
بسم الله الرحمن الرحيم

Applied Physics

Course Code - PHY 124

Class: BCS-B Semester: 1st-FA23

(27-30) November

13th week

Lecture: 1st

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Course Contents (Theory):

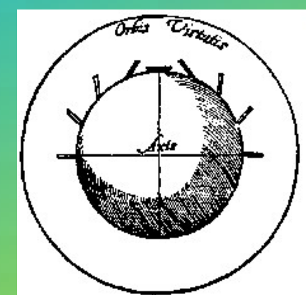
Electric force and its applications and related problems, conservation of charge, charge quantization, electric fields due to point charge and lines of force, ring of charge, disk of charge, point charge in an electric field, dipole in a electric field, the flux of vector field, the flux of electric field, Gauss's law, application of Gauss's law, spherically symmetric charge distribution, a charge isolated conductor, electric potential energy, electric potentials, calculating the potential from the field and related problem, potential due to point and continuous charge distribution, potential due to dipole, equipotential surfaces, calculating the field from the potential , electric current, current density, resistance, resistivity and conductivity, Ohm's law and its applications, Hall effect, the magnetic force on a current, Biot- Savart law, Line of B, two parallel conductors, Amperes' s law, solenoid, toroids, Faraday's experiments, Faraday's law of Induction, Lenz's law, motional emf, Induced electric field, Induced electric fields, the basic equation of electromagnetism, Induced magnetic field.

Magnetism
Magnets
And
Magnetic Fields

A brief history

1600 William Gilbert, *On magnetism*; magnetic materials; poles that attract & repel; Earth's magnetic field, compass 'dip'

1820 Hans Christian Oersted finds that an electric current deflects a compass needle.



1820 Andre Marie Ampère finds that parallel wires carrying current produce forces on each other.

1820s, 1830s Michael Faraday develops the concept of electric field and shows that

electric current + magnetism -> motion (motor effect)

motion + magnetism -> electric current (electromagnetic induction)

1860s James Clerk Maxwell (1831-1879) establishes a mathematical description of electromagnetism.

Types of Magnets

Magnetic material is classified by how it retains its magnetism

a. Soft – easy magnetized, but easily lose the magnetism

b. Hard – not easily magnetized, but once magnetized retain magnetism

Magnetizing & demagnetizing

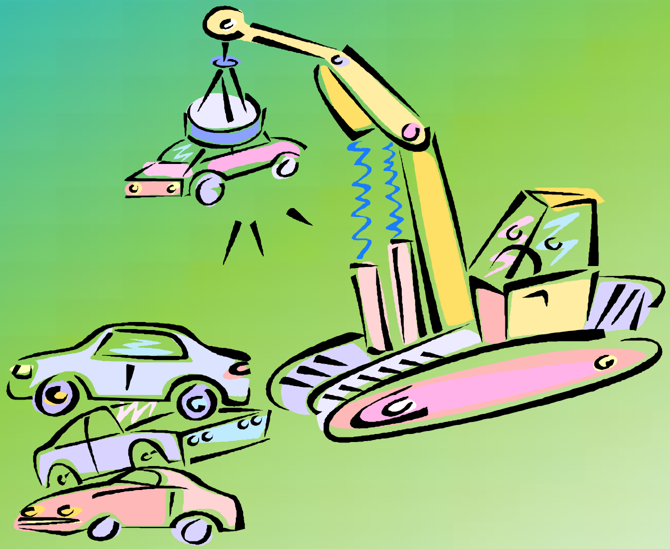
Make a magnet

- by stroking
- by using DC coil carrying current
- by tapping while aligned with the Earth’s field

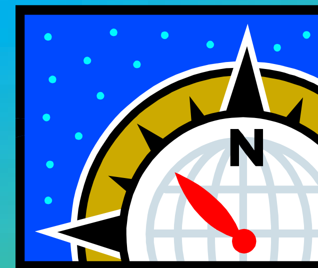
Demagnetize a magnet

- by dropping or banging randomly
- by heating
- by applying a diminishing AC current

Magnetism
Magnets and Magnetic Fields



Magnets

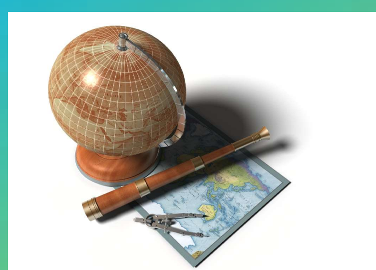


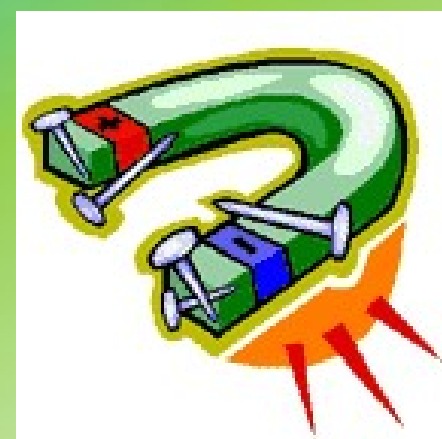
A. Magnets have two poles (ends)

1. North pole

2. South pole

→ A magnet will attempt to line itself up with the magnetic field of the Earth



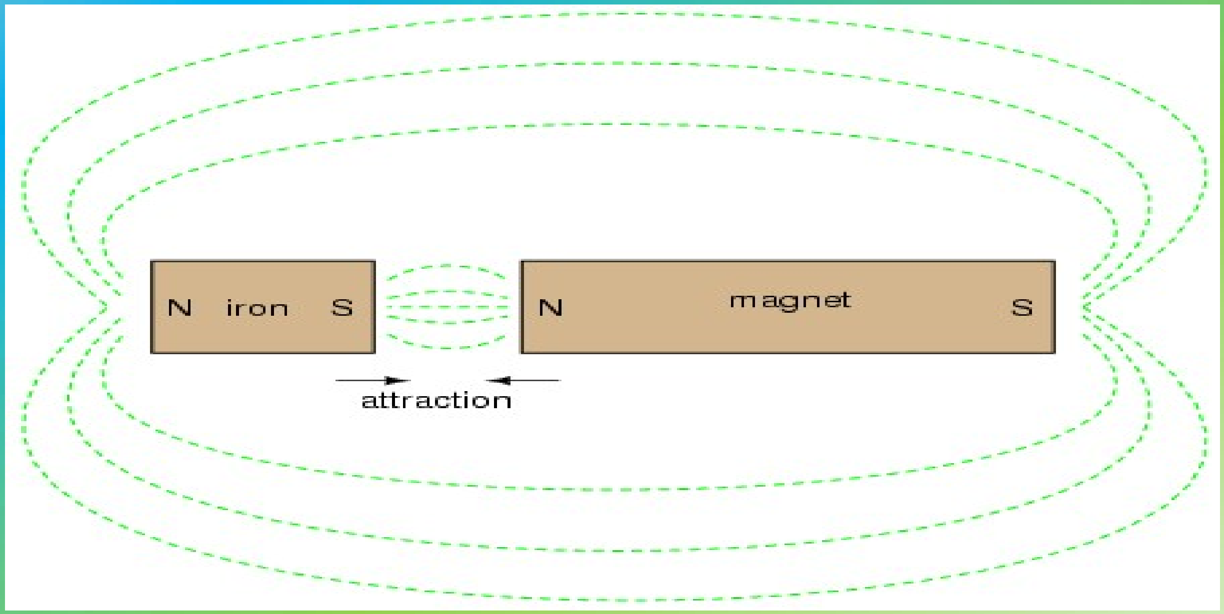


Technological applications of magnetism

1. Large electromagnets used to pick up heavy loads
2. Magnets used in meters, motors, loudspeakers
3. Magnetic tapes used in audio and video recording, and computer disks
4. Regulation of controlled nuclear fusion research
5. Maglev trains

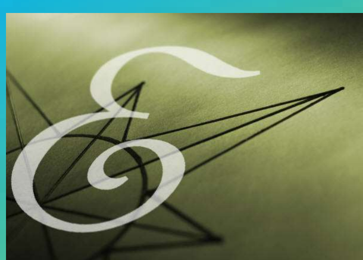
Magnetic forces exist between magnets

1. Like poles repel (south-south, or north-north)
2. Opposite poles attract (south-north)

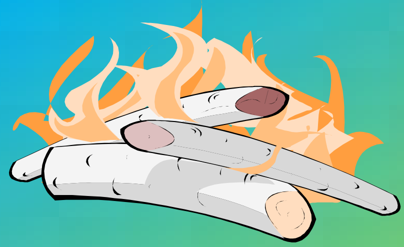


Magnetic poles always occur in pairs

1. Magnetic poles can never be isolated
2. If you break a magnet, each piece will have a north and a south pole

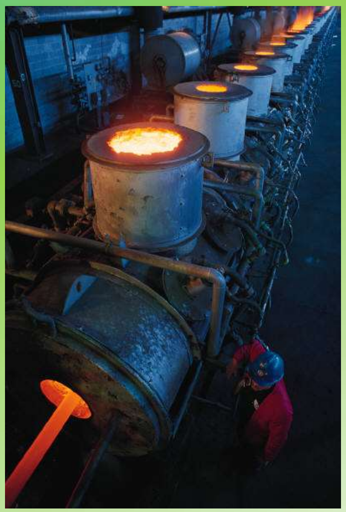


Permanent magnets

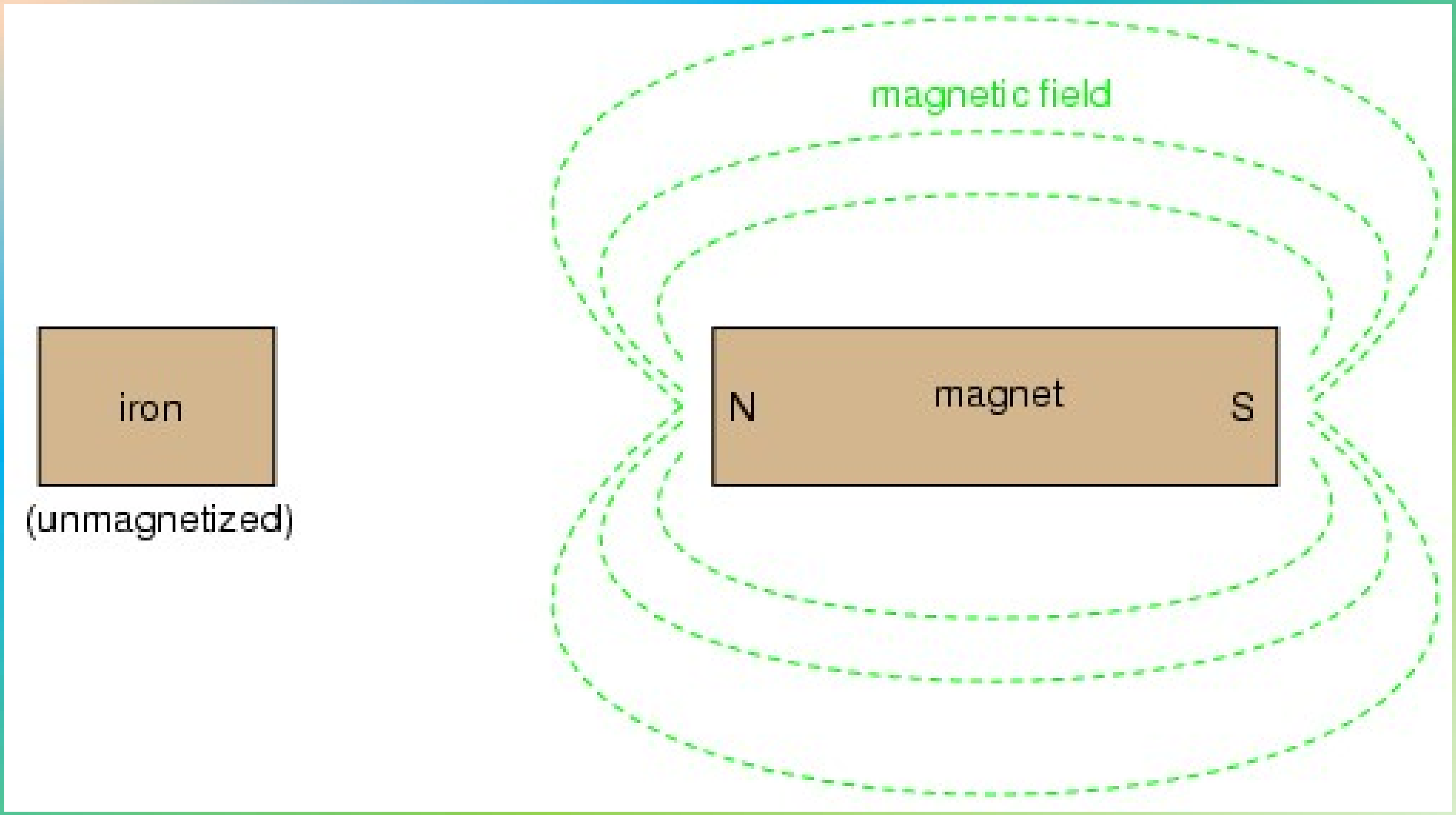


1. Unmagnetized iron can be magnetized by placing it near a strong permanent magnet or stroking it with a magnet

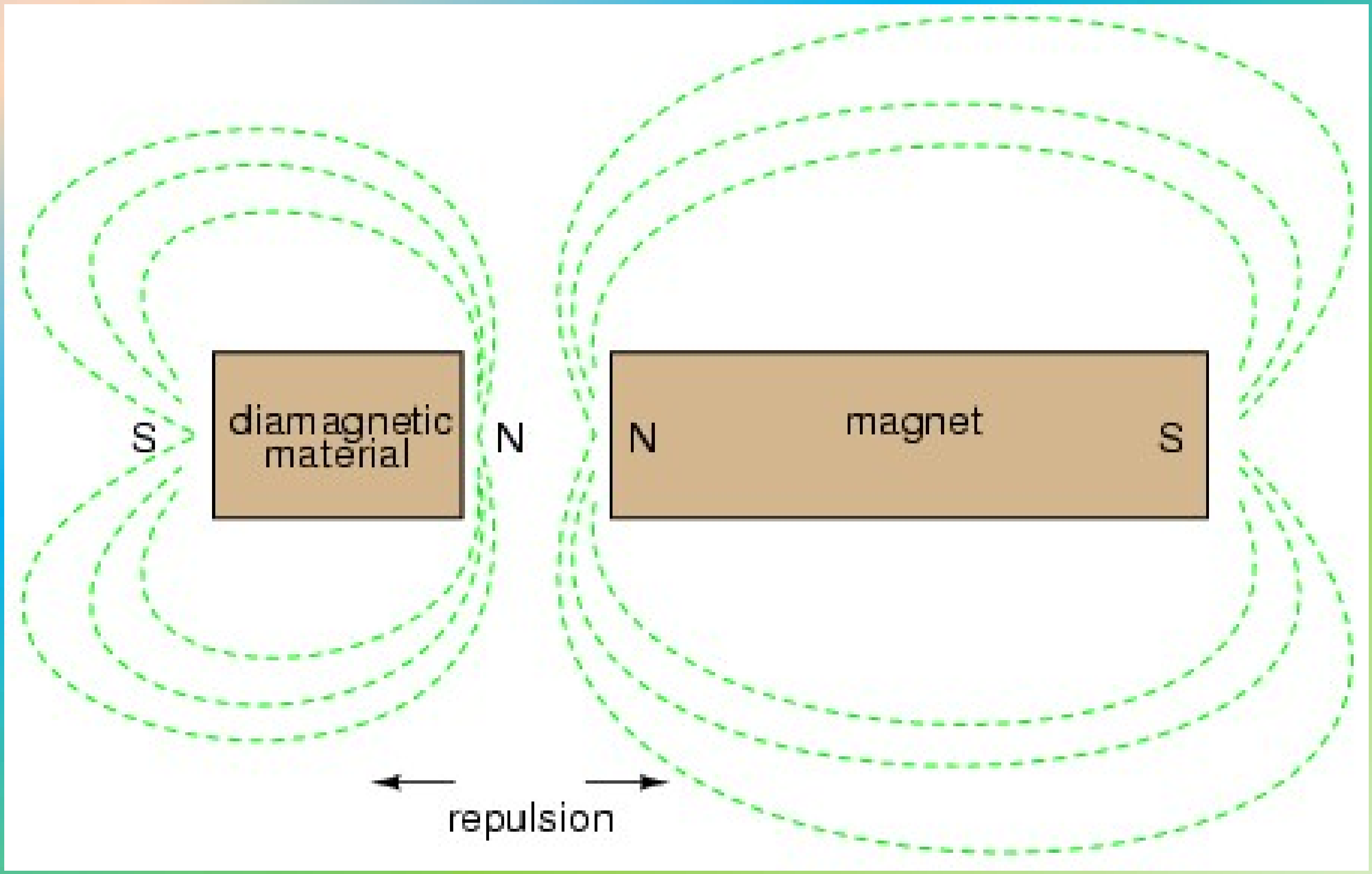
2. Process is reversible with heat or hammering



I. Magnets



Magnets



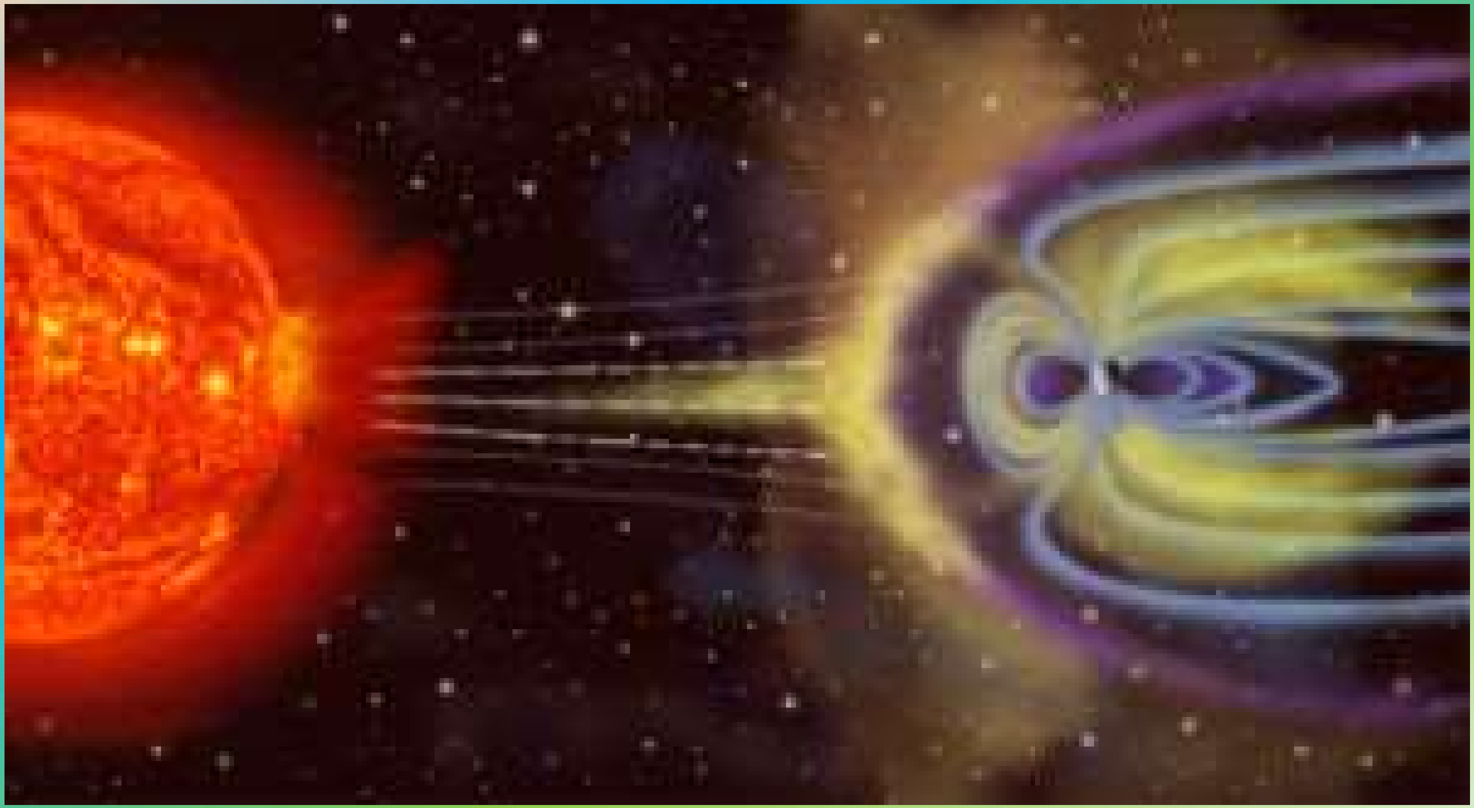
Magnetic fields

→ A region in which a magnetic force can be detected

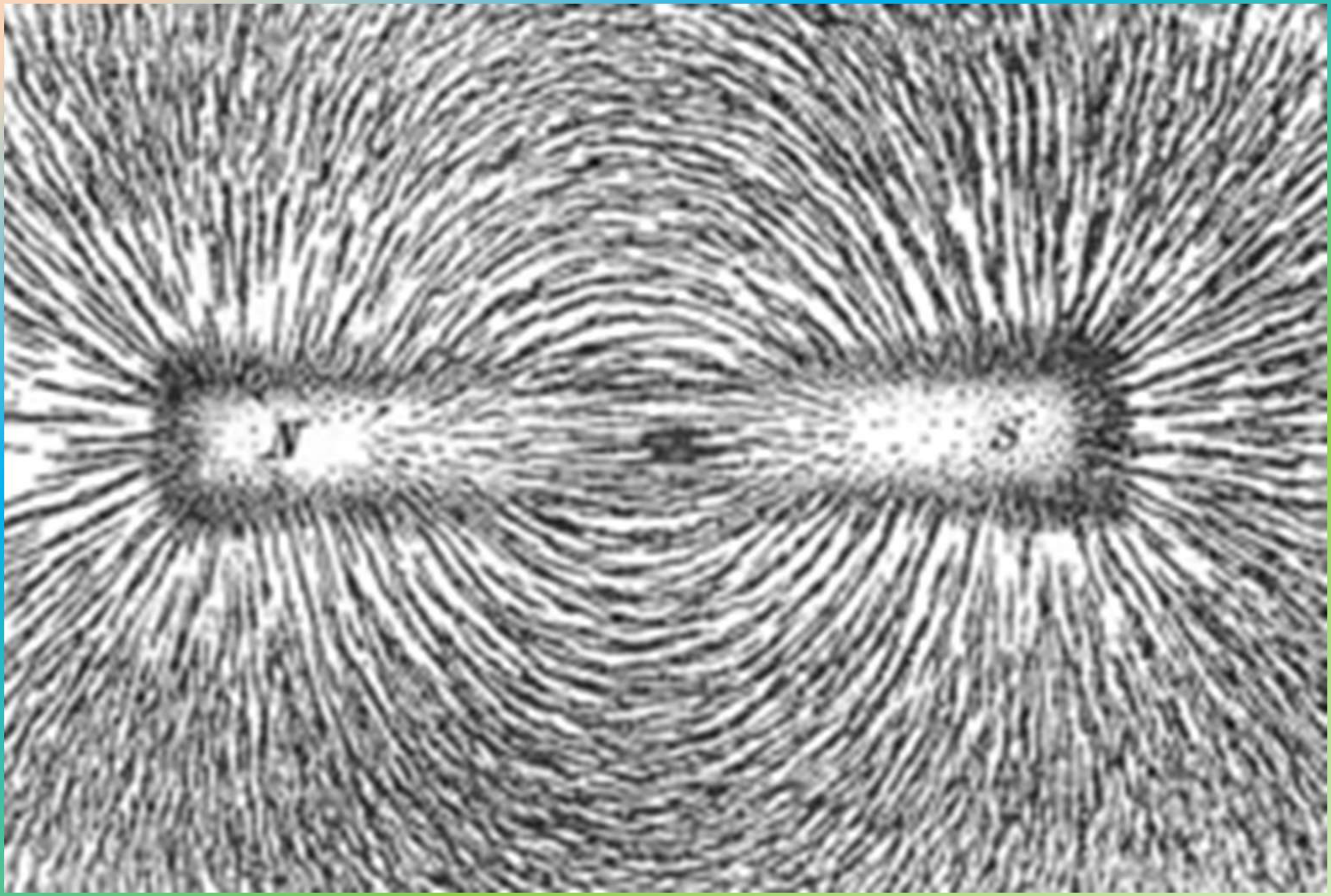
A. Direction of a magnetic field is the direction in which the north pole of a compass needle points at that location (Figure 21-2, page 767)

→ Magnitude of the field is higher closer to the pole

II. Magnetic fields



II. Magnetic fields



II. Magnetic fields

To indicate

1. In the plane of the page: →
2. Into the page: X
3. Out of the page: •

Magnetic fields

North-seeking vs. South seeking

1. Bar magnets will seek or point to the Geographic north or south pole.
2. Geographic north = magnetic south
3. Geographic south = magnetic north

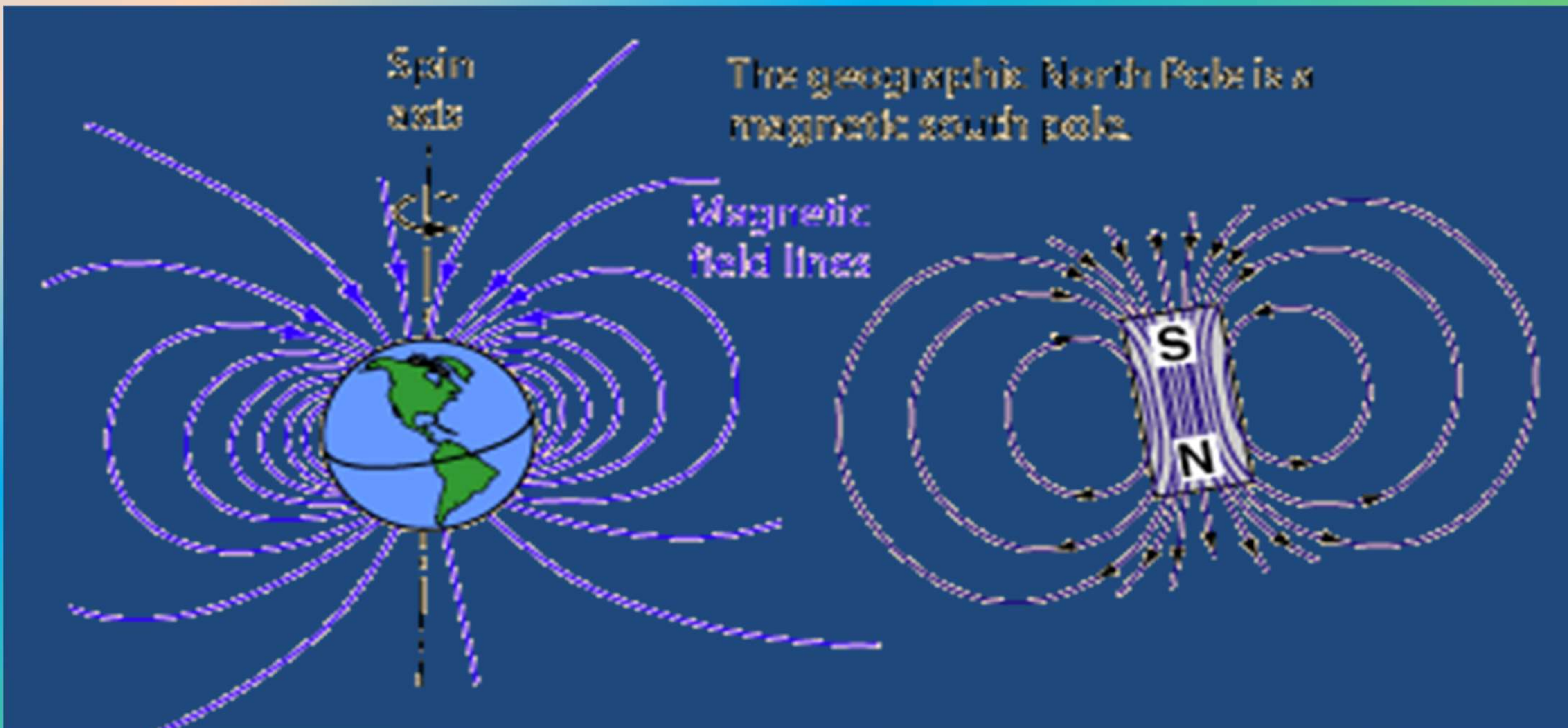
Magnetic fields

Magnetic fields

Earth's field is like a bar magnet buried in the Earth

→ Convection current in Earth's liquid iron outer core are the source of the field

→ Related to planet rotation.

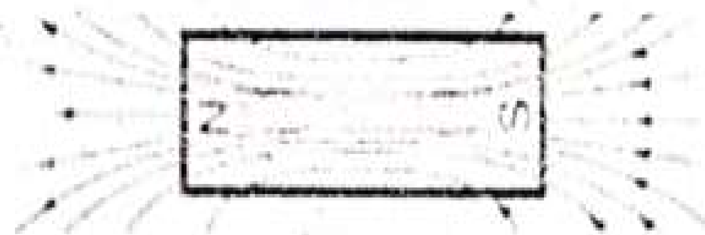


PROPERTIES OF PERMANENT MAGNETS

1. When a bar magnet is dipped into iron fillings, few of them adhere to central part while many of them cluster to ends. The ends are called poles of the bar magnet.

2. The magnet has two poles called north pole and south pole.

   The north pole and south pole attracts each other.

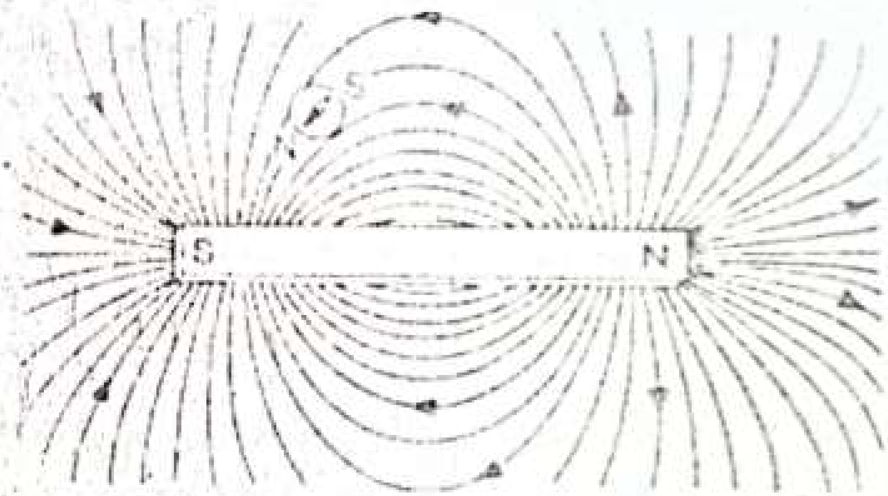


The north pole repels another north pole while a south pole repels another south pole.

3. The pole of a magnet never be separated from the magnet. The separated end is again magnet when it is separated. The magnetization is concentrated at poles than central part of the magnet.

4. The steel or iron bar gets magnetized when it is rubbed against the magnet. Heating or dropping it on ground several times can demagnetize it.

5. The space or region around a magnet in which attraction or repulsion with other magnets takes place is called magnetic field. It is denoted by $\vec{B}$. The magnetic field is a vector quantity. Its direction is defined by magnetic lines of force.



The magnetic lines of force come out from north pole

The magnetic lines of force enter into south pole.

2: ELECTROMAGNET

The magnetic field is generated around a straight conductor in the form of circles when current flows through it. This conductor is called electromagnet.

ELECTROMAGNETIZATION

The power of attraction of electromagnet is called electromagnetization.

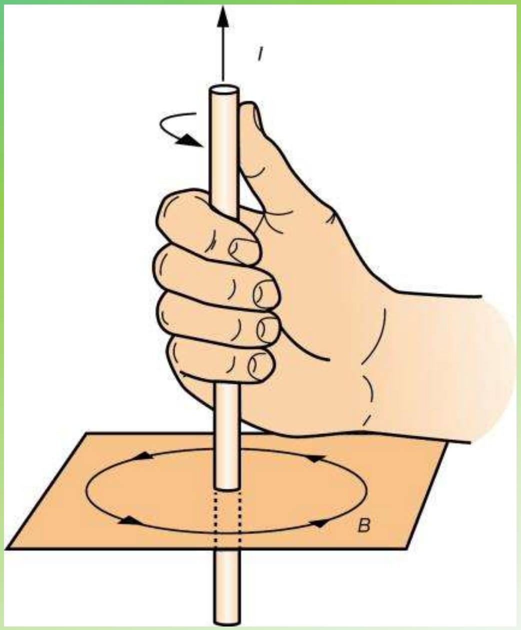
ELECTROMAGNETISM

The study of properties associated with electromagnet is called electromagnetism.

ELECTROMAGNETIC FIELD

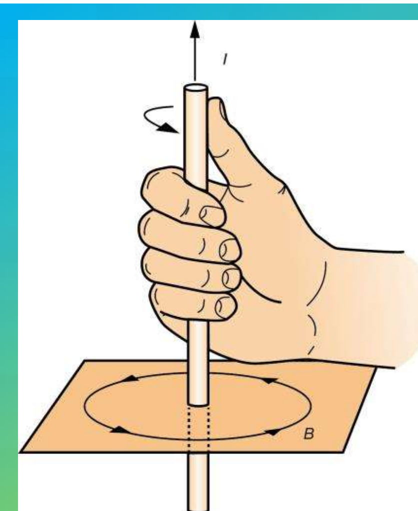
The magnitude of generated electromagnetic field depends upon the amount of current in conductor whose value is given by Ampere law. The direction of electromagnetic field is given by right hand rule.

Place thumb in direction of current; fingers indicate direction of the magnetic field.



RIGHT HAND RULE

Hold the current carrying conductor in your right hand in such a way that erect thumb is along the direction of current. The curled fingertips indicate the direction of magnetic field which will be clockwise or anticlockwise depending upon direction of current through conductor.



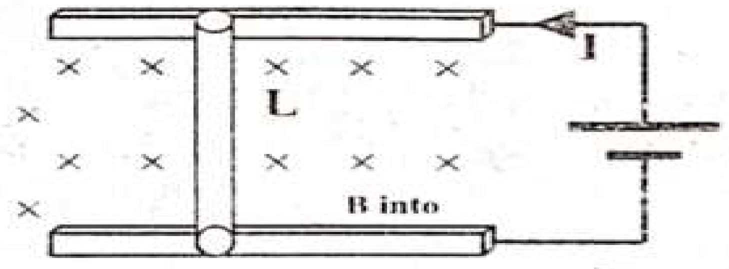
Uses of magnetic

1. The discovery of magnetism has a great practical use from small refrigerato magnets to magnetic recording tape and computer disks.
2. The magnetism of individual atomic nuclei is used by physicians to make images o organs deep within the body.
3. Spacecrafts have measured the magnetism of the earth and the other planets to learn about their internal structure.
4. The electromagnet is used in electric bells, electric motors, fans, radio, telephone, galvanometer, transformer etc.
5. Heavy pieces of iron can be lifted and shifted from one place to an other place by electromagnet.
6. Doctors use electromagnet to remove iron fillings from eyes and bullets from wounds.
7. The electromagnet is used in cyclotron accelerator.

Magnetic force on current carrying conductor placed in a magnetic field

Consider a conductor having length L is placed over a conducting rail in applied magnetic field B perpendicularly. The magnetic field is generated around the conductor in the form of circles when current I flows through conductor. The generated magnetic field and applied magnetic field interacts together and give rise to magnetic force.

It is experimentally observed that motion of conductor on rail becomes fast when amount of current through circuit or applied magnetic field increases. It is also observed that motion of conductor increases when length of conductor increases. Similarly, motion of conductor is also affected with its orientation to magnetic filed.



This magnetic force F_m acting on conductor is directly proportional to current "I", length "L", applied magnetic field "B" and orientation "$Sin\theta$" of the conductor with magnetic field.

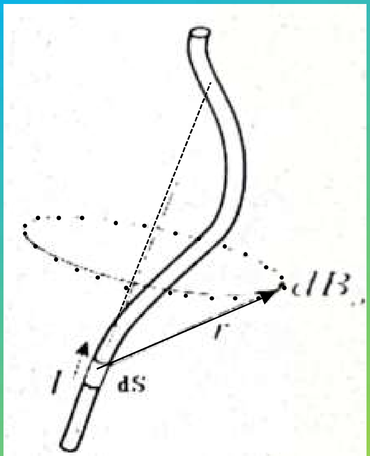
$F_m \propto I$ $\quad$ $F_m \propto L$ $\quad$ $F_m \propto B$ $\quad$ $F_m \propto Sin\theta$ $\quad$ $F_m \propto Sin\theta$

$F_m \propto ILBSin\theta$ $\quad$ $F_m = ILBSin\theta$

$$in\ vector\ form\ \vec{F}_m = I(\vec{L} \times \vec{B}) = ILB\ Sin\theta\ \hat{n}$$

Where $\vec{L}$ is called vector length of conductor whose magnitude is the length of the conductor and direction is the direction of current.

When wire is not straight or magnetic field is non-uniform, then to calculate magnetic force, divide the wire into small segments of length dS for which length becomes uniform approximately.



The magnetic force on each segment is

$$d\vec{F}_m = I(d\vec{S} \times \vec{B})$$

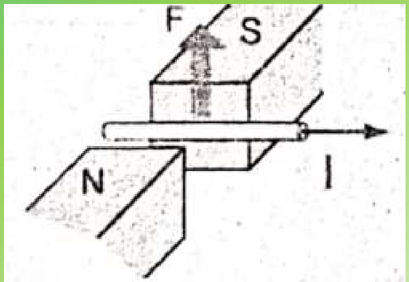
The net magnetic force on conductor having length L is

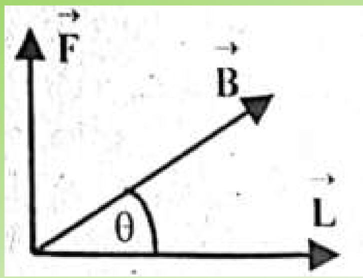
$$\vec{F}_m = \int_0^L I(d\vec{S} \times \vec{B})$$

DIRECTION OF MAGNETIC FORCE

The direction of magnetic force is given by right hand rule stated as

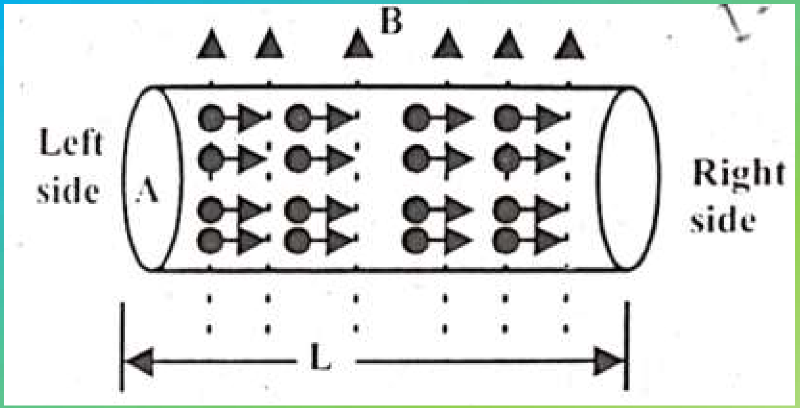
Place close-fisted right hand at a location where tails of length vector $\vec{L}$ and magnetic field vector are joined together in such a way that fingertips are along the direction of rotation through smaller angle, then stretched thumb indicates the direction of magnetic force.





Magnetic force on a moving charge in a magnetic field

consider a conductor having a length L and cross sectional area A and placed it in a uniform magnetic field B perpendicularly as shown in figure. The vo;ume of a conductor is AL. *But the conductor has many charge carriers*



Charge carriers

Unit volume of conductor has charge carriers $= n$

AL volume of conductor ha charge carriers $= n\,AL$

Total charge carriers = nAL

TOTAL CHARGE

One charge carrier has charge $=$ q

All charge carriers have charge $=$ nAL

Total charge on all charge carriers is

$$\Delta Q = n\,A\,L\,q$$

CURRENT FLOWING THROUGH CONDUCTOR

The charge carriers move from left side of a conductor with velocity V and come out at right side after covering distance L in time Δt given as

$$\Delta t = \frac{L}{V}$$

The current established within conductor is given as

$$I = \frac{\Delta Q}{\Delta t}$$

$$I = \frac{n\,A\,L\,q}{L/V}$$

$$I = n\,A\,q\,V$$

The magnetic force on current carrying conductor having length L is

MAGNETIC FORCE ON CURRENT CARRYING CONDUCTOR

The magnetic force $\vec{F}_L$ on current carrying conductor having length vector $\vec{L}$ placed in applied magnetic field $\vec{B}$ is

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

$$\vec{F}_L = n\,A\,qV(\vec{L} \times \vec{B})$$

$$\vec{F}_L = n\,A\,qV(L\,\hat{L} \times \vec{B})$$

Where $\hat{L} = \hat{V}$ because direction of length vector and velocity vector is same.

$$\vec{F}_L = n\,A\,qV(L\,\hat{V} \times \vec{B})$$

$$\vec{F}_L = n\,A\,q\,L(V\,\hat{V} \times \vec{B})$$

$$\vec{F}_L = n\,A\,q\,L(\vec{V} \times \vec{B})$$

MAGNETIC FORCE ON SINGLE CHARGE

The magnetic force $\vec{F}_m$ on a single charge q moving with velocity $\vec{V}$ in applied magnetic field $\vec{B}$

$$\vec{F}_m = \frac{\vec{F}_L}{n\,A\,q\,L} = \frac{n\,A\,q\,L\,(\vec{V} \times \vec{B})}{n\,A\,q\,L}$$

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

This is magnetic force on single charge which enters in applied magnetic field. can be written as

$$\vec{F}_m = q\,V\,B\,\mathrm{Sin}\theta\,\hat{n}$$

$$\boxed{\vec{F}_m = q(\vec{V} \times \vec{B}) = qVB\,Sin\theta\,\hat{n}}$$

MAGNITUDE OF MAGNETIC FORCE

The magnitude of magnetic force is

$$F_m = q\,V\,B\,\mathrm{Sin}\theta$$

The magnetic force is maximum when angle between V and B is 90^0.

$$F_{max} = q\,V\,B\,\mathrm{Sin}90^0$$

$$F_{max} = q\,V\,B$$

The magnetic force is minimum when angle between V and B is 0^0

$$F_{min} = q\,V\,B\,\mathrm{Sin}0^0$$

$$F_{min} = 0$$

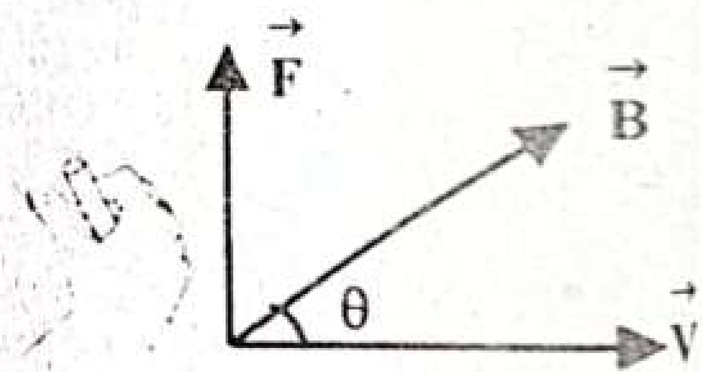
Similarly, magnetic force is minimum when angle between V and B is 180^0

$$F_{min} = q\,V\,B\,\mathrm{Sin}180^0$$

$$F_{min} = 0$$

DIRECTION OF MAGNETIC FORCE

The direction of magnetic force $\vec{F}_m$ is given by right hand rule stated as "join the tails of velocity vector $\vec{V}$ of +q charge and magnetic field vector $\vec{B}$ together. This defines a plane. Place close-fisted right hand at a location where tails of two vectors be joined in such a way that finger tips are along rotation through smaller angle. The erect thumb indicates the direction of magnetic force



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

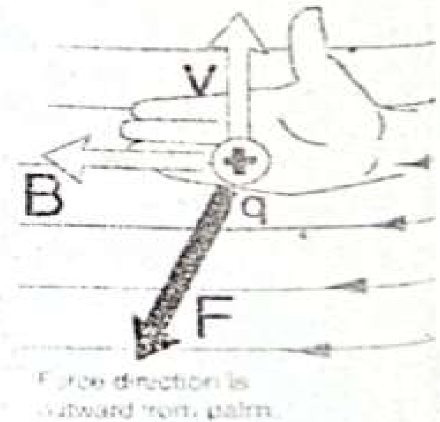
The direction of magnetic force is reversed when charge is negative.

SECOND DEFINITION OF RIGHT HAND RULE

The right hand rule can also be stated as

1. Point the thumb of your right hand in the direction of velocity $\vec{V}$ of +q charge
2. Fingers in the direction of magnetic field $\vec{B}$.
3. Palm direction is the direction of magnetic force

$$\vec{F}_m = q(\vec{V} \times \vec{B}).$$



This magnetic force F_m acting on an electron entering with velocity "V" in applied magnetic field "B" is $\vec{F}_m = -e(\vec{V} \times \vec{B})$

This magnetic force F_m acting on a proton entering with velocity "V" in applied magnetic field "B" is $\vec{F}_m = +e(\vec{V} \times \vec{B})$

When an electron and proton are projected into a magnetic field in the same direction both are deflected in opposite directions because magnetic force acts them in opposite direction

Lec-3 Dated 02/12/2023

$$Motion\ of\ charge\ particle\ in\ electric\ field\ and\ magnetic\ field\ and\ describe\ the\ Lorentz\ force$$

Biot savart law

Amperes Law and its integral and differential forms

Motion of charge particle in an electric field and magnetic field and describe the Lorentz force

Consider a +q charge is placed in a ***uniform electric field***. The electric force acting on the charge is given as

$$\vec{F}_e = q\vec{E} \qquad (1)$$

The charge +q will move parallel to electric field $\vec{E}$ if is free to move. The acceleration $\vec{a}$ develop is given by as

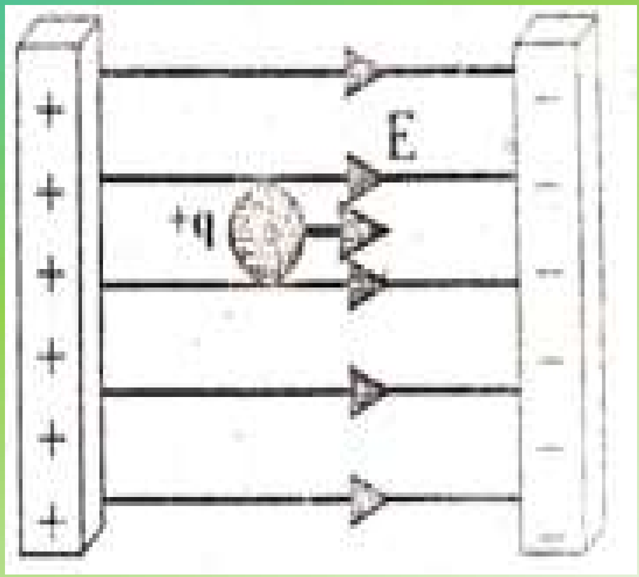
$$\vec{F}_e = m\vec{a} \qquad (2)$$

Comparing (1) and (2)

$$m\vec{a} = q\vec{E}\ , \qquad \vec{a} = q\vec{E}/m$$

The position of charge at any time can be calculated by using three equation of motions.

The electric force always do work on charge when placed inside electric field



When magnetic force $\vec{F}_m$ acts on the charge when +q charge enters into a ***uniform Magnetic field*** $(\vec{\boldsymbol{B}})$ with velocity $(\vec{\boldsymbol{V}})$. The magnetic force acting on the charge is given as

$$\vec{F}_m = +q(\vec{V} \times \vec{B})$$

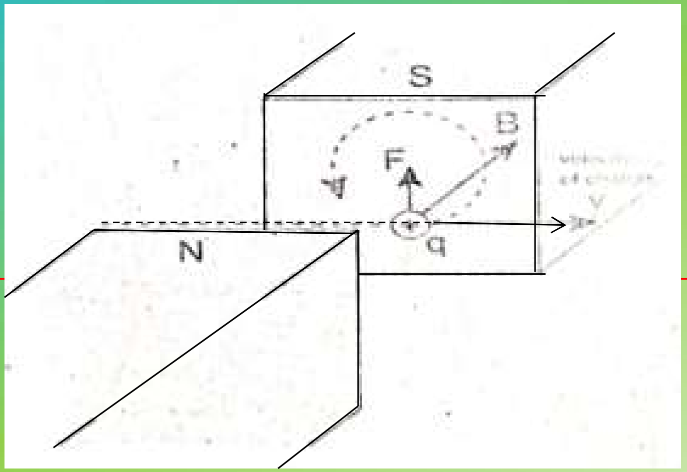
1- The maximum magnetic force acts on +q when it enters magnetic field perpendicularly.

2- The charge moves in circular path under the action of this magnetic force.

3- The magnetic force which is always perpendicular to the plane defined by $\vec{V}$ and $\vec{I}$ is only deflecting force.

4- It dose not perform any work.

$$W = \vec{F}_m . \vec{S} = \vec{F}_m . \vec{V}_t = FV_t Cos\, 90 = 0$$



The total force acting on the charge is called Lorentz force, when it enters in a region where electric and magnetic fields are applied at the same time.

The value of Lorentz force is given as

$$\vec{F} = \vec{F}_e + \vec{F}_m = q\vec{E} + q(\vec{V} \times \vec{B})$$

$Biot - Savart\ Law$

BIOT-SAVART LAW

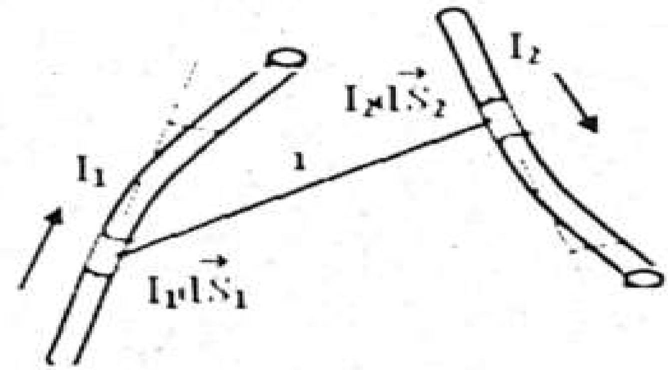
The magnitude of magnetic field at a point due to current distribution is directly proportional to amount of current and effective length of conductor and inversely proportional to square of distance between point and current distribution.

EXPLANATION

The magnetic field is generated around a conductor when current flows through it. Now place another current carrying conductor in the magnetic field of first conductor. The magnetic force acts on second conductor due to interaction of magnetic fields of both conductors. Similarly first conductor also experiences magnetic force which is placed in magnetic field of second conductor.

MATHEMATICAL TREATMENT

Now consider two conductors through which current I_1 and I_2 flows in opposite direction as shown in fig. Divide the first wire into differential element dS_1 and then define for each element a length vector $\vec{dS_1}$ that has magnitude length dS_1 and direction is the direction of current in dS_1. In this way, differential current length element of first wire is $I_1\vec{dS_1}$. Similarly differential current length element of second wire is $I_2\vec{dS_2}$.



The magnetic force $\vec{dF_{12}}$ exerted on current element $I_2\vec{dS_2}$ which is placed in magnetic field $\vec{B_1}$ of first conductor is

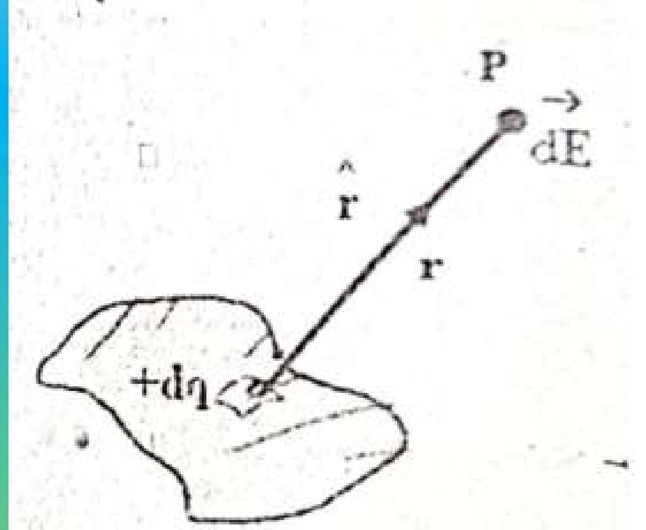
$$\vec{dF_{12}} = I_2 (\vec{dS_2} \times \vec{B_1})$$

The magnetic force $\vec{dF_{21}}$ exerted on current element $I_1\vec{dS_1}$ which is placed in magnetic field $\vec{B_2}$ of second conductor is

$$\vec{dF_{21}} = I_1 (\vec{dS_1} \times \vec{B_1})$$

Take a point P having distance r from charge dq of some charge distribution. The electric field $\vec{dE}$ at point P due to charge dq is given as

$$\vec{dE} = \frac{k\,dq}{r^2}\,\hat{r}$$

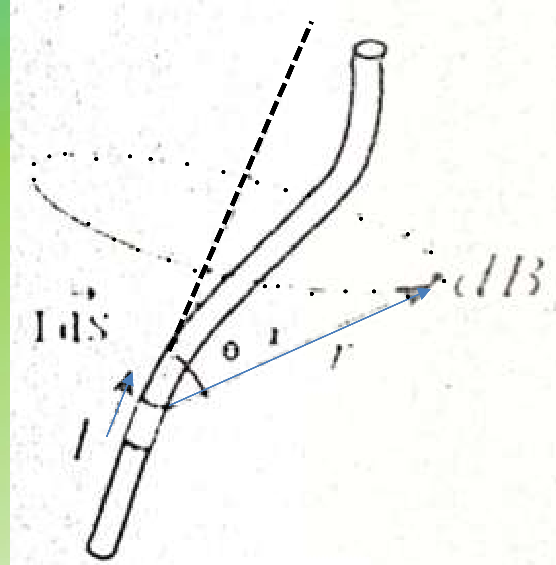


The direction of electric field is given by electric lines of force which come out from positive charge and enters into negative charge

Similarly take a point P having distance r from current element $\vec{IdS}$ of some current distribution. The magnetic field $\vec{dB}$ at point P due to current element $\vec{IdS}$ is given as

$$\vec{dB} = \frac{k\,I\,\vec{dS} \times \hat{r}}{r^2}$$

$$\vec{dB} = \frac{\mu_0}{4\pi}\,\frac{I\,\vec{dS} \times \hat{r}}{r^2}$$



Where $\hat{r}$ is unit vector directed from $I\vec{dS}$ to point P and k is proportionality constant having value $\frac{\mu_0}{4\pi}$. The constant μ_0 is called permeability of free space having value $4\pi \times 10^{-7}$ T–m/A.

The direction of magnetic field is the same as cross product of $\mathbf{dS} \times \hat{\mathbf{r}}$. According to right hand rule direction of magnetic field is into plane of paper.

The magnitude of magnetic field is given as

$$|\vec{dB}| = \frac{\mu_0 I}{4\pi r^2} |\vec{dS}| |\hat{r}| \sin\theta |\hat{n}|$$

$$dB = \frac{\mu_0}{4\pi} \frac{I\, dS \sin\theta}{r^2}$$

Where θ is the angle between $\vec{dS}$ and $\hat{r}$. The net magnitude of magnetic field due to entire current distribution is

$$B = \int dB$$

$$\boxed{B = \int \frac{\mu_o}{4\pi} \frac{IdB \, Sin\, \theta}{r^2}}$$

The net magnetic field in vector form due to entire current distribution is

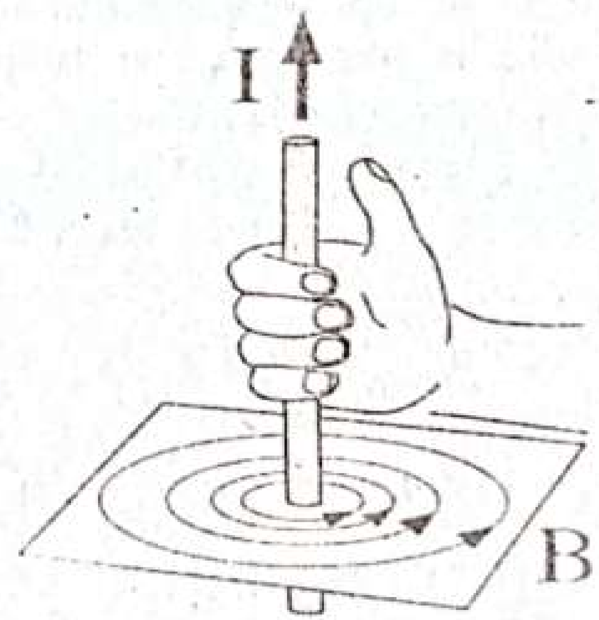
$$\vec{B} = \int \vec{dB}$$

$$\vec{B} = \int \frac{\mu_0}{4\pi} \frac{I\,\vec{dS} \times \hat{r}}{r^2}$$

$$\vec{B} = \int \frac{\mu_0}{4\pi} \frac{I\,\vec{dS} \times \vec{r}}{r^3} \qquad [\,\vec{r} = r\,\hat{r}\,]$$

AMPERE LAW

The Ampere law states that a magnetic field is generated around a conductor when current flows through it. The magnitude of generated magnetic field at a point is directly proportional to amount of current and inversely proportional to distance between point and straight current carrying conductor.



DIRECTION OF MAGNETIC FIELD

The direction of magnetic field is given by right hand rule stated as

Grasp the current carrying wire in your right hand in such a way that erect thumb is along the direction of current. The curled fingertips around the wire indicates the direction of magnetic field.

EXPLANATION

Consider a straight conductor through which current I flows. The magnetic field B is generated around it in the form of circles. The magnitude of magnetic field B depends upon current I and distance r between conductor and point P where we want to evaluate magnetic field.

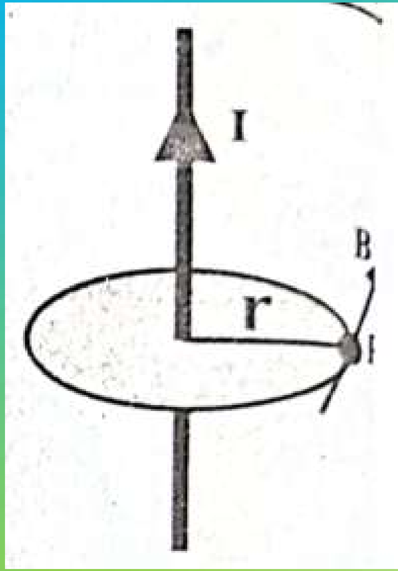
$B \propto I$

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

Combining both experimental facts

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

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



Where $\frac{\mu_0}{2\pi}$ is constant of proportionality and μ_0 is called permeability of free spac

Its value is $4\pi \times 10^{-7}$ Wb/A−m

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

Where $2\pi r$ is the length of path called circumference of circle and denoted by ℓ

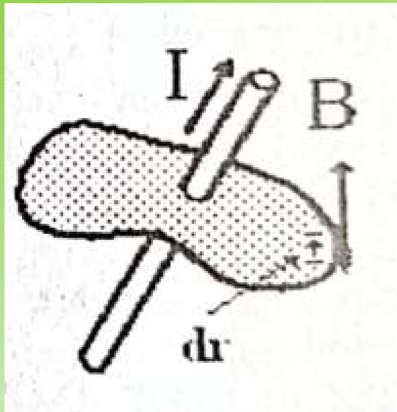
The value of B is constant around the path

$B\,\ell = \mu_0 I$

$B\,\ell \cos 0^0 = \mu_0 I$

$\vec{B} \cdot \vec{\ell} = \mu_0 I$

Now consider an amperian loop to find magnetic field set up by current in a long straight wire such that wire is perpendicular to plane of loop and current flows out of wire as shown in fig.



Take a small length element dr of the amperian loop. The total line integral for amperian loop is

$$\oint \vec{B} \cdot \vec{dr} = \mu_0 I$$

$$\oint B dr \cos\theta = \mu_0 I$$

AMPERE'S CIRCUITAL LAW

For any closed loop path, the sum of the length elements times the magnetic field i the direction of the length element is equal to the permeability times the electric curre enclosed in the loop.

INTEGRAL FORM OF AMPERE'S LAW

$$\oint \vec{B} \cdot \vec{dr} = \mu_0 I$$

The value of current in terms of current density is

$$I = \int \vec{J} \cdot \vec{da}$$

The above eq becomes

$$\oint \vec{B} \cdot \vec{dr} = \mu_0 \int \vec{J} \cdot \vec{da}$$

This is called integral form of Ampere's law

DIFFERENTIAL FORM

The integral form of Ampere's law is

$$\oint \vec{B} \cdot \vec{dr} = \mu_0 \int \vec{J} \cdot \vec{da} \qquad \text{----------(1)}$$

The Stoke's theorem is

$$\oint \vec{B} \cdot \vec{dr} = \int (\vec{\nabla} \times \vec{B}) \cdot \vec{da} \qquad \text{----------(2)}$$

Comparing eq (1) and eq(2)

$$\int (\vec{\nabla} \times \vec{B}) \cdot \vec{da} = \mu_0 \int \vec{J} \cdot \vec{da}$$

$$\int (\vec{\nabla} \times \vec{B} - \mu_0 \vec{J}) \cdot \vec{da} = 0$$

Since $\vec{da}$ cannot be zero so

$$\vec{\nabla} \times \vec{B} - \mu_0 \vec{J} = 0$$

$$\vec{\nabla} \times \vec{B} = \mu_0 \vec{J}$$

This is called differential form of Ampere's law.

By using Biot-Savart law, determine the magnetic field at a point having distance R away from the long straight current carrying wire.