Magnetic field intensity due to a magnetic dipole (bar magnet) along its axis

CLASS-XII

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

CHANGING YOUR TOMORROW

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Magnetism:

- Phenomenon of attracting magnetic substances like iron, nickel, cobalt, etc.
- A body possessing the property of magnetism is called a magnet.
- A magnetic pole is a point near the end of the magnet where magnetism is concentrated.
- Earth is a natural magnet.
- The region around a magnet in which it exerts forces on other magnets and on objects made of iron is a magnetic field.

Properties of a bar magnet:

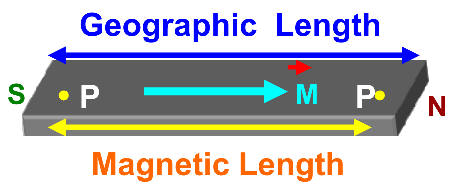
- A freely suspended magnet aligns itself along North – South direction.
- Unlike poles attract and like poles repel each other.
- Magnetic poles always exist in pairs. i.e. Poles can not be separated.
- A magnet can induce magnetism in other magnetic substances.
- It attracts magnetic substances.

Repulsion is the surest test of magnetisation: A magnet attracts iron rod as well as opposite pole of other magnet. Therefore, it is not a sure test of magnetisation.

But, if a rod is repelled with strong force by a magnet, then the rod is surely magnetised.

Bar Magnet:

1. The line joining the poles of the magnet is called magnetic axis.
2. The distance between the poles of the magnet is called magnetic length of the magnet.
3. The distance between the ends of the magnet is called the geometrical length of the magnet.
4. The ratio of magnetic length and geometrical length is nearly 0.84.



Magnetic Dipole & Dipole Moment:

A pair of magnetic poles of equal and opposite strengths separated by a finite distance is called a magnetic dipole.

The magnitude of dipole moment is the product of the pole strength m and the separation 2l between the poles.

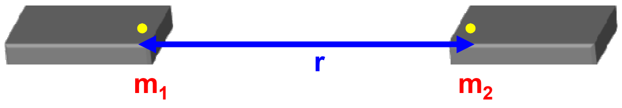
Magnetic Dipole Moment is $m = q_m \, 2l$

SI unit of pole strength is **A.m**

The direction of the dipole moment is from South pole to North Pole along the axis of the magnet.

Coulomb's Law in Magnetism:

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.



$F \alpha \; m_1 \, m_2$

$\alpha \; r^2$

$$F = \frac{k \, m_1 \, m_2}{r^2}$$

or

$$F = \frac{\mu_0 \, m_1 \, m_2}{4\pi \quad r^2}$$

(where $k = \mu_0 / 4\pi$ is a constant and $\mu_0 = 4\pi \times 10^{-7}$ T m A-1)

In vector form

$$\vec{F} = \frac{\mu_0 \, m_1 \, m_2 \, \hat{r}}{4\pi \quad r^2}$$

$$\vec{F} = \frac{\mu_0 \, m_1 \, m_2 \, \vec{r}}{4\pi \quad r^3}$$

Magnetic Field due to a Magnetic Dipole (Bar Magnet):

i) At a point on the axial line of the magnet:

$$B_P = \frac{\mu_0 \, 2 M x}{4\pi (x^2 - l^2)^2}$$

If l << x, then

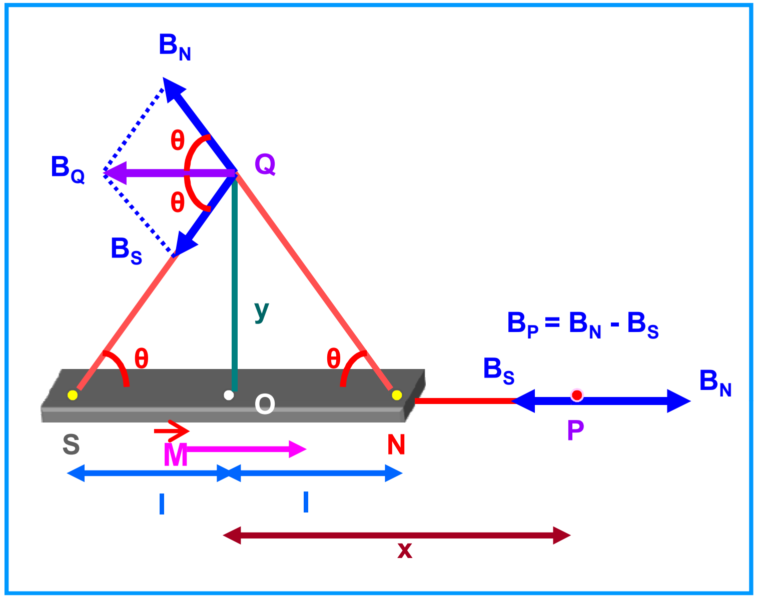
$$B_P \approx \frac{\mu_0 \, 2 M}{4\pi \, x^3}$$

ii) At a point on the equatorial line of the magnet:

$$B_Q = \frac{\mu_0 \, M}{4\pi (y^2 + l^2)^{3/2}}$$

If l << y, then

$$B_P \approx \frac{\mu_0 \, M}{4\pi \, y^3}$$

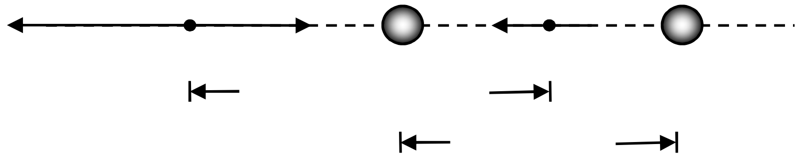


Magnetic Field at a point on the axial line acts along the dipole moment vector.

Magnetic Field at a point on the equatorial line acts opposite to the dipole moment vector.

MAGNETIC FIELD INTENSITY DUE TO A MAGNETIC DIPOLE (BAR MAGNET) ALONG ITS AXIS

Magnetic charge (or pole strength) of the north pole and the south poles are respectively q_m and $-q_m$.



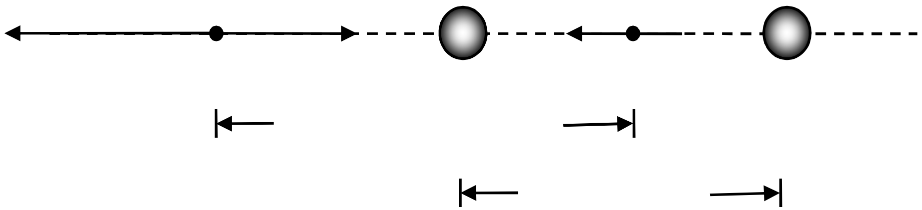
MAGNETIC FIELD INTENSITY DUE TO A MAGNETIC DIPOLE (BAR MAGNET) ALONG ITS AXIS

Magnetic charge (or pole strength) of the north pole and the south poles are respectively q_m and $-q_m$. The magnetic field intensities at P due to north and south poles are respectively

$$\vec{\boldsymbol{B}}_N = \frac{\mu_0}{4\pi}\frac{q_m}{(r-a)^2}\hat{\boldsymbol{m}}$$

$$\vec{\boldsymbol{B}}_S = \frac{\mu_0}{4\pi}\frac{-q_m}{(r+a)^2}\hat{\boldsymbol{m}}$$

where $\hat{\boldsymbol{m}}$ is the unit vector along the dipole axis (from south pole to north pole).



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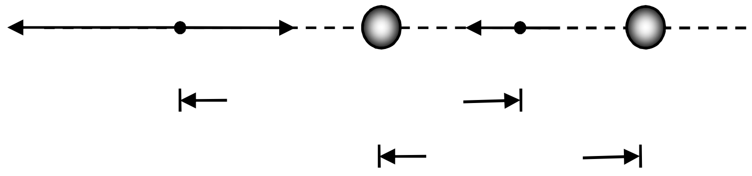

So the total field at P is

$$\vec{\boldsymbol{B}} = \vec{\boldsymbol{B}}_N + \vec{\boldsymbol{B}}_S$$

$$= \frac{\mu_0}{4\pi} q_m \left[\frac{1}{(r-a)^2} - \frac{1}{(r+a)^2}\right] \hat{\boldsymbol{m}}$$

$$= \frac{\mu_0}{4\pi} \frac{4raq_m}{(r^2-a^2)^2} \hat{\boldsymbol{m}}$$

$$= \frac{\mu_0}{4\pi} \frac{2r\vec{\boldsymbol{m}}}{(r^2-a^2)^2}$$

where, $\vec{\boldsymbol{m}} = 2aq_m\hat{\boldsymbol{m}}$ is the magnetic moment of a bar magnet.

For $r \gg a$,

$$\vec{\boldsymbol{B}} \approx \frac{\mu_0}{4\pi} \frac{2\vec{\boldsymbol{m}}}{r^3}$$

Numerical

Question: Two identical-looking iron bars A and B are given, one of which is definitely is known to be magnetised. (We do not know which one.) How would one ascertain whether or not both are magnetised? If only one is magnetised, how does one ascertain which one? [Use nothing else but the bars A and B.]

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Solution:
Try to bring different ends of the bars closer. A repulsive force in some situation establishes that both are magnetised. If it is always attractive, then one of them is not magnetised. In a bar magnet, the intensity of the magnetic field is the strongest at the two ends (poles) and weakest at the central region. This fact may be used to determine whether A or B is the magnet. In this case, to see which one of the two bars is a magnet, pick up one, (say, A) and lower one of its ends; first on one of the ends of the other (say, B), and then on the middle of B. If you notice that in the middle of B, A experiences no force, then B is magnetised. If you do not notice any change from the end to the middle of B, then A is magnetised.

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Numerical

Question: What happens if a bar magnet is cut into two pieces:

a) transverse to its length,

b) along its length? (NCERT)

Solution:

In either case, one gets two magnets, each with a north and south pole.

Numerical

Question: What is the magnitude of the axial field due to a bar magnet of length 5.0 cm at a distance of 50 cm from its mid-point? The magnetic moment of the bar magnet is 0.40Am^2.

Solution:

$$B \approx \frac{\mu_0}{4\pi}\frac{2m}{r^3} = 6.4 \times 10^{-7} T$$

Numerical

Question: Two magnetic poles (north and south) ±10 $\mu A \cdot m$ are placed 5.0 mm apart. Determine the magnetic field at a point on the axis of the dipole 15 cm away from its centre on the side of the north pole.

Numerical

Question: A bar magnet has pole strengths ±10 $\mu A \cdot m$ located at points N: (0, 0, –15 cm) and S: (0,0, +15 cm), respectively. What is the magnetic dipole moment of the system?

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MCQ Questions

1. The magnetic lines of force inside a bar magnet:
(a) do not exist
(b) depends on area of cross-section of bar magnet
(c) are from N-pole to S-pole of the magnet
(d) are from S-pole to N-pole of the magnet.

2. A wire of length l has a magnetic moment M. It is then bent into a semi-circular arc. The new magnetic moment is :
(a) M
(b) Ml
(c) 2M/π
(d) M/π

A current carrying power line carries current from west to east. What will be direction of magnetic field 1 meter above it?
(a) N to S
(b) S to N
(c) E to W
(d) W to E

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(c) are from N-pole to S-pole of the magnet
(d) are from S-pole to N-pole of the magnet.
Answer: (d) are from S-pole to N-pole of the magnet.

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(a) M
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(c) $2M/\pi$
(d) M/π
Answer: (c) $2M/\pi$

A current carrying power line carries current from west to east. What will be direction of magnetic field 1 meter above it?
(a) N to S
(b) S to N
(c) E to W
(d) W to E
Answer: (a) N to S

THANKING YOU

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