Bar magnet as an equivalent solenoid, magnetic field lines

CLASS-XII

SUBJECT : PHYSICS
CHAPTER NUMBER: 05
CHAPTER NAME : MAGNETISM AND MATTER

CHANGING YOUR TOMORROW

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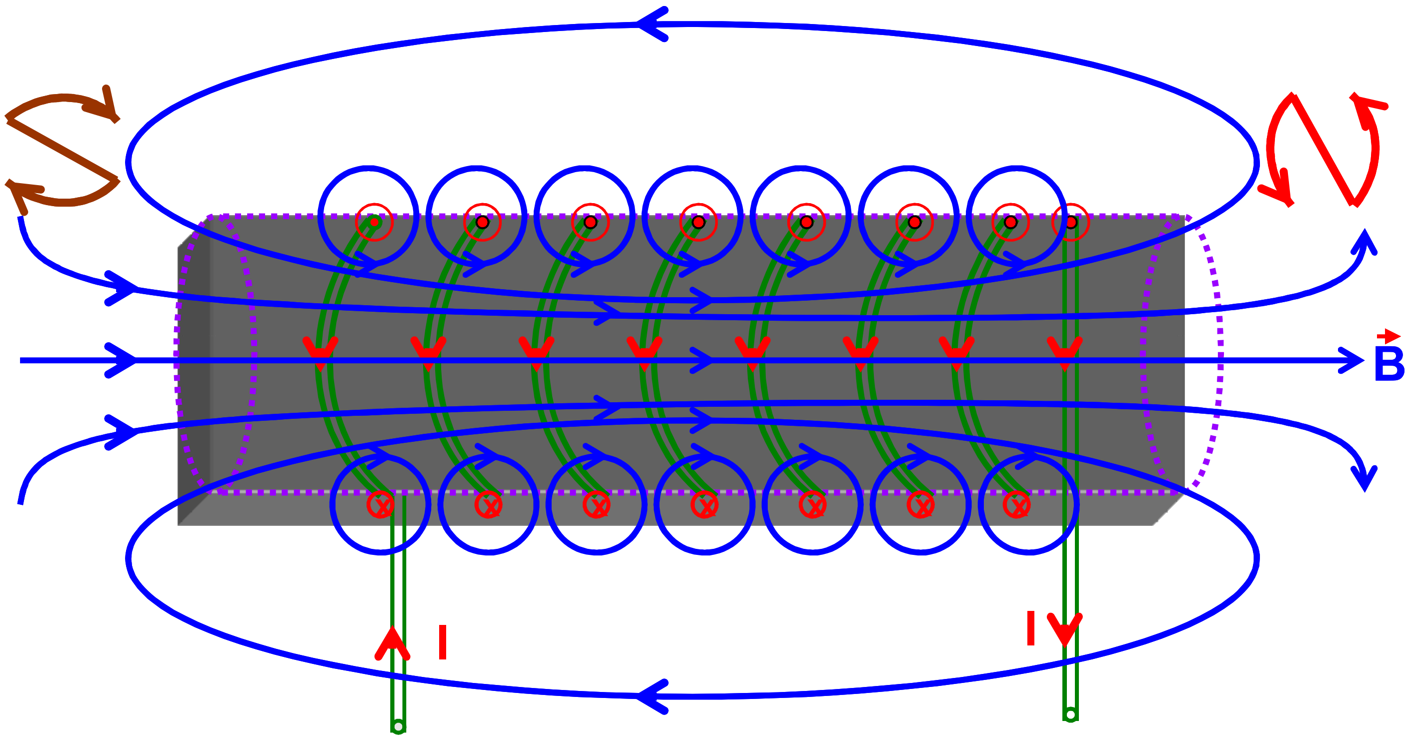
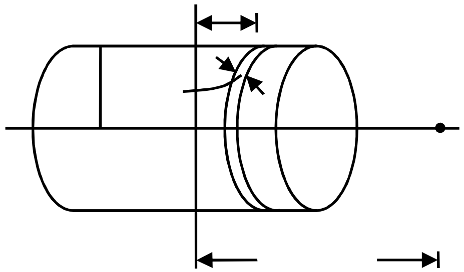
Current Solenoid as a Magnetic Dipole or Bar Magnet:

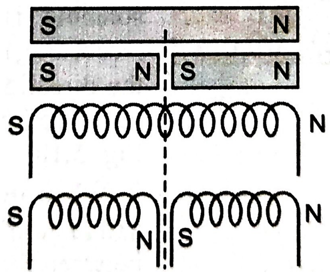


BAR MAGNET AS AN EQUIVALENT SOLENOID

Let the solenoid of fig. (1) consists of n turns per unit length. Let its length be 2l and radius a. We can evaluate the axial field at a point P, at a distance r from the centre O of the solenoid. To do this, consider a circular element of thickness dx of the solenoid at a distance x from its centre. It consists of ndx turns. Let I be the current in the solenoid. The magnitude of the field at point P due to the circular element is

$$dB = \frac{\mu_0}{2} \frac{(ndx)Ia^2}{\{a^2 + (r-x)^2\}^{3/2}}$$





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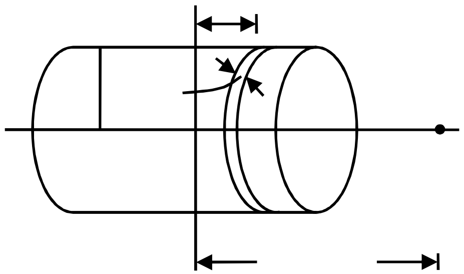


The magnitude of the total field at P is

$$B = \int_{x=-l}^{l} \frac{\mu_0}{2}\frac{(ndx)Ia^2}{\{a^2 + (r-x)^2\}^{3/2}}$$

Let $r \gg a$ and $r \gg l$. So

$$B = \frac{\mu_0 Ina^2}{2}\int_{x=-l}^{l}\frac{dx}{r^3}$$

$$\Rightarrow B = \frac{\mu_0 Ina^2}{2r^3}\int_{x=-l}^{l} dx$$

$$\Rightarrow B = \frac{\mu_0 Ina^2}{2r^3} 2l$$

$$\Rightarrow B = \frac{\mu_0}{4\pi}\frac{2m}{r^3}$$

NUMERICAL

A closely wound solenoid of 800 turns and area of cross-section $2.5 \times 10^{-4} m^2$ carries a current of 3.0 A. Explain the sense in which the solenoid acts like a bar magnet. What is its associated magnetic moment? If the solenoid is free to turn about the vertical direction and a uniform horizontal magnetic field of 0.25 T is applied, what is the magnitude of the torque on the solenoid when its axis makes an angle of 30° with the direction of applied field? (NCERT)

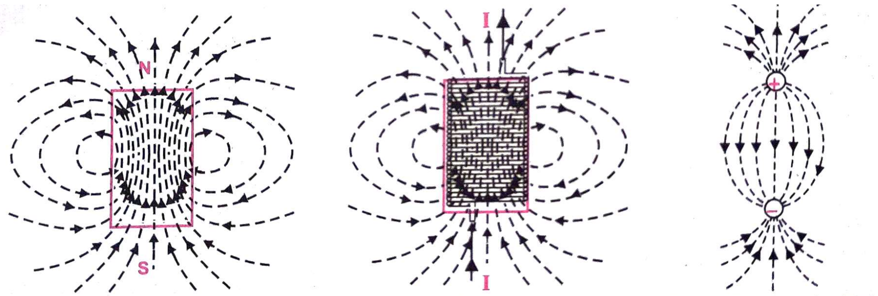
PROPERTIES OF MAGNETIC FILED LINES

- The magnetic field lines of a magnet (or a solenoid) form continuous closed loops. This is unlike the electric dipole where these field lines begin from a positive charge and end on the negative charge or escape to infinity.

- The tangent to the field line at a given point represents the direction of the net magnetic field B at that point.

- The larger the number of field lines crossing per unit area, the stronger is the magnitude of the magnetic field B.

- The magnetic field lines do not intersect, for if they did, the direction of the magnetic field would not be unique at the point of intersection.



Magnetic field lines due to a bar magnet (a)

Magnetic field lines due to a solenoid carrying current (b)

Electric filed lines due to an electric dipole (c)

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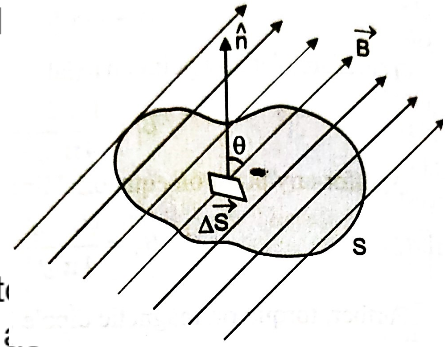
Gauss Law in Magnetism

According to Gauss's law for magnetism, the net magnetic flux (ϕ_B) through any closed surface is always zero.



The law implies that the number of magnetic field lines leaving any closed surface is always equal to the number of magnetic field lines entering it.

Suppose a closed surface S is held in a uniform magnetic field B. Consider a small vect area element $\Delta\vec{s}$ of this surface, Fig. Magnetic flux through this area element is defined a $\Delta\phi_B = \vec{B}.\Delta\vec{s}$. Summing over all small area elements of the surface, we obtain according to Gauss's law for magnetism.

$$\phi_B = \sum_{all} \Delta\phi_B = \sum_{all} \vec{B}.\Delta\vec{s} = 0$$

If the area elements are really small, we can rewrite this equation as

$$\phi_B = \oint_S \vec{B}.\overrightarrow{ds} = 0$$

Compare this equation with Gauss's law in electrostatics, i.e., electric flux through a closed surface S is given by

$$\phi_E = \oint_S \vec{E}.\overrightarrow{ds} = \frac{q}{\epsilon_0}$$

NUMERICAL

(a)Magnetic field lines show the direction (at every point) along which a small magnetised needle aligns (at the point). Do the magnetic field lines also represent the lines of force on a moving charged particle at every point?

(b) Magnetic field lines can be entirely confined within the core of a toroid, but not within a straight solenoid. Why?

(c) Does a bar magnet exert a torque on itself due to its own field? Does one element of a current-carrying wire exert a force on another element of the same wire?

(d) Magnetic field arises due to charges in motion. Can a system have magnetic moments even though its net charge is zero?(NCERT)

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© If magnetic monopoles existed, how would the Gauss magnetism be modified?

(d) Does a bar magnet exert a torque on itself due to its own field? Does one element of a current-carrying wire exert a force on another element of the same wire?

(e) Magnetic field arises due to charges in motion. Can a system have magnetic moments even though its net charge is zero?(NCERT)

Solution

(a) ***No.*** **The magnetic force is always normal to B (remember magnetic force = $q\mathbf{v} \times \mathbf{B}$). It is misleading to call *magnetic field lines* as *lines of force.***

(b) If field lines were entirely confined between two ends of a straight solenoid, the flux through the cross-section at each end would be non-zero. But the flux of field B through any closed surface must always be zero. For a toroid, this difficulty is absent because it has no

(c) Gauss B through any

closed surface is always zero $\oint_S \mathbf{B} \cdot d\mathbf{s} = 0$.

If monopoles existed, the right hand side would be equal to the monopole (magnetic charge) q_m enclosed by S. [Analogous to

Gauss $\int_S \mathbf{B} \cdot d\mathbf{s} = \mu_0 q_m$ where q_m is the

(monopole) magnetic charge enclosed by *S*.]

(d) ***No.*** **There is no force or torque on an element due to the field produced by that element itself. But there is a force (or torque) on an element of the same wire. (For the special case of a straight wire, this force is zero.)**

(e) ***Yes.*** **The average of the charge in the system may be zero. Yet, the mean of the magnetic moments due to various current loops may not be zero. We will come across such examples in connection with paramagnetic material where atoms have net dipole moment through their net charge is zero.**

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