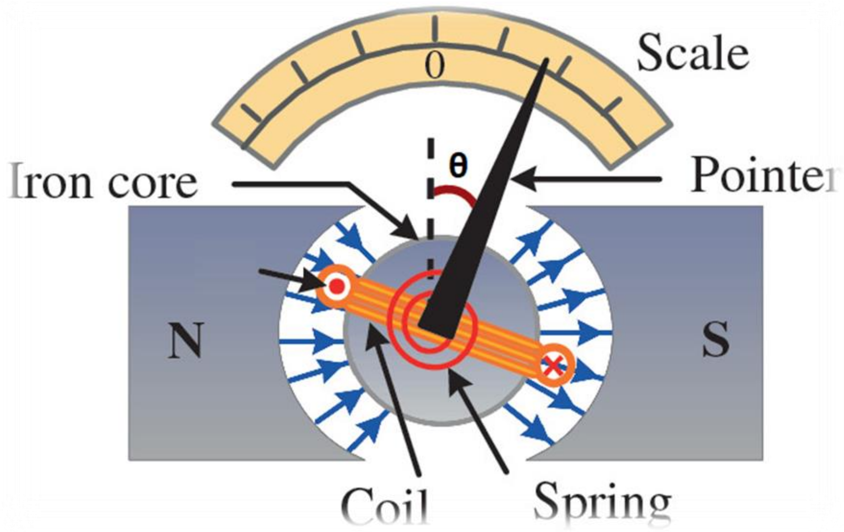
B = magnetic field strength
I = current through the coil
N = number of turns
A = Area of coil
α = angle between 'B' and the plane of the coil.

The coil is suspended in a radial magnetic field in which its plane is always parallel to the field, i.e., α = 0º.

$$Deflecting\ torque = BINA\ \cos 0^0$$

$$Deflecting\ torque = BINA\ (1)$$

$$Deflecting\ torque = BINA$$



This magnetic torque causes the coil to rotate, leading to the twisting of the phosphor bronze strip. Simultaneously, the spring (S) attached to the coil exerts a counter-torque, known as the storing torque

$$Restoring\ torque\ \ \alpha\ \ Angle\ of\ deflection\ (\theta)$$

$$Restoring\ torque = k\ \theta$$

where k is the stiffness constant of the spring. Representing a restoration of a couple of torque per unit twists of suspension fiber. It depends upon the nature of the suspension fiber For the equilibrium position of the coil, the restoring torque is equal to the deflecting torque.

$Restoring\ torque\ \ =\ \ Deflecting\ torque$

$$k\ \theta\ = BINA$$

$$\theta\ = \frac{BINA}{k}$$

$$\theta\ = \frac{BNA}{k}\ \ (I)$$

Where $\frac{BNA}{k}$ is a constant for a given galvanometer

$$\theta\ = constant\ \ (I)$$

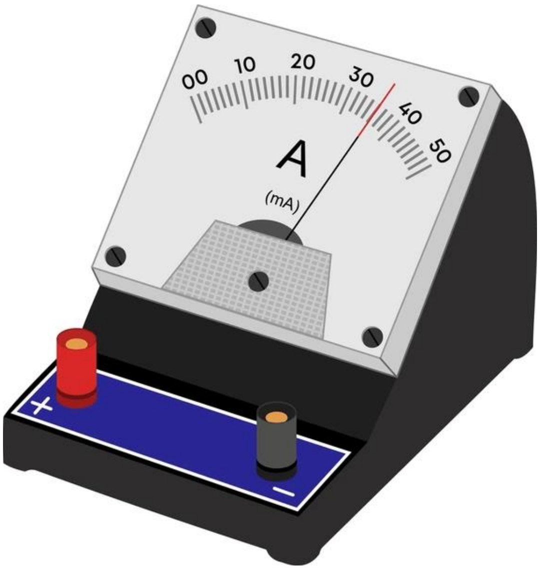
$$\theta\ \alpha\ \ I$$

The above expression shows that the deflection observed in the galvanometer is directly proportional to the current flowing through it.

THE AMMETER

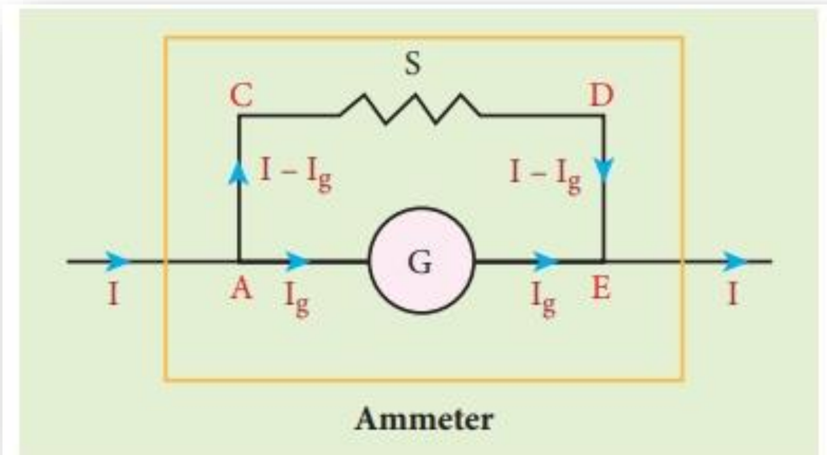
DEFINITION

An instrument used to measure currents is called an ammeter.



CONVERSION OF GALVANOMETER INTO AMMETER

An ammeter is a modified form of a galvanometer. To convert a galvanometer into an ammeter, a suitable low-resistance device called a shunt is connected in parallel to it.



WORKING

The Shunt resistance should be adjusted so that when the current passes through the meter, most of the current gives off the full-scale deflection, and the remaining excess should pass through the shunt.

DERIVATION

Let R_s = Shunt resistance

R_g = resistance of galvanometer

I_g = current for full deflection

I = current to be measured.

$(I - I_g)$ = current through shunt.

The voltages across the galvanometer and shunt are equal due to their parallel connection. Hence, we can establish the following equation:

.The potential difference across shunt = Potential difference across galvanometer

$$(I - I_g)\, R_s = I_g\, R_g$$

$$R_s = \frac{I_g\, R_g}{(I - I_g)}$$

From this equation, a suitable value of shunt can be calculated.

CONNECTION

An ammeter is a very low-resistance device, always connected in series in a circuit.

THE VOLTMETER

DEFINITION

An instrument used to measure potential difference is called a voltmeter.

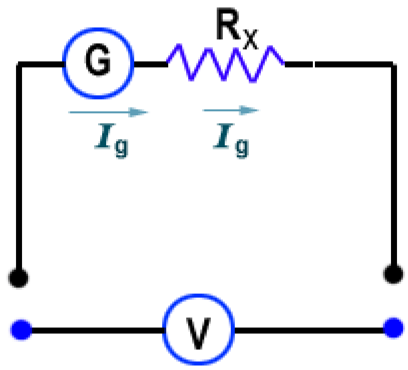
CONVERSION OF GALVANOMETER INTO VOLTMETER

A voltmeter is a modified form of a galvanometer. A very high resistance is connected in series to convert a galvanometer into a voltmeter. This resistance is known as a multiplier.

WORKING

To convert a galvanometer into a voltmeter, a very high resistance is connected in series to it. Most of the potential drop will occur across the multiplier. The series resistor R_x is chosen so that the current through the galvanometer deflects full scale when the desired full-scale voltage appears across the voltmeter.

DERIVATION



Let R_X = multiplier resistance

R_g = galvanometer resistance

I_g = full deflection current

V = Potential to be measured.

The R_X R_g and are connected in series, so the same current I_g flows through each. Hence

potential difference across resistor(R_g) $V_g = I_g R_g$

the potential difference across the resistor (R_X) $V_X = I_g R_X$

The total potential difference V applies will equal the sum of the above potential differences.

$$\text{Total potential difference} = \begin{pmatrix} Potentail Difference \\ Across\ Galvanometer \end{pmatrix} + \begin{pmatrix} Potentail Difference \\ Across\ Resistor \end{pmatrix}$$

$$V = I_g R_X + I_g R_g$$

$$V = I_g (R_X + R_g)$$

$$\frac{V}{I_g} = R_X + R_g$$

$$\frac{V}{I_g} - R_g = R_X$$

$$R_X = \frac{V}{I_g} - R_g$$

From this equation, a suitable value of R_x can be calculated.

CONNECTION

A voltmeter is a very high-resistance device that is always connected in parallel to the circuit.