Magnetism.

A magnet is a piece of material that has both attractive and directive properties. It attracts small pieces of iron, nickel, cobalt, etc. This property of attraction is called magnetism.

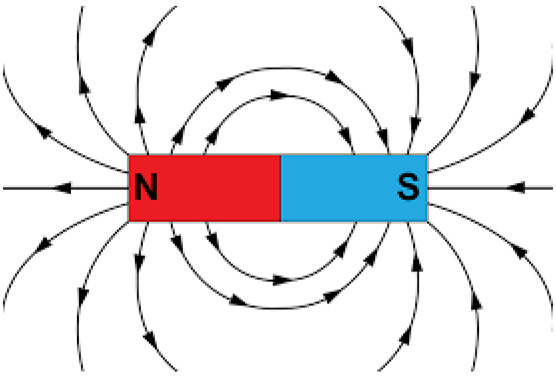
Basic properties of magnets.

These are as follows:

- **Attractive property. A magnet attracts small pieces of iron, nickel, cobalt, etc.**
- **Directive property. A freely suspended magnet aligns itself nearly in the geographic north-south direction.**
- **Like poles repel and unlike poles attract. This is a fundamental law of magnetic poles.**
- **Magnetic poles exist in pairs. Isolated magnetic poles do not exist. If we break a magnet into two pieces, we get two smaller dipole magnets.**

Magnetic field.

The space around a magnet within which its influence can be experienced is called its magnetic field.



Uniform magnetic field.

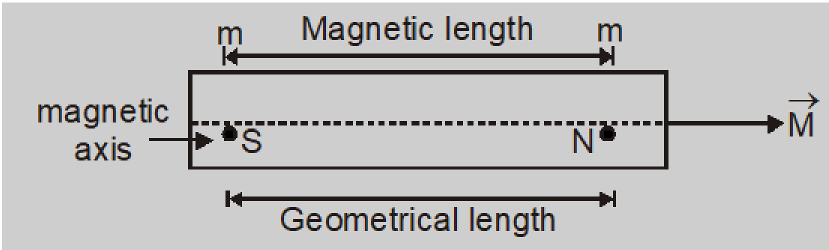
A magnetic field in a region is said to be uniform if it has same magnitude and direction at all points of that region.

Magnetic poles.

These are the regions of apparently concentrated magnetic strength in a magnet where the magnetic attraction is maximum.

Magnetic axis.

The line passing through the poles of a magnet is called its magnetic axis.



Magnetic equator.

The line passing through the centre of the magnet and at right angles to the magnetic axis is called the magnetic equator of the magnet.

Magnetic length.

The distance between the two poles of a magnet is called its magnetic length. It is slightly less than the geometrical length of the magnet.

Couomb's law of magnetic force.

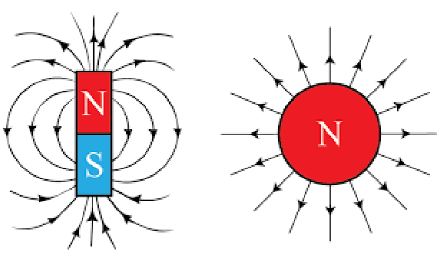
This law states that the force of attraction or repulsion between two magnetic poles is directly proportional to the product of their pole strengths and inversely proportional to the square of the distance between them. If q_{m_1} and q_{m_2} are the pole strengths of two magnetic poles separated by distance r, then the force of attraction or repulsion between them is

$$F = \frac{\mu_0}{4\pi} \cdot \frac{q_{m_1} q_{m_2}}{r^2}$$

Where μ_0 is the permeability of free space and its value is $4\pi \times 10^{-7}$ henry/metre.

Magnetic dipole.

Any arrangement of two equal and opposite magnetic poles separated by a small distance is called a magnetic dipole. A bar magnet and a current-carrying loop are magnetic dipoles.



Magnetic dipole moment.

It is equal to the product of the pole strength (q_m) and the magnetic length ($2l$) of the magnet.

$$m = q_m \times 2l$$

The SI unit of magnetic dipole moment is Am^2 or JT^{-1}.

Magnetic lines of force.

A magnetic line of force may be defined as the curve the tangent to which at any point gives the direction of the magnetic field at that point. It may also be defined as the path along which a unit north pole would tend to move if free to do so.

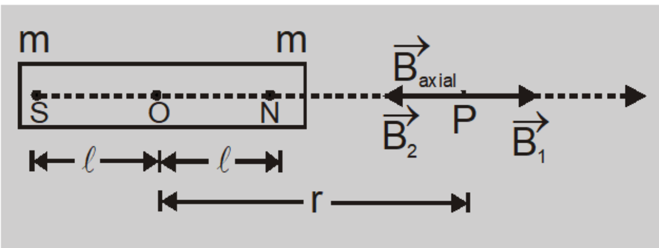
Properties of lines of force.

- Magnetic lines of force are closed curves which start in air from the N-pole and end at the S-pole and then return to the N-pole through the interior of the magnet.
- The lines of force never cross each other
- They start from, and end on the surface of the magnet normally.
- The lines of force have a tendency to contract lengthwise and expand sidewise. This explains attraction between unlike poles and repulsion between like poles.
- The relative closeness of the lines of force is a measure of the strength of the magnetic field which is maximum at the poles.

Magnetic field of a bar magnet at an axial point.

$$(i)\ \ B_{axial} = \frac{\mu_0}{4\pi} \cdot \frac{2mr}{(r^2 - l^2)^2}$$

Where r is the distance of the point from the centre of the magnet.



$$(ii)\ \ For\ a\ short\ magnet, l \ll r,$$

$$B_{axial} = \frac{\mu_0}{4\pi} \cdot \frac{2m}{r^3}$$

The magnetic field at any axial point of magnetic dipole is in the same direction as that of its magnetic dipole moment.

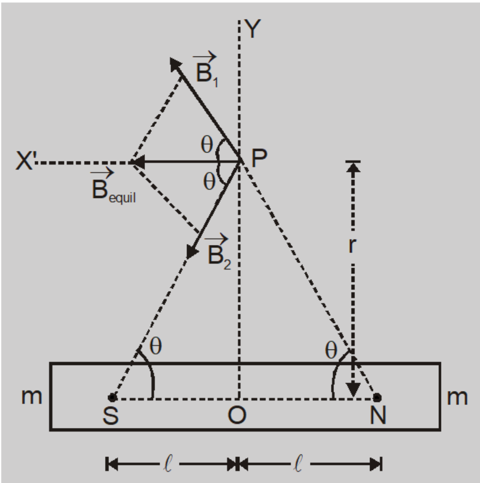
Magnetic field of a bar magnet at an equatorial point.

$$(i) \quad B_{equa} = \frac{\mu_0}{4\pi} \cdot \frac{m}{(r^2 + l^2)^{3/2}}$$

$$(ii) \quad For\ short\ magnet, l \ll r,$$

$$B_{equa} = \frac{\mu_0}{4\pi} \cdot \frac{m}{r^3}$$

The magnetic field at any equatorial point of a magnetic dipole is in the direction opposite to that of its magnetic dipole moment.



Torque on a magnet in a magnetic field.

If a magnet of dipole moment $\vec{m}$ is placed in a magnetic field $\vec{B}$ making an angle θ with it, then torque acting on the magnet is

$$\tau = mB\ sin\theta$$

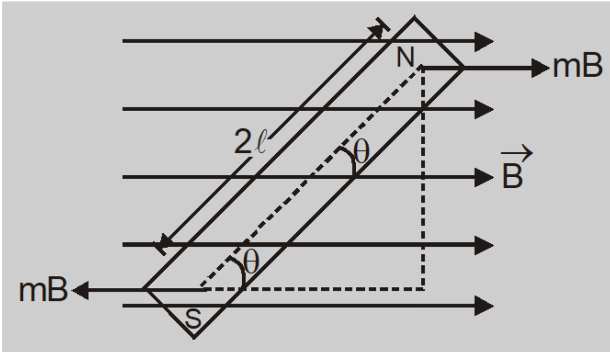
In vector notation,

$$\vec{\tau} = \vec{m} \times \vec{B}$$

The effect of the torque is to align the dipole parallel to the field $\vec{B}$.

If $\theta = 90°$, then $\tau = mB$

Hence the magnetic dipole may be defined as the torque acting on a magnetic dipole placed perpendicular to a uniform magnetic field of unit strength.



Potential energy of a magnetic dipole in a magnetic field.

When a magnetic dipole is rotated in a magnetic field against the torque from initial position θ_1 to final position θ_2, then work done or the potential energy stored is given by

$$W = U = -mB(cos\theta_2 - cos\theta_1)$$

P.E is zero when $\vec{m} \perp \vec{B}$. Hence P.E of the dipole in any orientation θ is

$$U = -mB\ cos\theta = -\vec{m}.\vec{B}$$

Special cases:

(i) when $\theta = 0°$, $U = -mB$. Thus the P.E of a dipole is minimum when $\vec{m}$ is parallel to $\vec{B}$. This is the position of the stable equilibrium.

(ii) When $\theta = 90°$, $U = 0$

(iii) When $\theta = 180°$, $U = +mB$.

Thus, the P.E of the dipole is maximum when $\vec{m}$ is antiparallel to $\vec{B}$. This is the position of unstable equilibrium.

Current loop as a magnetic dipole.

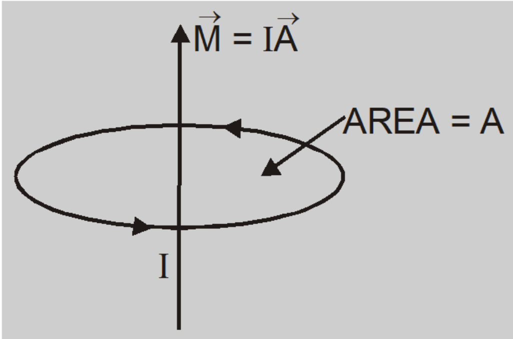
A planar current loop of area A and carrying current I behaves as a magnetic dipole of dipole moment,

$$m = IA$$

In vector notation,

$$\vec{m} = I\vec{A}$$

The direction of $\vec{m}$ is given by right hand thumb rule. if we curl the fingers of the right hand along the direction of the current in the loop, then the extended thumb gives the direction of the magnetic moment.



Magnetic dipole moment of a revolving electron.

The orbital magnetic moment of an electron revolving around a nucleus in nth orbit of radius r with speed v is given by

$$\mu_l = \frac{evr}{2} = \frac{e}{2m_e}\, l = n\left(\frac{eh}{4\pi m_e}\right)$$

Where l is the magnitude of the angular momentum of the electron revolving around the nucleus.

Bohr's magneton.

It is the magnetic dipole moment associated with an electron due to its orbital motion in the first orbit of hydrogen atom. It is the smallest value of μ_l.

$$\mu_B = (\mu_l)_{min} = \frac{eh}{4\pi m_e} = 9.27 \times 10^{-24}\ Am^2$$

Gauss law in magnetism.

This law states that the net magnetic flux through any closed surface is zero.

Mathematically,

$$\phi_B = \oint_S \vec{B}\,.\,\vec{dS} = 0$$

This law indicates that isolated magnetic poles (also called monopoles) do not exist.