MAGNETISM AND MATTER

Magnet is a substance which attracts iron. Magnets are basically classifieds in to two types

(i) Natural magnets - Eg: lode stone

(ii) Artificial magnets - Eg: Magnetic needle, electromagnets, barmagnet

Properties of a magnet

(i) Attractive property – A magnet attract magnetic substance.

(ii) Directive property – A freely suspended magnet always comes to rest in north-south direction

(iii) Every magnet has two poles. ie Magnetic monopole does not exist.

(iv) Like pole repel and unlike poles attract each other.

Magnetic field

The space around a magnet where magnetic force is experienced is called the magnetic field.

Poles and Pole strength

Poles are the points where the magnetic force is maximum. Pole strength is the term that indicates the strength of the pole. Its unit is Am. The pole with pole strength 1 unit is called a unit pole.

Intensity of magnetic field (B)

Intensity of magnetic field at a point can be defined as the force experienced by a unit pole kept at that point. It is a vector quantity and its unit is Tesla.

Magnetic field lines and its properties

The are imaginary lines or curves, the tangent to which at any point gives the direction of magnetic field at that point

(i) They starts from north pole and ends at south pole externally and starts from south pole and ends at north pole internally. ie they form closed loops.

(ii) Two field lines will never intersect. If they intersect at a point, there will be two different directions for the magnetic field. It is impossible

(iii) Crowded lines represent strong magnetic field and seperated lines represent weak magnetic field.

(iv) Uniform magnetic field is represented by equidistant parallel lines.

Magnetic dipole and dipole moment

A pair of equal and opposite poles seperated by a small distance is called a magnetic dipole.

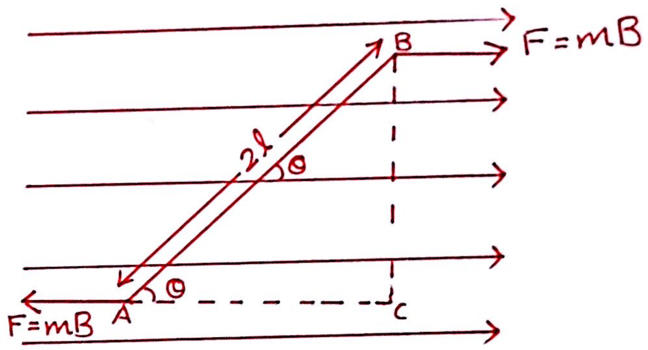
Eg: Bar magnet.

The strength of a dipole is indicated by the term dipole moment. It can be measured as the product of polestrength and the distance between the poles.

ie $\vec{M} = m \times \vec{2l}$

It is a vector quantity and is directed from north to south pole. Its unit is Am^2.

<u>Torque acting on a dipole kept in a uniform magnetic field</u>



consider a magnetic dipole of polestrength 'm' and length '2l' is kept in a uniform magnetic field of intensity 'B' at an angle 'θ' as shown in the figure.

Forces experienced by the two poles are equal (F=mB) and opposite acting at two different ~~poles~~ points hence constitute a couple. ie the dipole experiences a torque.

Torque τ = Force × ⊥r distance

$= mB \times BC$

$= mB \times 2l\sin\theta$

$= MB\sin\theta$

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

From ΔABC,

$\sin\theta = \frac{BC}{AB}$

$BC = AB\sin\theta$

$= 2l\sin\theta$

Special Cases

Case 1: Let $\theta = 0^\circ$,

ie "The torque is maximum when the dipole is kept ⊥r to the field and is minimum when it is kept parallel to the field".

$$\tau = MB\sin 0$$

$$\tau = MB$$

Case 2: Let $\theta = 90^\circ$

$$\tau = MB\sin 90$$

$$= MB$$

Potential Energy of a dipole kept in a uniform magnetic field.

We have the torque acting on a dipole kept in a uniform magnetic field, $\tau = MB\sin\theta$

∴ The small workdone in rotating the dipole through a small angle $d\theta$,

$$dW = \tau\, d\theta$$

$$= MB\sin\theta \cdot d\theta$$

∴ The total workdone in rotating the dipole from θ_1 to θ_2,

$$W = \int_{\theta_1}^{\theta_2} MB\sin\theta\, d\theta = MB\int_{\theta_1}^{\theta_2} \sin\theta\, d\theta$$

$$= MB\left[-\cos\theta\right]_{\theta_1}^{\theta_2} = -MB\left[\cos\theta_2 - \cos\theta_1\right]$$

Let $\theta_1 = 90^\circ$ and $\theta_2 = \theta$

$$\therefore W = -MB\left[\cos\theta - \cos 90\right] = -MB\cos\theta$$

This workdone is stored as the potential energy of the dipole.

∴ Potential energy, $U = -MB\cos\theta$

$$U = -\vec{m}\cdot\vec{B}$$

Intensity of magnetic field due to a dipole.

(i) At a point on the axial line of the dipole.

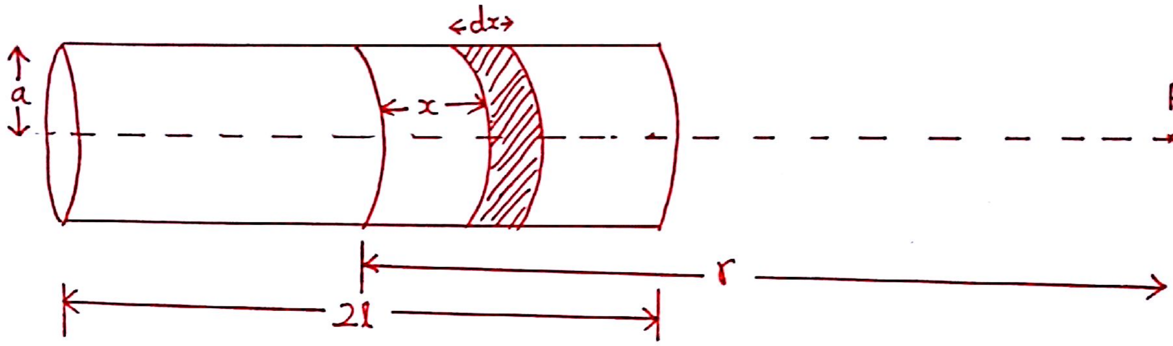


Figure shows a solenoid of length 2l and radius 'a'. Let N be the total no. of turns and 'n' be the no. of turns per unit length. P is a point on the axial line at a distance 'r' from the centre of the solenoid. To find the intensity of magnetic field at P, consider a small port of the coil with length dx and at a distance 'x' from the centre.

Magnetic field at P due to the small element of length dx is given by

$$dB = \frac{\mu_0 n dx I a^2}{2\left[a^2 + (r-x)^2\right]^{3/2}}$$ where I is the current.

Since $r >> a$ & $r >> l$,

$$dB = \frac{\mu_0 n dx I a^2}{2 r^3}$$

$\therefore$ The total magnetic field at P due to the entire solenoid,

$$B = \int_{-l}^{l} \frac{\mu_0 n dx I a^2}{2r^3}$$

$$= \frac{\mu_0 n I a^2}{2 r^3} \int_{-l}^{l} dx$$

$$= \frac{\mu_0 n I a^2}{2 r^3} \left[x \right]_{-l}^{l}$$

$$= \frac{\mu_0 n I a^2}{2 r^3} \times 2l$$

$$= \frac{\mu_0 N I a^2}{2 r^3}, \quad \text{where } N = n \times 2l$$

$$= \frac{\mu_0 N I a^2}{2 r^3} \times \frac{2\pi}{2\pi}$$

$$= \frac{\mu_0 2 N I A}{4\pi r^3}, \quad \text{Where } A = \pi r^2, \text{ area of the loop}$$

$$\boxed{B = \frac{\mu_0}{4\pi} \frac{2M}{r^3}}, \quad \text{where } M = NIA, \text{ the magnetic dipole moment.}$$

(ii) At a point on the equatorial line of the dipole.

$$\boxed{B = \frac{\mu_0}{4\pi} \frac{M}{r^3}}$$

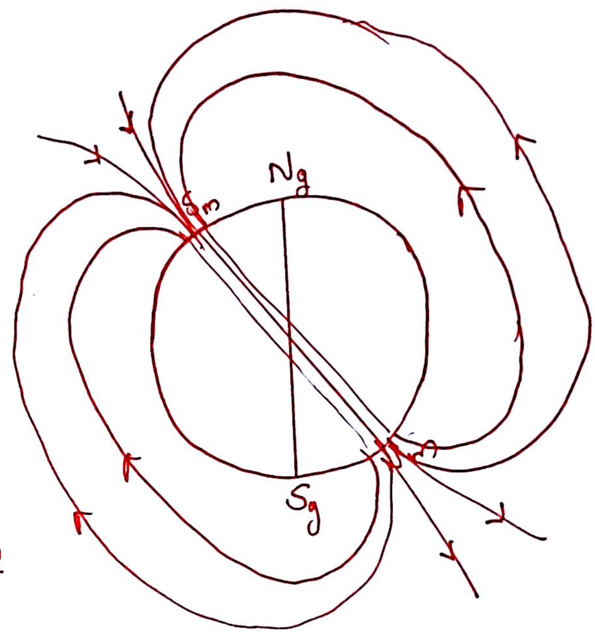
Gauss's theorem in Magnetism

" It states that the total magnetic flux passing through any closed surface is equal to zero".

Earth's magnetic field.

Earth is a big magnet. ie there is magnetic field around the earth. The intensity of earth's magnetic field is of the order of 10^{-4} T.

The magnetic poles of earth does not coincide with the geographic poles. The magnetic pole near to the geographic south pole is the magnetic north pole and the magnetic pole near to the geographic north pole is the magnetic south pole.

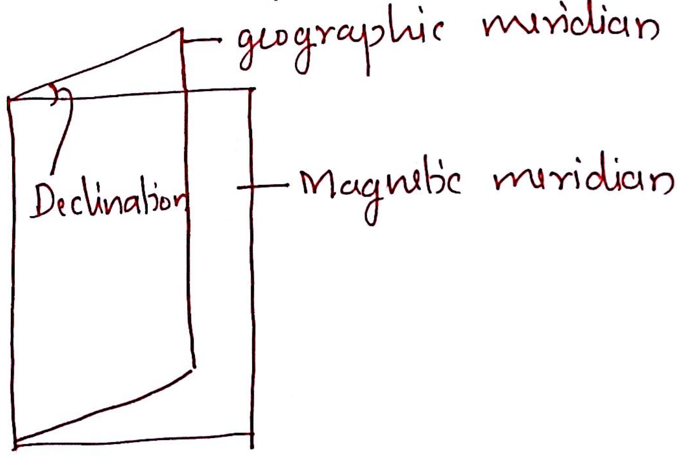


Magnetic elements of earth

The quantities which completely describes the earth magnetic field at a point are called the magnetic elements. They are (i) declination (ii) dip & (iii) Horizontal Intensity

Declination

Declination at a point is the angle between geographic meridian and magnetic meridian at ~~that~~ point.

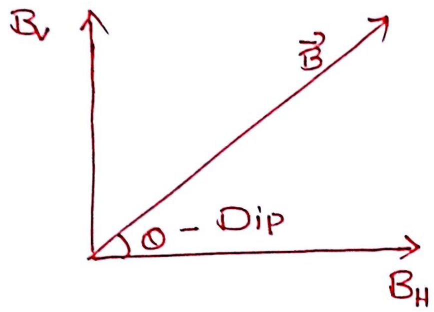


geographic meridian – geographic meridian at a point is a plane passing through that point and geographic north and south poles.

Magnetic meridian – Magnetic meridian at a point is a vertical plane passing through ~~that~~ the axis of a bar magnets suspended freely at that point.

<u>Dip</u> :- Dip at a point is the angle between earths total magnetic field and its horizontal component.

<u>Horizontal Intensity</u> :- The horizontal component of earth's magnetic field at a point is called the horizontal Intensity.



$$B_V = B\sin\theta \quad \text{---} \quad (1)$$

$$B_H = B\cos\theta \quad \text{---} \quad (2)$$

$$\frac{B_V}{B_H} = \tan\theta$$

$$B_V = B_H \tan\theta$$

$(1)^2 + (2)^2 \Rightarrow$

$$B_V^2 + B_H^2 = B^2\sin^2\theta + B^2\cos^2\theta$$

$$B = \sqrt{B_V^2 + B_H^2}$$

<u>Some magnetic terms</u>

1. Magnetic Intensity (H) :- When a substance is kept in a magnetic field, it gets magnetised. The ability of a magnetic field to magnetise a magnetic material is called the magnetic intensity. Its unit is A/m.
2. Intensity of magnetisation (I) :- It measures the degree of magnetisation. It can be measured as the magnetic moment per unit volume.

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$$I = \frac{M}{V} = \frac{m \times 2l}{A \times 2l} = \frac{m}{A}$$

i.e. It can also be defined as the polestrength per unit area. It is unit A/m

3. Magnetic Induction (B)

When a magnetic substance is kept in a magnetic field is kept in a magnetic field, it gets magnetised. The total field inside the substance is equal to the sum of applied field and induced field. This total field is called the magnetic induction.

$$B = B_0 + B_m$$

4. Magnetic Susceptibility (χ)

Magnetic susceptibility of a substance can be defined as the ratio of Intensity of magnetisation (I) to the magnetic intensity (H)

$$\chi = \frac{I}{H}$$

5. Magnetic Permeability (μ)

Magnetic permiability of a substance can be defined as the ratio of magnetic induction (B) to the magnetic intensity (H) $\mu = \frac{B}{H}$

$$B = B_0 + B_m$$

$$= \mu_0 H + \mu_0 I$$

$$B = \mu_0 (H + I)$$

$\div H \Rightarrow$ $$\frac{B}{H} = \mu_0 \left(\frac{H}{H} + \frac{I}{H}\right)$$

$$\mu = \mu_0 (1 + \chi) \quad \text{—— (1)}$$

We have $\mu = \mu_0 \mu_r$ —— (2)

From (1) & (2), we get. $\boxed{\mu_r = 1 + \chi}$

Classification of magnetic materials

1. Diamagnetic Substance :- Substance which gets weakly magnetised opposite to the direction of applied field when kept in a magnetic field is called diamagnetic

Eg: Copper, water, alcohol, antimony, bismuth etc

Properties

1) Weakly repelled when kept in a mag. field
2) $\mu_r < 1$
3) χ is small and -ve
4) χ is independent of temperature.

2. Paramagnetic substance:- Substance which gets weakly magnetised in the same direction of the applied field when kept in a magnetic field is called paramagnetic.

Eg: Aluminium, chromium, liquid oxygen etc.

properties

1) Weakly attracted when kept in a magnetic field
2) $\mu_r > 1$
3) χ is small and +ve
4) χ is inversly proportional to temperature.

3. Ferromagnetic Substance:- Substance which gets strongly magnetised in the same direction of the applied field when kept in a magnetic field is called ferromagnetic.

Eg: Iron, Cobalt, Nickel etc

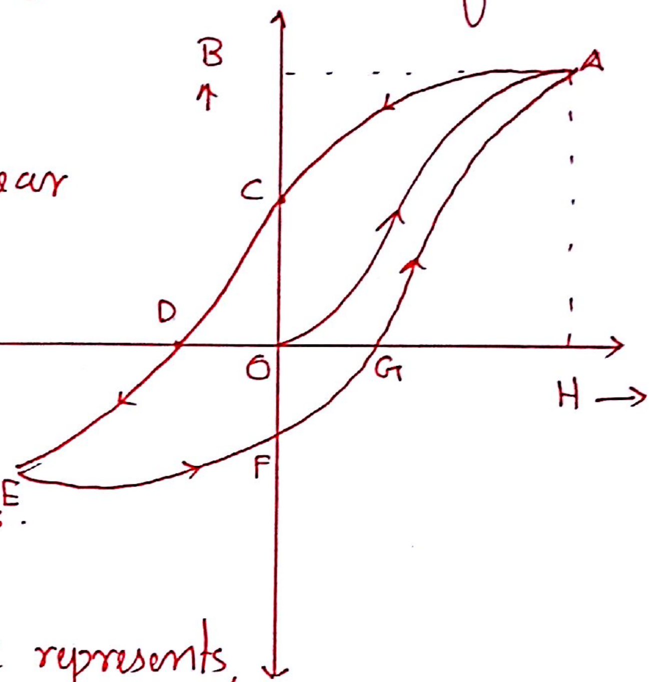
properties

1) Strongly attracted when kept in a magnetic field
2) $\mu_r >> 1$
3) χ is large and +ve
4) χ is inversly proportional to temperature.

ie When temperature increases, the ferromagnetic property decreases. At a particular temperature called curie temperature, the substance completely becomes paramagnetic.

Magnetic Hysterisis

Figure shows the variation of magnetic induction (B) with magnetic intensity (H) in a cycle of magnetisation.

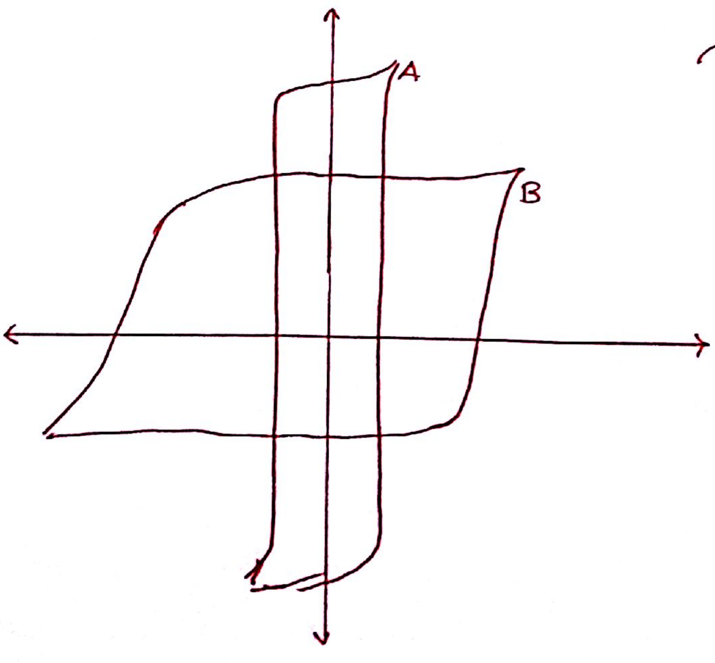


From the graph, it is clear that, B is lagging behind H.
This lagging of B behind H is called the magnetic hysterisis.

Retentivity :- In figure OC represents, value of B when H=0. This residual magnetic field when H=0 is called retentivity.

Coercivity :- The reverse magnetic field required to reduce B to zero is called coercivity.

Note :-



The hysterisis loop of two materials A and B are shown in figure.

A is used for electromagnet. Because high retentivity and low coercivity.

B is used for permanent magnet. Because high coercivity and low retentivity.