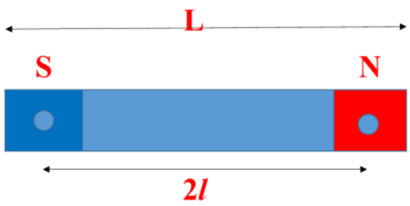
# Magnetic Properties of Materials

**Magnet:**
An object which can attract magnetic substance and can show north and south direction on when it is freely suspended is known as magnet.




**Properties of magnet:**
1. It can attract magnetic substances
2. There is attraction between unlike poles and repulsion between like poles of magnet.
3. A freely suspended magnet always points north and south direction.
4. Single pole (monopole) of magnet does not exist.
5. Magnet can transfer its magnetic properties to other magnetic substances.

**Magnetic Field:**
When a compass needle is brought near the magnet, it gets deflected. Magnetic field is defined as the space around the magnet upto which its effect on magnetic material or other magnet is experienced.

**Magnetic Field Intensity:**
Magnetic field intensity at any point in the magnetic field is defined as the magnetic force experienced by unit magnetic north pole placed at that point. It is simply known as magnetic intensity or magnetic field strength or magnetic field. It is denoted by B and is a vector quantity.
S.I. unit of magnetic field intensity is Newton per ampere metre (N/Am) or Tesla (T). Tesla is also expressed as weber per square meter ($W\ m^{-2}$). Its C.G.S. unit is Gauss (G)

$$1\ G = 10^{-4}\ T.$$

**Magnetic Lines of Force:**
Magnetic line of force is a hypothetical concept which is used to visualize the strength of magnetic field in different regions.
Magnetic lines of force are imaginary continuous curves in the magnetic field of a magnet such that tangent to any point of which gives resultant magnetic intensity at that point. In weak magnetic field, lines of forces are far while in strong magnetic field, they are crowded.

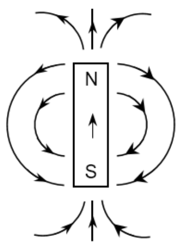



**Fig-(a): Magnetic lines of force around a bar magnet**

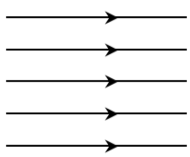


**Fig-(b): uniform magnetic field**

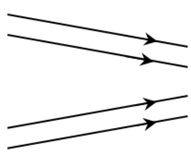
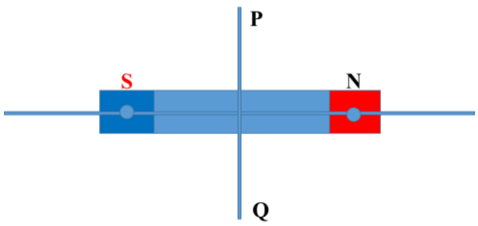


**Fig-(c) Non-uniform magnetic field**

Thus a magnetic line of force in a magnetic field may also be defined as a path on which a unit north pole would move if free to do so.

**Some general terms which are frequently used in magnetism are given below:**



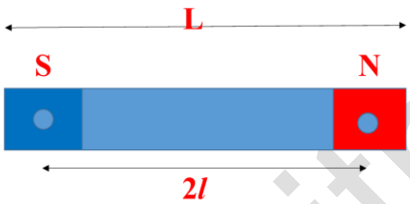

**Magnetic axis:**

The straight line joining two poles of a magnet is called magnetic axis or axial line of a magnet. In Fig, line NS is magnetic axis.

**Equatorial line:**

A straight line passing through the centre of the magnet and perpendicular to the magnet and perpendicular to the magnetic axis is known as equatorial line of the magnet. In Fig, PQ is equatorial line of magnet NS.

**Equivalent length and Geometrical length:**




The distance between two poles of a magnet is called equivalent length or magnetic length or effective length of a magnet. If is denoted by $2l$.

Actual length of the magnet (distance between two ends of a magnet) is called geometrical length or real length of a magnet (L). Effective length of the magnet is 0.85 times the geometrical length of magnet.

Effect length ($2l$) = 0.85 × geometrical length (L)

**Magnetic dipole:**

Every magnet possesses two magnetic poles so known as magnetic dipole.

**Magnetic moment or Magnetic dipole moment:**

Product of strength of one of the magnetic poles and its effective length is known as magnetic moment or magnetic dipole moment. If 'm' be the pole strength and $2l$ be the effective length of a magnet,

Magnetic moment, $M = m \times 2l$

It is a vector quantity having same direction as that of magnetic length. S.I. unit of magnetic moment is ampere square meter ($Am^2$).

**Neutral Point:**

Neutral point is defined as that point where the resultant of the magnetic field intensities due to magnet and earth is zero i.e. magnetic field intensity is exactly equal and opposite to the horizontal component of earth's magnetic field.

Magnetic field of earth is uniform over a considerable area while the magnetic field of the magnet varies considerably even over a small area. At certain points it is found that the magnetic field of the magnet becomes equal in magnitude and opposite in direction to the magnetic field of earth. At these points, the resultant magnetic field intensity becomes zero. These points are called neutral points. A small compass needle placed at the neutral point does not experience any net force or couple. So, it sets itself in any direction.

**Geographic meridian:**

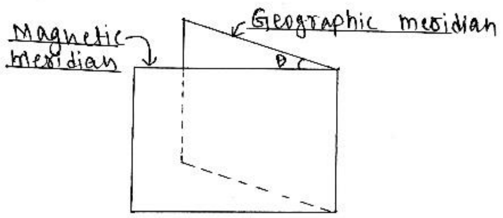
An imaginary vertical plane passing through the geographic north pole and south pole of earth is known as geographic meridian.

**Magnetic meridian:**

An imaginary vertical plane passing through the magnetic north pole and south pole of earth magnet is known as geographic meridian.

**Angle of declination:**

It is defined as the angle between geographic meridian and magnetic meridian.




In figure, $\theta$ is the angle of declination.

**Angle of dip:**

The angle of dip at place is defined as the angle made by total intensity of earth magnetic field with its horizontal component. It is denoted by $\delta$.

The value of angle of dip is $90^o$ at pole and $0^\circ$ at equator.

**# Dip circle**

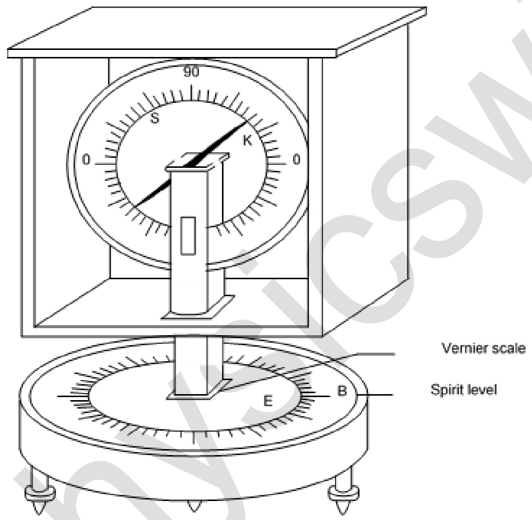



**Fig-: Dip circle**

Dip circle is a device which is used to measure the value of angle of dip at any place when it is in magnetic meridian.

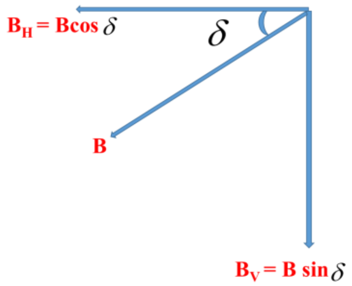
**# Construction:**

It consists of a magnetic needle pivoted at the centre of vertical circular scale. The vertical circular scale is divided into four quadrants and calibrated from $0^o$- $90^o$ with $0^o$ - $0^o$ at horizontal and $90^o$ - $90^o$ at vertical. The magnetic needle is placed inside a metallic box with a glass cover. The metallic box is placed on a horizontal circular scale which is calibrated from $0^o$ - $360^o$.

**# Working:**

After labelling the device properly, the metallic box is rotated until the magnetic needle becomes exactly vertical and points $90^o$ - $90^o$ on the vertical circular scale. In this case, there is an effect of the vertical component of Earth's magnetic field only. Now, the metallic box is rotated through $90^o$ about horizontal circular scale. On doing so, the magnetic needle will be exactly in the position of magnetic meridian. In this case, the angle measured by the dip circle is the angle of dip.

**Relation between horizontal component, vertical component and total intensity of earth's magnetic field.**




Let us consider 'B' be the total intensity of earth's magnetic field at a place and $\delta$ be the angle of dip. Then the horizontal component of earth magnetic field is

$B_H = B \cos\delta$ ......(i)

and the vertical component of earth's magnetic field is

$B_V = B \sin\delta$ .......(ii)

Dividing equation (ii) by (i), we get

$$\frac{B_V}{B_H} = \frac{B \sin\delta}{B \cos\delta}$$

$$\tan\delta = \frac{B_V}{B_H} \quad ......(iii)$$

On squaring and adding (i) & (ii)

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

$$\therefore B = \sqrt{B_H^2 + B_V^2} \quad .....(iv)$$

***Q. The horizontal component and vertical component of magnetic field at a place are equal in magnitude. Calculate the value of angle of dip.***

Here, Since, $B_V = B_H$

We have,

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

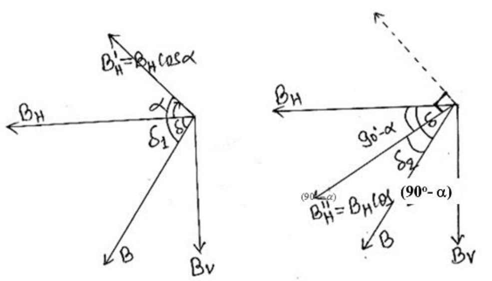
Or, $\tan\delta = 1$

Or, $\tan\delta = \tan 45^\circ$

$\delta = 45^\circ$

**Apparent Dip**

The angle of dip measured by dip circle when it is not in magnetic meridian is known as apparent dip.




Let us consider the total intensity of earth's magnetic field at a place be 'B' and actual value (true value) angle of dip is $\delta$. The horizontal and vertical component of earth magnetic field at that place are $B_H$ & $B_V$ respectively. Let us consider a dip circle which is out of magnetic meridian by an angle $\alpha$ where the apparent angle of dip is $\delta_1$. Then the horizontal component of earth magnetic field becomes

$$B_H' = B_H \text{ Cos } \alpha$$

Then we can write,

$$\text{Tan } \delta_1 = \frac{B_V}{B_H'}$$

$$\text{Tan } \delta_1 = \frac{B_V}{B_H \cos\alpha}$$

$$\text{Tan } \delta_1 = \frac{\tan\delta}{\cos\alpha} \qquad \text{since Tan } \delta = \frac{B_V}{B_H}$$

$$\cos\alpha = \tan\delta.\cot\delta_1 \text{ ......(i)}$$

Now, let us consider the dip circle is rotated through 90°. In this case, the dip circle will be out of magnetic meridian by an angle (90° $-\alpha$ ), where the apparent angle of dip is $\delta_2$. Then the horizontal component of earth's magnetic field is

$$B_H'' = B_H \text{ Cos } (90^o - \alpha) = B_H \sin\alpha \ (90^o - \alpha)$$

Then we can write,

$$\text{Tan } \delta_2 = \frac{B_V}{B_H''} = \frac{B_V}{B_H \sin\alpha}$$

$$\text{Tan } \delta_2 = \frac{\tan\delta}{\sin\alpha} \qquad \text{since Tan } \delta = \frac{B_V}{B_H}$$

$$\sin\alpha = \tan\delta.\cot\delta_2 \text{ ......(ii)}$$

Squaring and adding (i) and (ii), we get

$$\cos^2\alpha + \sin^2\alpha = \tan^2\delta.\cot^2\delta_1 + \tan^2\delta.\cot^2\delta_2$$

$$1 = \tan^2\delta(\cot^2\delta_1 + \cot^2\delta_2)$$

$$\frac{1}{\tan^2\delta} = \cot^2\delta_1 + \cot^2\delta_2$$

$$\therefore \ \cot^2\delta = \cot^2\delta_1 + \cot^2\delta_2$$

This is the required expression between true dip and apparent dip.

**Magnetizing field (H):**

Such type of magnetic field in which magnetic substance get magnetized is known as magnetizing field. It is denoted by H. Its unit is $Am^{-1}$.

**Intensity of magnetization (I):**

The intensity of magnetization is defined as the magnetic dipole moment per unit volume. It is denoted by I. Mathematically,

$$\text{i.e. } I = \frac{M}{V}$$

$$\text{Or, } I = \frac{m \times 2l}{A \times 2l}$$ ($\because$ M = m×2*l* & V = A×2*l, 2l is the effective length of a bar magnet.*)

$$\therefore I = \frac{m}{A}$$

Thus, the intensity of magnetization also can be defined as the pole strength per unit area. Its unit is $Am^{-1}$.

**Magnetic Permeability ( $\mu$ ):**

It is defined as the ratio of magnetic induction to the magnetizing field. It is denoted by $\mu$ and given by

$$\mu = \frac{B}{H}$$

Magnetic permeability measure the degree of concentration magnetic lines of force through magnetic materials. Its unit is $TmA^{-1}$.

**Relative permeability**

It is defined as the ratio of magnetic permeability of any medium to that of free space. It is denoted by $\mu_r$ and given by

$$\mu_r = \frac{\mu}{\mu_o}$$

It has no unit.

**# Magnetic susceptibility**

It is defined as the ratio of intensity of magnetization to the magnetizing field. It is denoted by $\chi$ and given by

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

It has no unit.

Magnetic susceptibility gives the information that how easily a magnetic substance can be magnetized.

**# Relation between relative permeability & magnetic susceptibility.**

Let us consider a magnetic substance is placed inside magnetizing field (H). The total magnetic induction developed in the magnetic substance is due to external factor and internal factor. So the total magnetic induction developed in the magnetic substance is the sum of external factor and internal factor. i.e.

$$B = B_{ext} + B_{int}$$

$$B = \mu_o H + \mu_o I$$

$$B = \mu_o H \left(1 + \frac{I}{H}\right)$$

$$\frac{B}{H} = \mu_o\left(1 + \frac{I}{H}\right)$$

$$\mu = \mu_o(1+\chi) \quad \left(\because \mu = \frac{B}{H} \;\&\; \chi = \frac{I}{H}\right)$$

$$\frac{\mu}{\mu_o} = 1 + \chi \qquad [\mu_r = \frac{\mu}{\mu_o}]$$

$$\therefore \mu_r = 1 + \chi$$

This is the required relation between relative permeability & magnetic susceptibility.

**# Classification of magnetic substance.**

Magnetic substances are divided into three categories,
i.e.
1. Diamagnetic substance
2. Paramagnetic substance
3. Ferromagnetic substance

**1. Diamagnetic substance:**

Such type of magnetic substance which are feebly (weakly) repelled by a magnet are known as diamagnetic substance.

**# Properties of Diamagnetic substance:**

1. They are feebly repelled by a magnet.
2. They tend to move from stronger to weaker magnetic field.
3. They get magnetized in the opposite direction of the magnetic field.
4. When a diamagnetic substance is suspended freely, it sets itself in the direction perpendicular to that of the magnetic field.
5. The value of magnetic permeability is very less.
6. The value of magnetic susceptibility is small and negative.

7. The magnetic properties of diamagnetic substances is independent to the temperature.

8. They does not obey Curie law i.e. ( $\chi \propto \frac{1}{temp^r}$ )

## 2. Paramagnetic Substances

Such types of magnetic substance which are feebly attracted by a magnet are known as paramagnetic substance.

## # Properties of Paramagnetic Substances

1. They are feebly attracted by a magnet.
2. They tend to move from weaker to a stronger field.
3. They get magnetized in the direction of magnetic field.
4. When a paramagnetic substance is suspended freely, it sets itself in the direction magnetic field.
5. The value of magnetic permeability is slightly greater than 1.
6. The value of magnetic susceptibility is small and positive.
7. The magnetic properties of paramagnetic substance decrease with increase in temperature.
8. They obey Curie law i.e. $\chi \propto \frac{1}{temp^r}$

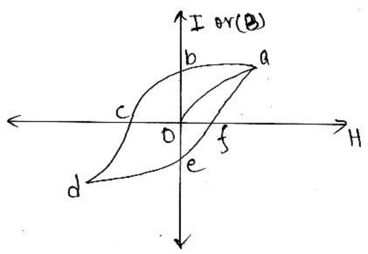
## 3. Ferromagnetic substance

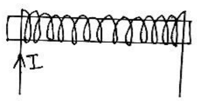
Such types of magnetic substances which are strongly attracted by magnets are known as ferromagnetic substance.

## # Properties of Ferromagnetic substance

1. They are strongly attracted by a magnet.
2. They tend to move from weaker to a stronger field.
3. They get magnetized in the direction of the magnetic field.
4. When a paramagnetic substance is suspended freely, it sets itself in the direction of the magnetic field.
5. The value of magnetic permeability is very high.
6. The value of magnetic susceptibility is high and positive.
7. The magnetic properties of ferromagnetic substances decrease with increase in temperature.
8. They obey Curie law.

## # Magnetic Hysteresis:




When a ferromagnetic material is taken through a cycle of magnetization, heat is produced in it. It has been observed that in each cycle of magnetization, the heat developed per unit of the material is proportional to the area enclosed by the hysteresis loop. Thus, the hysteresis loop gives a clear indication of the loss of energy as heat due to hysteresis. Such loss is known as hysteresis loop. In certain cases, we need the material which has a narrow hysteresis loop. As an illustration, soft iron is used as the core of the transformer having a narrow hysteresis loop so that hysteresis loss is minimized. Similarly, while making permanent magnets material having high retentivity is chosen.

## Retentivity (OB):

The capacity of a magnetic substance to retain its magnetism (magnetic property) even when magnetizing field is ceased. For H = 0, $I \neq 0$

## Coercivity (OC):

It is defined as the magnetizing field (–ve) required to demagnetize a substance.