PHYSICS

Class - XII

MAGNETISM

MAGNETISM

1. Bar Magnet and its properties
2. Current Loop as a Magnetic Dipole and Dipole Moment
3. Current Solenoid equivalent to Bar Magnet
4. Bar Magnet and it Dipole Moment
5. Coulomb's Law in Magnetism
6. Important Terms in Magnetism
7. Magnetic Field due to a Magnetic Dipole
8. Torque and Work Done on a Magnetic Dipole
9. Terrestrial Magnetism
10. Elements of Earth's Magnetic Field
11. Tangent Law
12. Properties of Dia-, Para- and Ferro-magnetic substances
13. Curie's Law in Magnetism
14. Hysteresis in Magnetism

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.

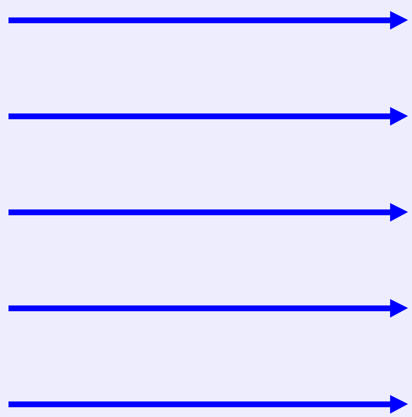
Properties of a bar magnet:

1. A freely suspended magnet aligns itself along North – South direction.
2. Unlike poles attract and like poles repel each other.
3. Magnetic poles always exist in pairs. i.e. Poles can not be separated.
4. A magnet can induce magnetism in other magnetic substances.
5. 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.

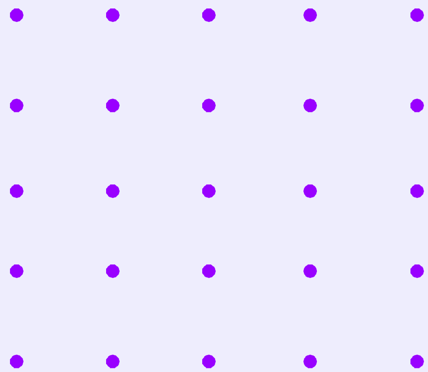
But, if a rod is repelled with strong force by a magnet, then the rod is surely magnetised.

Representation of Uniform Magnetic Field:



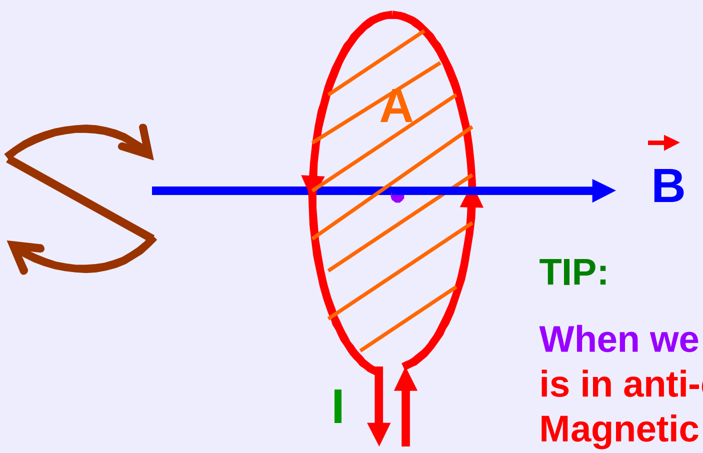
Uniform field on the plane of the diagram

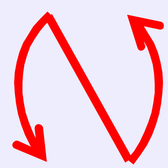
Uniform field perpendicular & into the plane of the diagram



Uniform field perpendicular & emerging out of the plane of the diagram

Current Loop as a Magnetic Dipole & Dipole Moment:





Magnetic Dipole Moment is

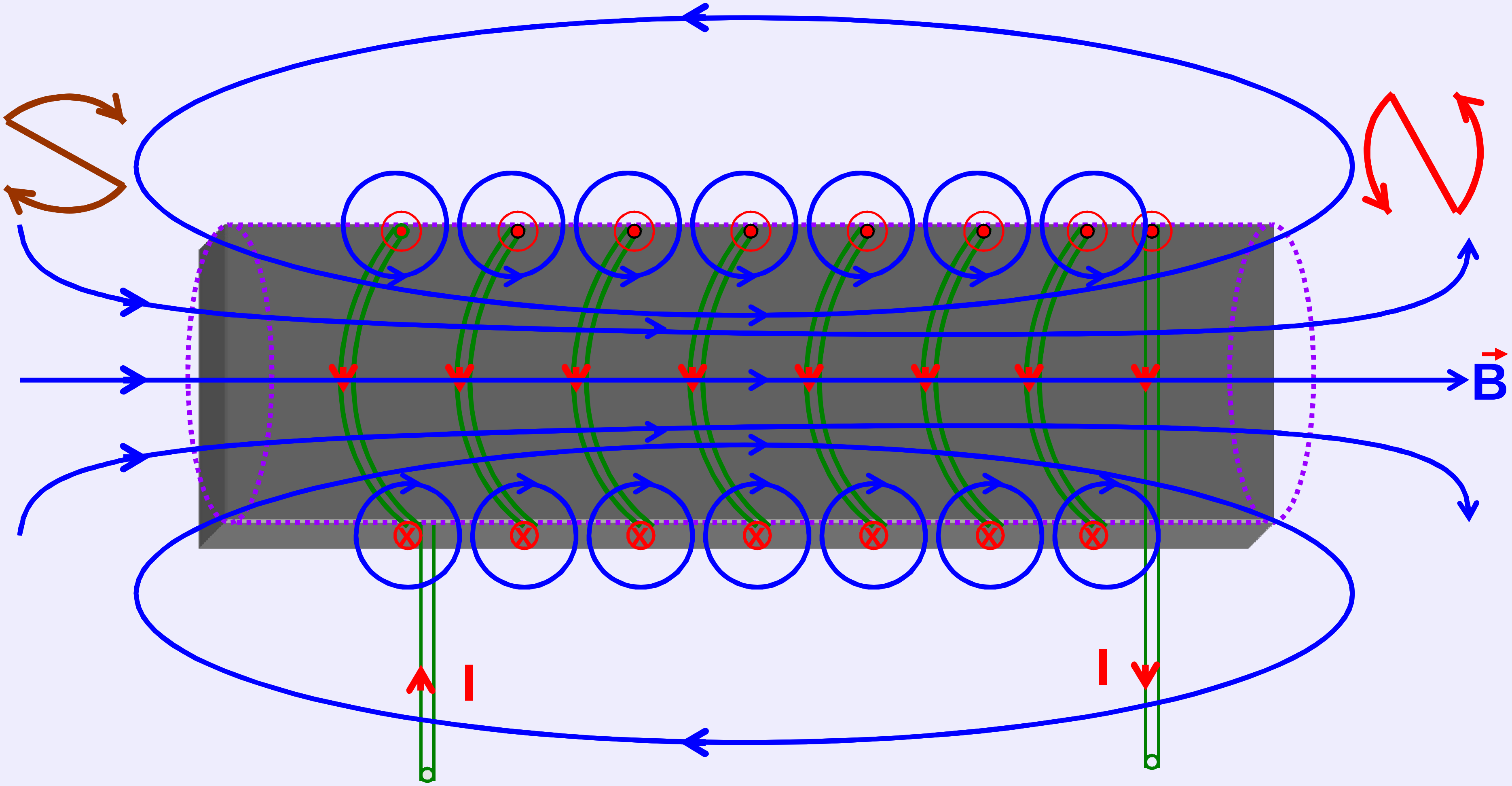
$\vec{M} = I A \hat{n}$

SI unit is A m^2.

TIP:

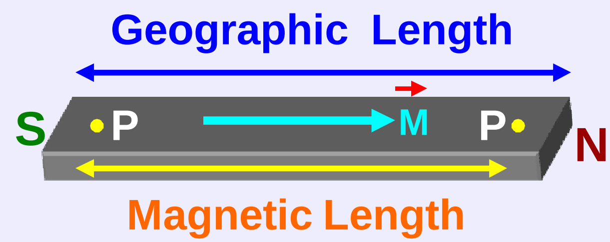
When we look at any one side of the loop carrying current, if the current is in anti-clockwise direction then that side of the loop behaves like Magnetic North Pole and if the current is in clockwise direction then that side of the loop behaves like Magnetic South Pole.

Current Solenoid as a Magnetic Dipole or Bar Magnet:



TIP: Play previous and next to understand the similarity of field lines.

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.

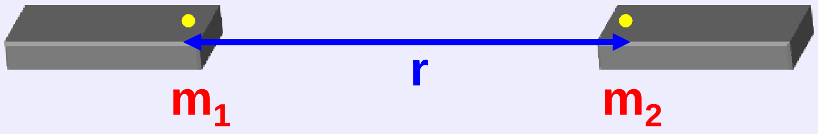
Magnetic Dipole Moment is $\vec{M} = m.2l.\hat{l}$

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 Intensity or Magnetising force (H):

i) Magnetic Intensity at a point is the force experienced by a north pole of unit pole strength placed at that point due to pole strength of the given magnet. $H = B / \mu$

ii) It is also defined as the magnetomotive force per unit length.

iii) It can also be defined as the degree or extent to which a magnetic field can magnetise a substance.

iv) It can also be defined as the force experienced by a unit positive charge flowing with unit velocity in a direction normal to the magnetic field.

v) Its SI unit is ampere-turns per linear metre.

vi) Its cgs unit is oersted.

Magnetic Field Strength or Magnetic Field or Magnetic Induction or Magnetic Flux Density (B):

i) Magnetic Flux Density is the number of magnetic lines of force passing normally through a unit area of a substance. $B = \mu H$

ii) Its SI unit is weber-m^{-2} or Tesla (T).

iii) Its cgs unit is gauss. 1 gauss = 10^{-4} Tesla

Magnetic Flux (Φ):

i) It is defined as the number of magnetic lines of force passing normally through a surface.

ii) Its SI unit is weber.

Relation between B and H:

$B = \mu H$ (where μ is the permeability of the medium)

Magnetic Permeability (μ):

It is the degree or extent to which magnetic lines of force can pass enter a substance.

Its SI unit is $T\ m\ A^{-1}$ or $wb\ A^{-1}\ m^{-1}$ or $H\ m^{-1}$

Relative Magnetic Permeability (μ_r):

It is the ratio of magnetic flux density in a material to that in vacuum.

It can also be defined as the ratio of absolute permeability of the material to that in vacuum.

$$\mu_r = B / B_0 \quad \text{or} \quad \mu_r = \mu / \mu_0$$

Intensity of Magnetisation: (I):

i) It is the degree to which a substance is magnetised when placed in a magnetic field.

ii) It can also be defined as the magnetic dipole moment (M) acquired per unit volume of the substance (V).

iii) It can also be defined as the pole strength (m) per unit cross-sectional area (A) of the substance.

iv) $I = M / V$

v) $I = m(2l) / A(2l) = m / A$

vi) SI unit of Intensity of Magnetisation is A m^{-1}.

Magnetic Susceptibility (c_m):

i) It is the property of the substance which shows how easily a substance can be magnetised.

ii) It can also be defined as the ratio of intensity of magnetisation (I) in a substance to the magnetic intensity (H) applied to the substance.

iii) $c_m = I / H$

Susceptibility has no unit.

Relation between Magnetic Permeability (μ_r) & Susceptibility (c_m):

$$\mu_r = 1 + c_m$$

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

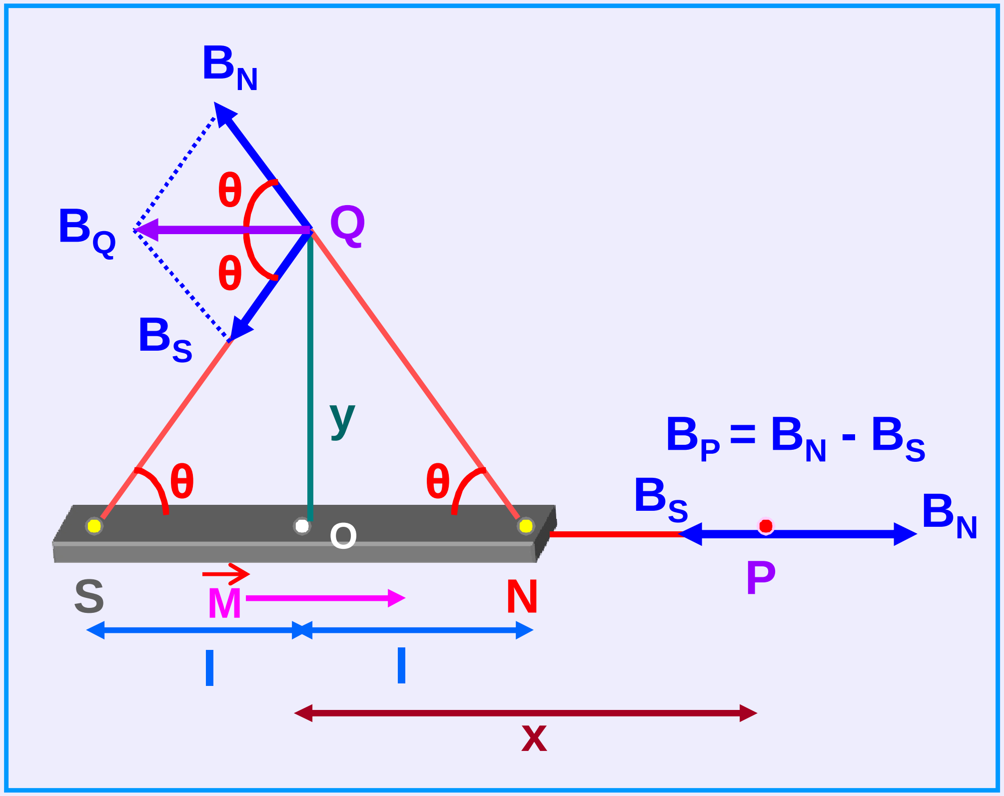
$$B_P \approx \frac{\mu_0 \, 2 M}{4\pi \, x^3}$$

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

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

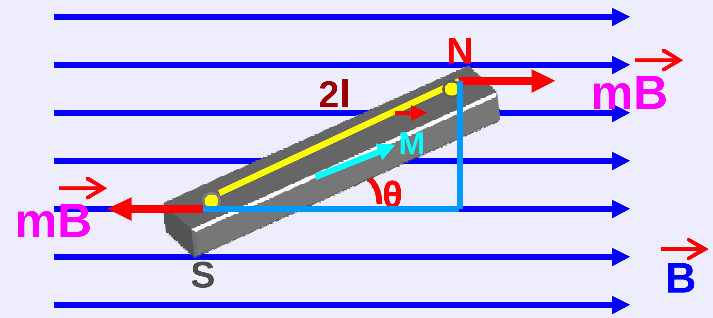


Magnetic Field at a point on the axial line acts along the dipole moment vector.

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

Torque on a Magnetic Dipole (Bar Magnet) in Uniform Magnetic Field:

The forces of magnitude mB act opposite to each other and hence net force acting on the bar magnet due to external uniform magnetic field is zero. So, there is no translational motion of the magnet.



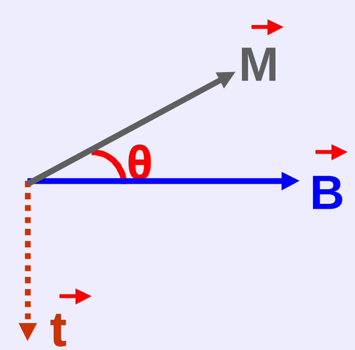
However the forces are along different lines of action and constitute a couple. Hence the magnet will rotate and experience torque.

Torque = Magnetic Force x ⊥ distance

$t = mB\,(2l \sin\theta)$

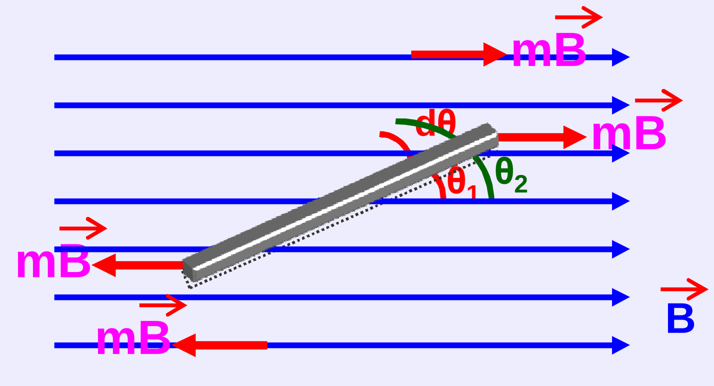
$= M\,B \sin\theta$

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



Direction of Torque is perpendicular and into the plane containing $\vec{M}$ and $\vec{B}$.

Work done on a Magnetic Dipole (Bar Magnet) in Uniform Magnetic Field:



$$dW = t d\theta$$

$$= M\ B \sin\theta\ d\theta$$

$$W = \int_{\theta_1}^{\theta_2} M\ B \sin\theta\ d\theta$$

$$W = M\ B\ (\cos\theta_1 - \cos\theta_2)$$

If Potential Energy is arbitrarily taken zero when the dipole is at 90 , then P.E in rotating the dipole and inclining it at an angle θ is

Potential Energy = - M B cos θ

Note:

Potential Energy can be taken zero arbitrarily at any position of the dipole.

Terrestrial Magnetism:

i) **Geographic Axis** is a straight line passing through the geographical poles of the earth. It is the axis of rotation of the earth. It is also known as polar axis.

ii) **Geographic Meridian** at any place is a vertical plane passing through the geographic north and south poles of the earth.

iii) **Geographic Equator** is a great circle on the surface of the earth, in a plane perpendicular to the geographic axis. All the points on the geographic equator are at equal distances from the geographic poles.

iv) **Magnetic Axis** is a straight line passing through the magnetic poles of the earth. It is inclined to Geographic Axis nearly at an angle of 17°.

v) **Magnetic Meridian** at any place is a vertical plane passing through the magnetic north and south poles of the earth.

vi) **Magnetic Equator** is a great circle on the surface of the earth, in a plane perpendicular to the magnetic axis. All the points on the magnetic equator are at equal distances from the magnetic poles.

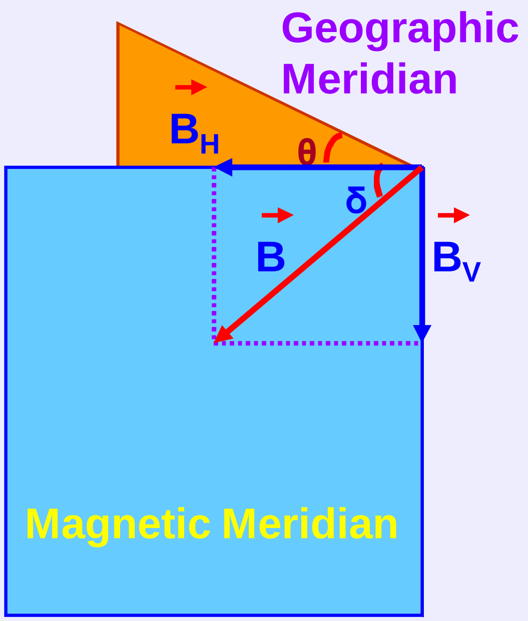
Declination (θ):

The angle between the magnetic meridian and the geographic meridian at a place is Declination at that place.

It varies from place to place.

Lines shown on the map through the places that have the same declination are called isogonic line.

Line drawn through places that have zero declination is called an agonic line.



Dip or Inclination (δ):

The angle between the horizontal component of earth's magnetic field and the earth's resultant magnetic field at a place is Dip or Inclination at that place.

It is zero at the equator and 90° at the poles.

Lines drawn up on a map through places that have the same dip are called isoclinic lines.

The line drawn through places that have zero dip is known as an aclinic line. It is the magnetic equator.

Horizontal Component of Earth's Magnetic Field (B_H):

The total intensity of the earth's magnetic field does not lie in any horizontal plane. Instead, it lies along the direction at an angle of dip (δ) to the horizontal. The component of the earth's magnetic field along the horizontal at an angle δ is called Horizontal Component of Earth's Magnetic Field.

$$B_H = B \cos \delta$$

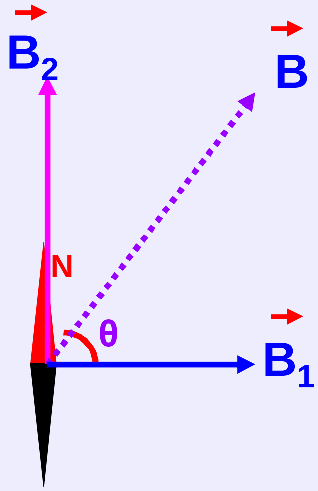
Similarly Vertical Component is $B_V = B \sin \delta$

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

Tangent Law:

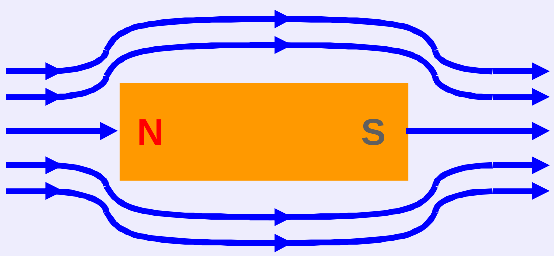
If a magnetic needle is suspended in a region where two uniform magnetic fields are perpendicular to each other, the needle will align itself along the direction of the resultant field of the two fields at an angle θ such that the tangent of the angle is the ratio of the two fields.

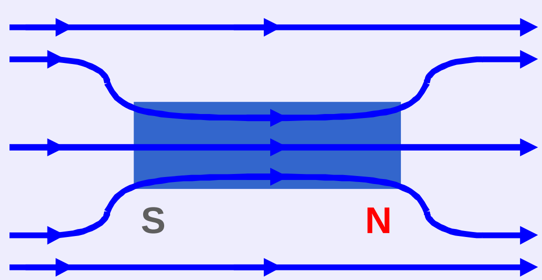
$$\tan \theta = B_2 / B_1$$

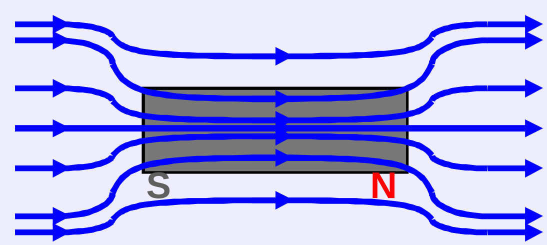


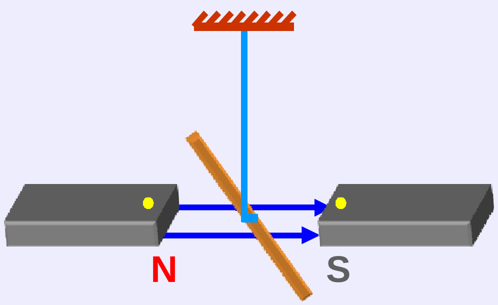
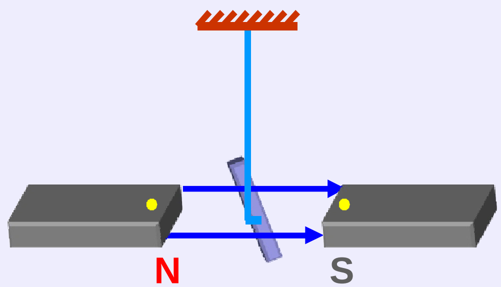
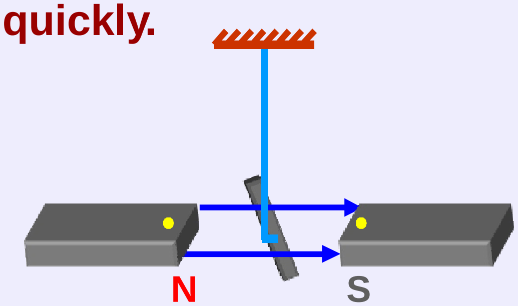
Comparison of Dia, Para and Ferro Magnetic materials:

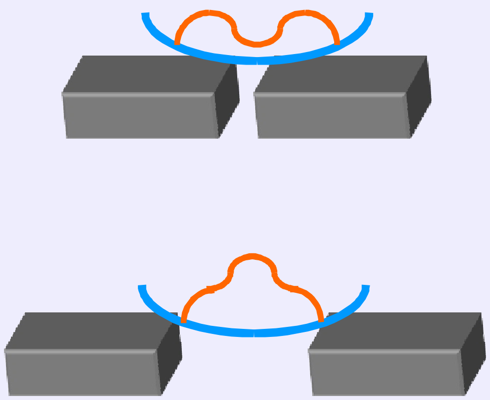
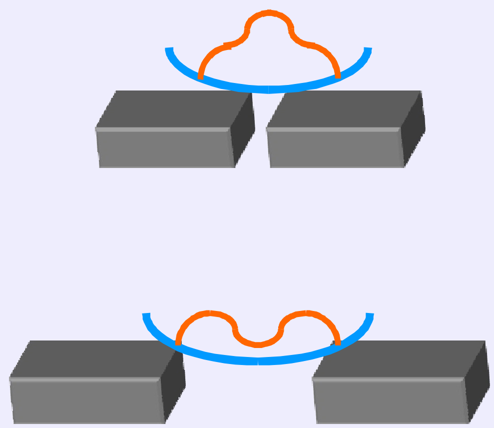
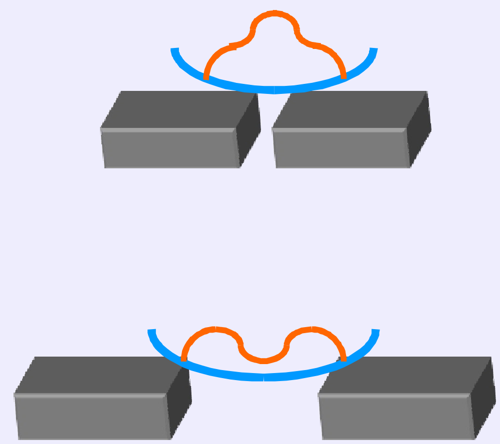
DIA	PARA	FERRO
1. Diamagnetic substances are those substances which are feebly repelled by a magnet. Eg. Antimony, Bismuth, Copper, Gold, Silver, Quartz, Mercury, Alcohol, water, Hydrogen, Air, Argon, etc.	Paramagnetic substances are those substances which are feebly attracted by a magnet. Eg. Aluminium, Chromium, Alkali and Alkaline earth metals, Platinum, Oxygen, etc.	Ferromagnetic substances are those substances which are strongly attracted by a magnet. Eg. Iron, Cobalt, Nickel, Gadolinium, Dysprosium, etc.
2. When placed in magnetic field, the lines of force tend to avoid the substance.	The lines of force prefer to pass through the substance rather than air.	The lines of force tend to crowd into the specimen.







2. When placed in non-uniform magnetic field, it moves from stronger to weaker field (feeble repulsion).	When placed in non-uniform magnetic field, it moves from weaker to stronger field (feeble attraction).	When placed in non-uniform magnetic field, it moves from weaker to stronger field (strong attraction).
3. When a diamagnetic rod is freely suspended in a uniform magnetic field, it aligns itself in a direction perpendicular to the field. 	When a paramagnetic rod is freely suspended in a uniform magnetic field, it aligns itself in a direction parallel to the field. 	When a paramagnetic rod is freely suspended in a uniform magnetic field, it aligns itself in a direction parallel to the field very quickly. 

4. If diamagnetic liquid taken in a watch glass is placed in uniform magnetic field, it collects away from the centre when the magnetic poles are closer and collects at the centre when the magnetic poles are farther.	If paramagnetic liquid taken in a watch glass is placed in uniform magnetic field, it collects at the centre when the magnetic poles are closer and collects away from the centre when the magnetic poles are farther.	If ferromagnetic liquid taken in a watch glass is placed in uniform magnetic field, it collects at the centre when the magnetic poles are closer and collects away from the centre when the magnetic poles are farther.
		

5. When a diamagnetic substance is placed in a magnetic field, it is weakly magnetised in the direction opposite to the inducing field.	**When a paramagnetic substance is placed in a magnetic field, it is weakly magnetised in the direction of the inducing field.**	**When a ferromagnetic substance is placed in a magnetic field, it is strongly magnetised in the direction of the inducing field.**
6. Induced Dipole Moment (M) is a small – ve value.	**Induced Dipole Moment (M) is a small + ve value.**	**Induced Dipole Moment (M) is a large + ve value.**
7. Intensity of Magnetisation (I) has a small – ve value.	**Intensity of Magnetisation (I) has a small + ve value.**	**Intensity of Magnetisation (I) has a large + ve value.**
8. Magnetic permeability μ is always less than unity.	**Magnetic permeability μ is more than unity.**	**Magnetic permeability μ is large i.e. much more than unity.**

9. Magnetic susceptibility c_m has a small – ve value.	Magnetic susceptibility c_m has a small + ve value.	Magnetic susceptibility c_m has a large + ve value.

10. They do not obey Curie's Law. i.e. their properties do not change with temperature.	They obey Curie's Law. They lose their magnetic properties with rise in temperature.	They obey Curie's Law. At a certain temperature called Curie Point, they lose ferromagnetic properties and behave like paramagnetic substances.

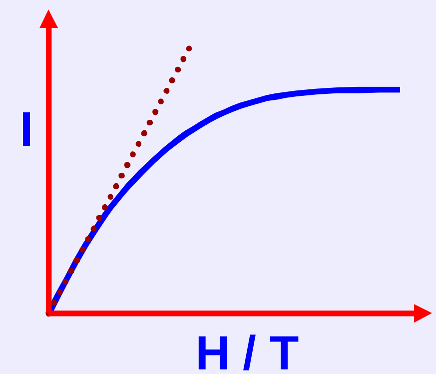
Curie's Law:

Magnetic susceptibility of a material varies inversely with the absolute temperature.

$I \propto H / T$ or $I / H \propto 1 / T$

$c_m \propto 1 / T$

$c_m = C / T$ (where C is Curie constant)



Curie temperature for iron is 1000 K, for cobalt 1400 K and for nickel 600 K.

Hysteresis Loop or Magnetisation Curve:

Intensity of Magnetisation (I) increases with increase in Magnetising Force (H) initially through OA and reaches saturation at A.

When H is decreased, I decreases but it does not come to zero at H = 0.

The residual magnetism (I) set up in the material represented by OB is called Retentivity.

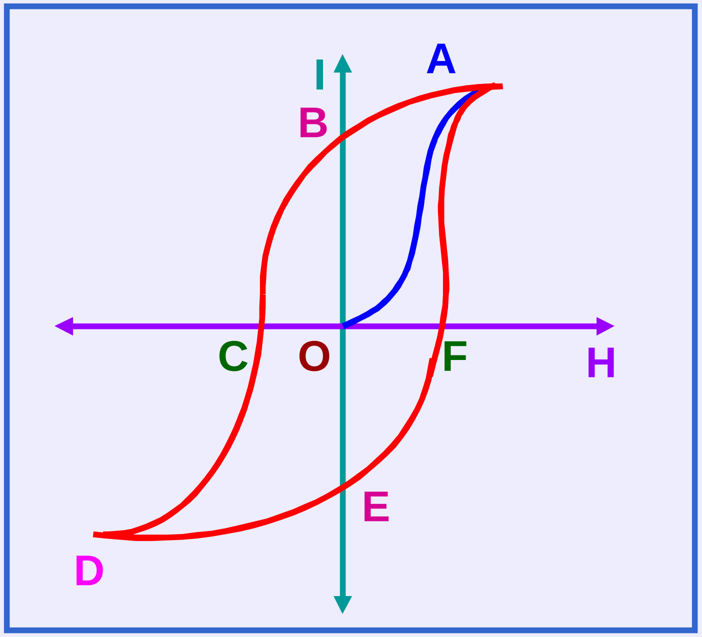
To bring I to zero (to demagnetise completely), opposite (negative) magnetising force is applied. This magetising force represented by OC is called coercivity.

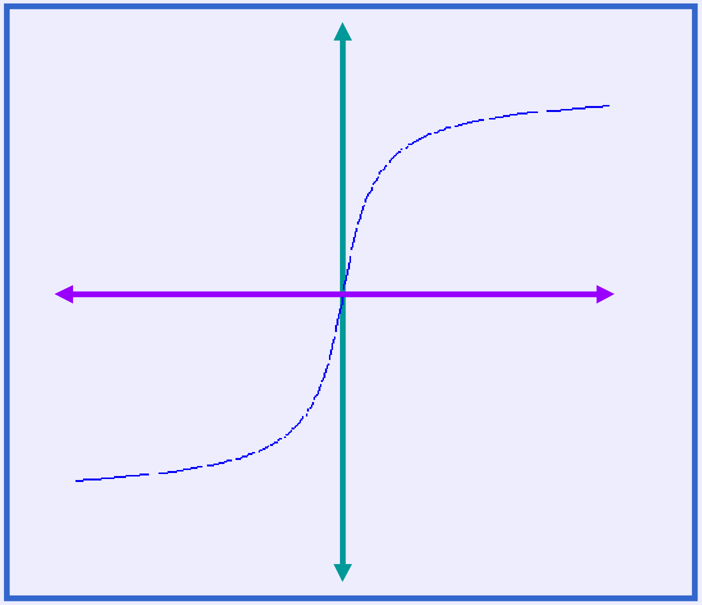
After reaching the saturation level D, when the magnetising force is reversed, the curve closes to the point A completing a cycle.

The loop ABCDEFA is called Hysteresis Loop.

The area of the loop gives the loss of energy due to the cycle of magnetisation and demagnetisation and is dissipated in the form of heat.

The material (like iron) having thin loop is used for making temporary magnets and that with thick loop (like steel) is used for permanent magnets.





Animating Hysteresis Loop: Courtesy - Website

End of Magnetism