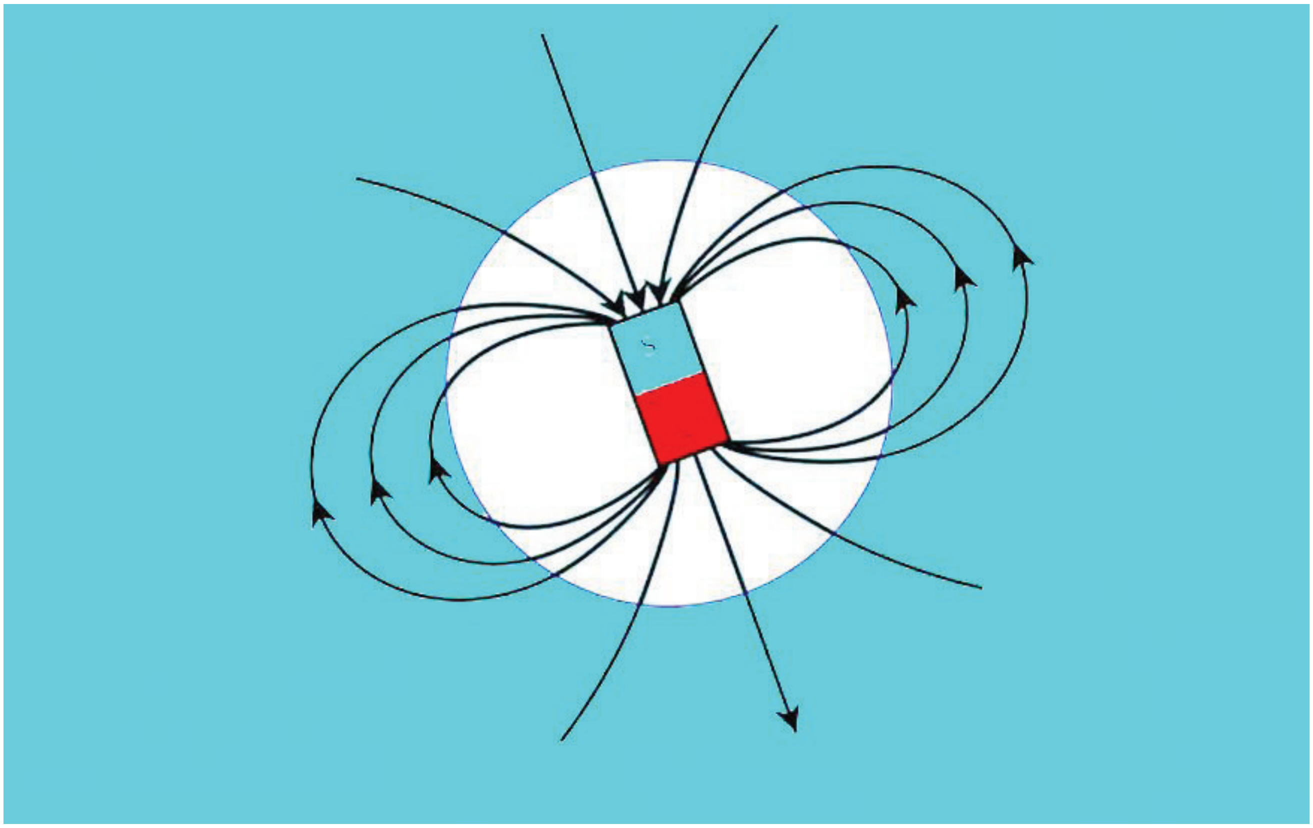
MAGNETISM AND MATTER



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Magnetism and Matter

The phenomenon of magnetism was known to Greeks as early as about 800 B.C. They discovered certain stones now known as magnetite (Fe_3O_4) which attracted pieces of iron. Magnetite was found near the city of magnesia and hence the name magnetite.

Bar magnet

A device that produces a magnetic field is generally called a magnet. The simplest way of obtaining magnetic fields is by using *bar magnets*. A bar magnet is a rod, generally of rectangular cross section and made of materials containing elements like iron, nickel, cobalt etc. and their alloys.

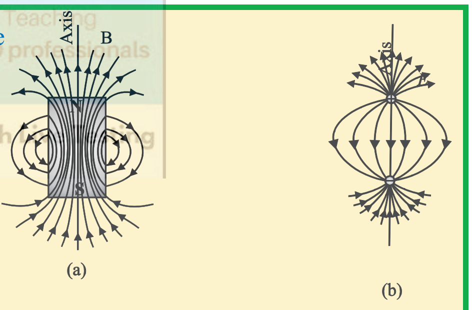
Properties of bar magnets

1. When a bar magnet is suspended freely near the surface of the earth, it tends to align always in the nearly North-South direction. One end of the bar magnet always pointing towards the geographic North is called the **North pole** of the magnet. The other end that always point towards the geographic South is called the **South pole** of the magnet.
2. Like poles repel and unlike poles attract each other.
3. The North and South poles of a bar magnet cannot be separated. *The magnetic monopoles do not exist*.
4. Bar magnets are made up of ferromagnetic materials, like iron, cobalt, nickel etc.

Characteristics of Magnetic Field lines

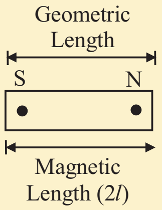
1. The tangent to the magnetic field line at a point gives the direction of the net magnetic field acting at that point.
2. *Magnetic field lines are always closed paths*, whatever may be the source of magnetic field. Hence, there is no beginning or end point for a magnetic field line. There are no sources or sinks for magnetic field lines in a magnetic field. That is, there is no isolated magnetic pole.
3. *The magnetic field lines can never intersect*.
4. The number of magnetic field lines across unit area in a region of space is a measure of the strength of the magnetic field in that region.

- The configuration of field lines of the magnetic field produced outside a bar magnet resemble that of the electric field lines around an electric dipole as shown in Fig. (a) and (b).



Field lines due to (a) a bar magnet (b) electric dipole

- Magnetic length ($2l$) = $\frac{7}{8}\times$ geometric length

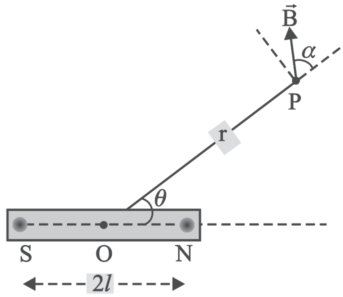


- There can be magnets without poles. A magnetized ring called toroid and a solenoid of infinite length has magnetic properties but has no poles.

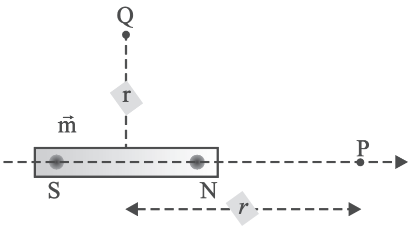
Magnetic field due to a bar magnet

- The magnetic field due to a small bar magnet at a point p, at a distance r from the centre of the magnet and at angle θ with the magnetic axis is $B=\frac{\mu_0}{4\pi}\times\frac{m}{r^3}\sqrt{3\cos^2\theta+1}$

The direction of field makes an angle 'α' with the line OP such that $\tan\alpha=\frac{1}{2}\tan\theta$.



Field at an arbitrary point due to a bar magnet



Field points on the axis and equatorial line for a short bar magnet

- For a point P on the axis of a short bar magnet the field is $B_d = \frac{\mu_0}{4\pi} \times \frac{m}{r^3}$
- For a point θ on the equatorial line of a short bar magnet the field is $B_e = \frac{\mu_0}{4\pi} \times \frac{2m}{r^3}$
- We see that, the field at a certain distance along *x* axis of a short bar magnet is twice that at the same distance along the equatorial line.

Magnetic field along the axis of a solenoid and of a bar magnet

Consider a solenoid of length 2*l*, radius of cross section and 'a' having N turns. If n is the number of turns per unit length then, N = n × 2*l*.

Consider a point P at a distance r from the center O of the solenoid.

The total magnetic field at point P due to the entire solenoid is

$$B_P = \frac{\mu_0 NIa^2}{2r^3} \qquad \text{(for } r >> l \text{ and } r >> a\text{)},$$

(a)

(b)

Field along (a) the axis of a solenoid and (b) a bar magnet

If the radius 'a' of the solenoid is very small compared to r, we get, or $B_P = \frac{\mu_0}{4\pi} \times \frac{2NIA}{r^3}$

where A = πa^2 is area of cross section of the solenoid

$$B_P = \frac{\mu_0}{4\pi} \frac{2m}{r^3} \qquad \text{…(1)}$$

where m = NIA is magnetic moment of the solenoid.

This equation is similar to the equation for the magnetic field due to a short bar magnet on the axial line

$$B_P = \frac{\mu_0}{4\pi} \frac{2m}{r^3} \qquad \text{...(2)}$$

m represents the magnetic moment of the magnet, which is the product of its pole strength and magnetic length. The resemblance of Eqs., (1) and (2) reveal the equivalence of a solenoid and a bar magnet.

Magnetic Charge or Pole Strength

Magnetic moment m = n(2*l*)IA = nIA (2*l*)

i.e., m = nIA (2*l*) ...(3)

The electric field on the axial line of a short dipole is also given by a similar equation.

$$E = \frac{1}{4\pi\varepsilon_0} \frac{2p}{r^3} \qquad \text{...(4)}$$

where p is the electric dipole moment given by

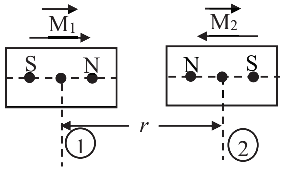
$$p = q_m (2l) \qquad \text{...(5)}$$

Comparing Eqs., (3) and (5) we observe that the quantity nIA can be regarded as the magnetic analogue of electric charge. It is sometimes called *magnetic charge* or *pole strength.*

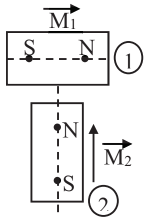
By convention, the positive pole of the magnet having a pole strength $+q_m$ (= nIA) is referred to as the N-pole and the negative pole of strength $-q_m$ is referred to as the S-pole.

Magnetic Force between short magnetic dipoles (Bar magnets) at distance 'r' a part

(i) If their magnetic moments are parallel to each other. Then, $F_m = \frac{\mu_0}{4\pi}\frac{6m_1m_2}{r^4}$



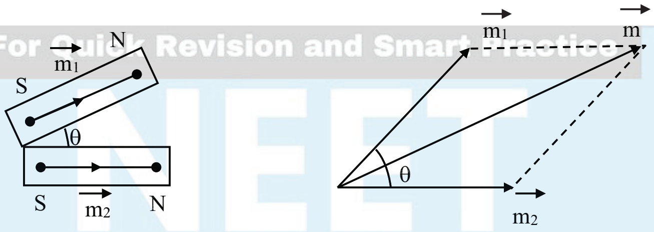
(ii) If their magnetic moments are ⊥ to each other.



Then, $F_m = \frac{\mu_0}{4\pi}\frac{3m_1m_2}{r^4}$

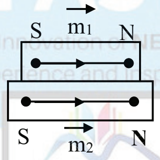
Magnetic moment of system:

(i)



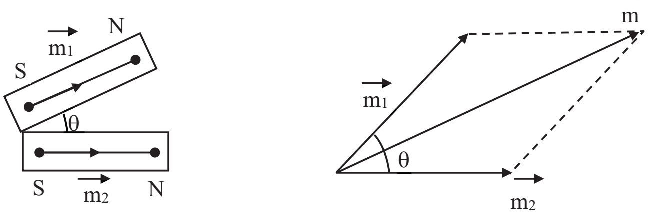
$$\therefore\ |\vec{m}| = \sqrt{m_1^2 + m_2^2 + 2m_1m_2\cos\theta}$$

Special case



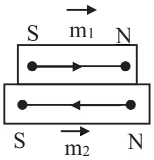
If $\theta = 0°$. Then $m = m_1 + m_2$

(ii)



$$\therefore\ |\vec{m}| = \sqrt{m_1^2 + m_2^2 + 2m_1m_2\cos\theta}$$

Special case

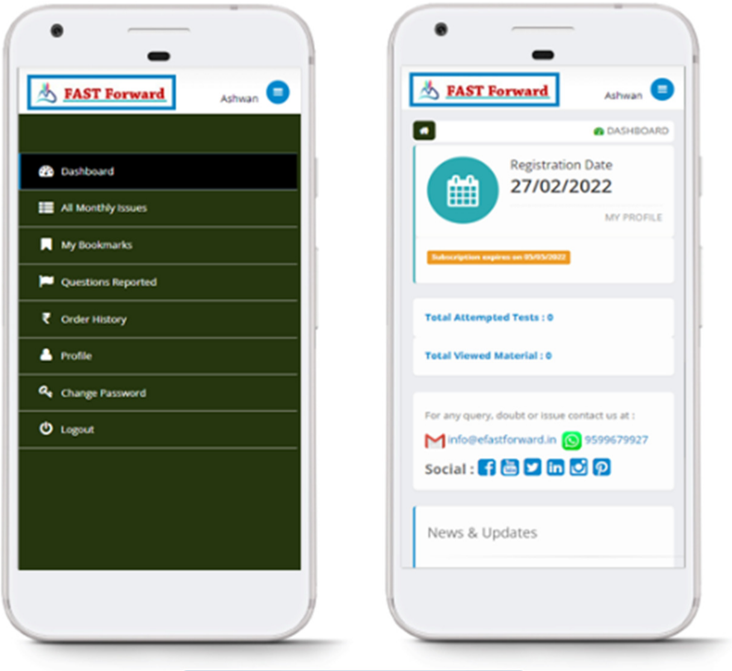


If one magnet is placed over the other with unlike poles touching $\theta = 0°$

$\therefore\ m = m_1 - m_2$

(iii) If they are arranged to form a cross like T or L $(\theta = 90°)$

$$\therefore\ m = \sqrt{m_1^2 + m_2^2}$$



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