Magnetic properties of materials

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MAGNET

The substance which has attractive and directive properties is called a **magnet**.

General Properties of a Magnet

(i) A magnet exerts magnetic force on the magnetic material and hence it attracts magnetic material i.e., it has attractive property.

(ii) If a magnet is freely suspended, it will come to rest in a position close to the north-south direction i.e. it has directive property.

(iii) A magnet has always two poles North and South and these poles are of equal strength.

(iv) The ratio of magnetic length to the geometrical length of a magnet always bears a constant equal to 0.85.

(v) Like poles repel and unlike poles attract each other.

(vi) Magnetic poles always exist in pairs. If we break magnet into pieces each piece will contain two new poles. If these pieces are again broken, then also each small piece will contain a north and a south pole. Thus every tiny piece is a magnet.

SOME TERMS RELATED TO MAGNETISM

Polar Region

The region near the ends of the magnet where there is attraction or repulsion is called **polar region**. A magnet has two polar regions, north and south polar regions.

Neutral Region

The region at the middle portion of the magnet where there is neither attraction nor repulsion is called **neutral region**.

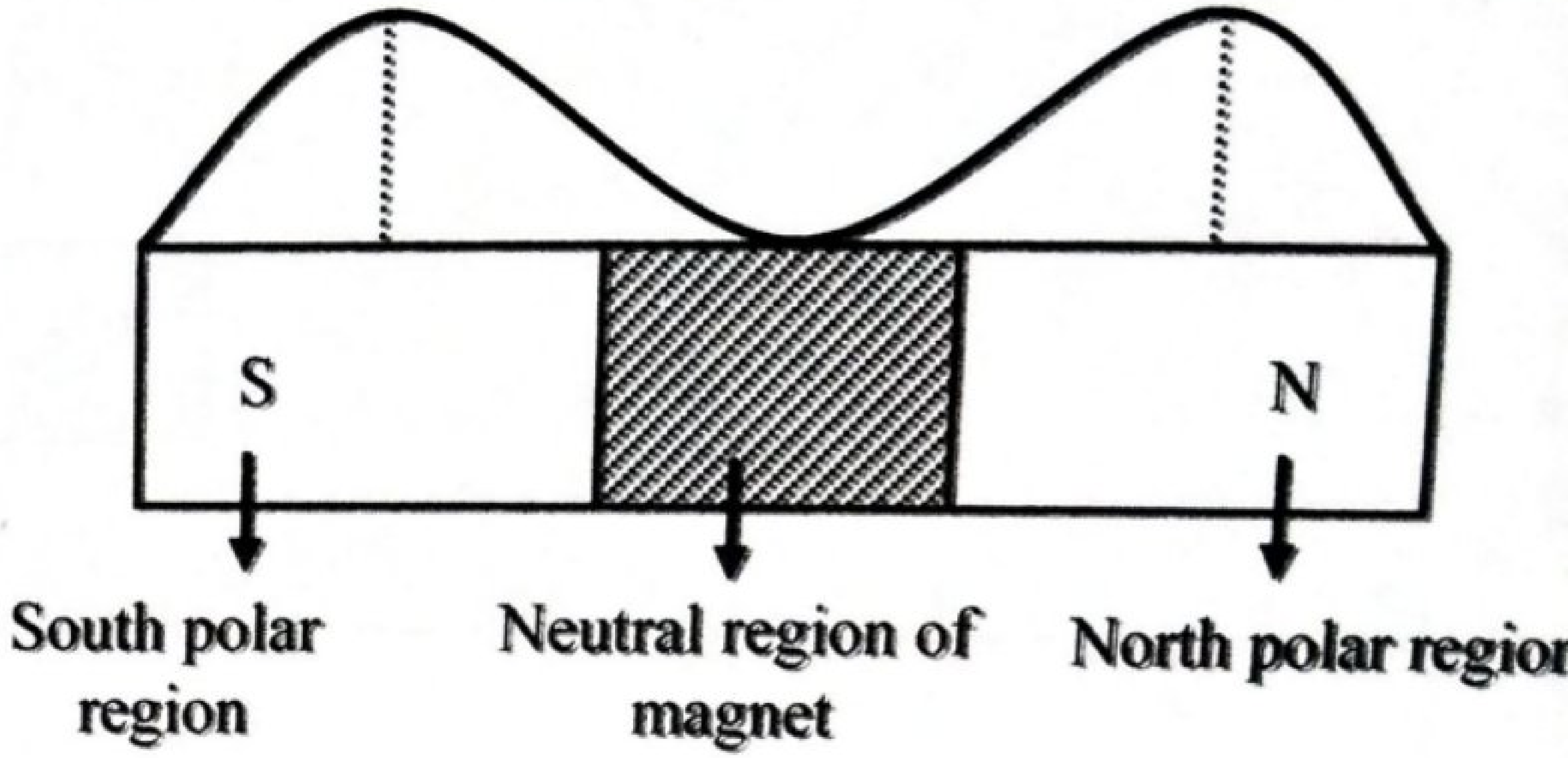


Fig. 19.1: Magnet with polar and

... with magnetic axis.

Magnetic length

The distance between poles of a magnet is called **magnetic length or effective length**. It is denoted by **2*l***.

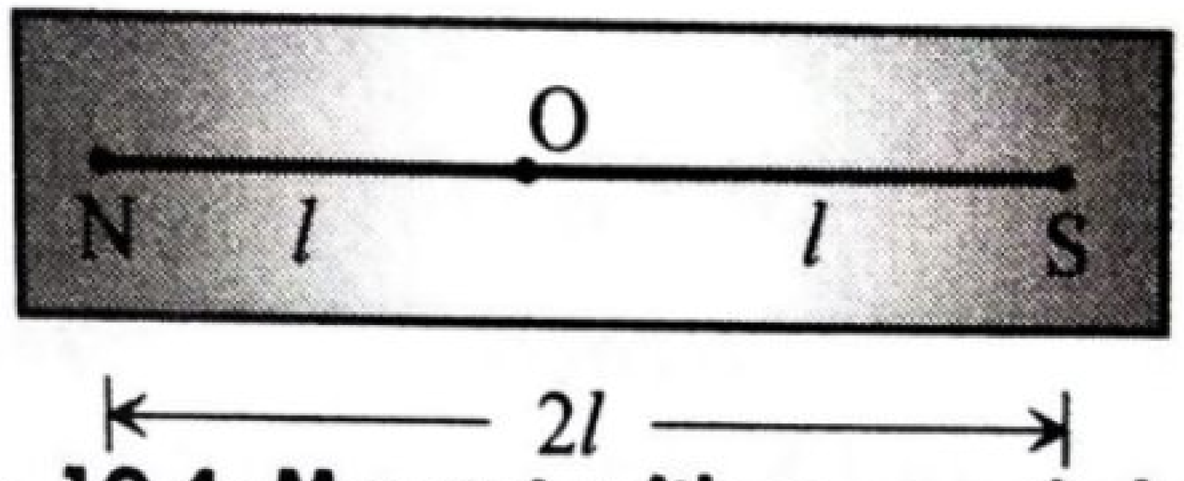


Fig. 19.4: Magnet with magnetic length.

In the Fig. 19.4, ON = OS = $2l$ is the magnetic length of the magnet and l is semi-magnetic length.

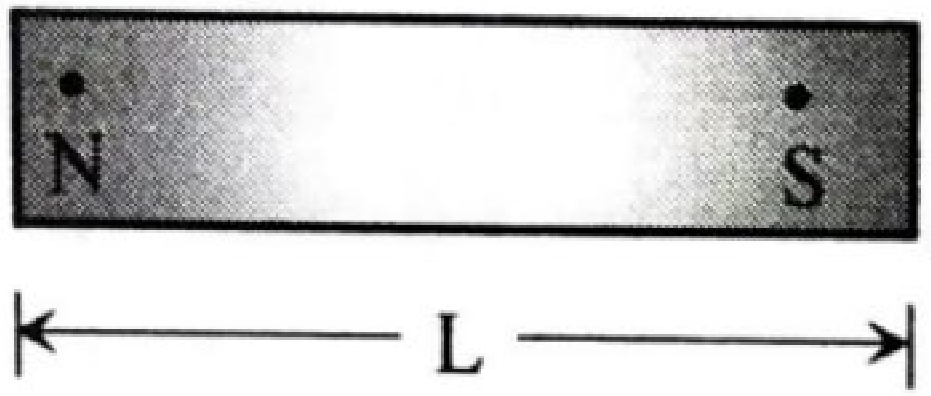


Fig. 19.5: Magnet with a geometrical length.

The distance between the ends of a magnet is called its **geometrical length or real length or actual length**. Obviously, geometrical length (L) > magnetic length ($2l$). For any magnet the ratio of magnetic length and geometrical length always remains constant i.e. $\dfrac{\text{magnetic length}(2l)}{\text{geometrical length (L)}} = 0.85$.

Magnetic Pole Strength

The force acting on the pole of a magnet in magnetic field of unit strength is called **pole strength**. Thus magnetic pole strength is equal to the force exerted on the pole divided by the magnetic field strength. It is also called **magnetic charge**. It is denoted by m.

Its S.I. units is ampere metre (Am) or weber (Wb).

Magnetic dipole: If N-pole and S-pole of a magnet are separated by very small but certain distance then that system is called **magnetic dipole**. The pole strengths of a magnet for both poles are the same.

NS be a magnet whose N-pole strength be +m and S-pole strengths be –m. The length of the magnet is $2l$ which is so small that l^2 becomes negligible. Thus NS is a magnetic dipole. A short bar magnet, magnetic compass etc are magnetic dipoles.

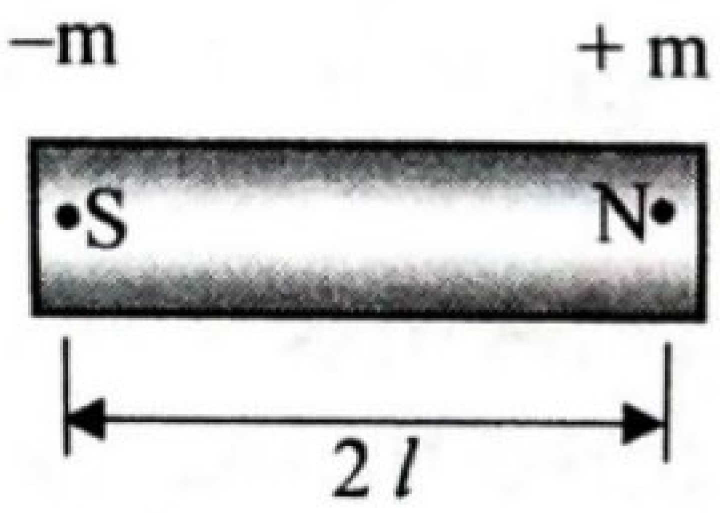
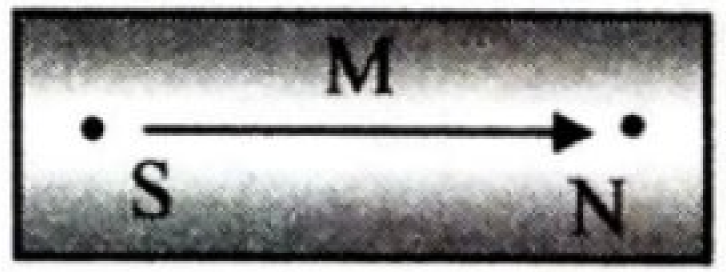


Fig. 19.10: Magnetic dipole.

Magnetic dipole moment

The product of a pole strength and magnetic length of a magnetic dipole is called **magnetic dipole moment**. If M be the magnetic dipole moment, we have

$$\mathbf{M = m \times 2}l \qquad \text{....... (19.1)}$$



It is a vector quantity whose direction is along SN inside the magnet

Evidence of existence of the Earth's magnetism

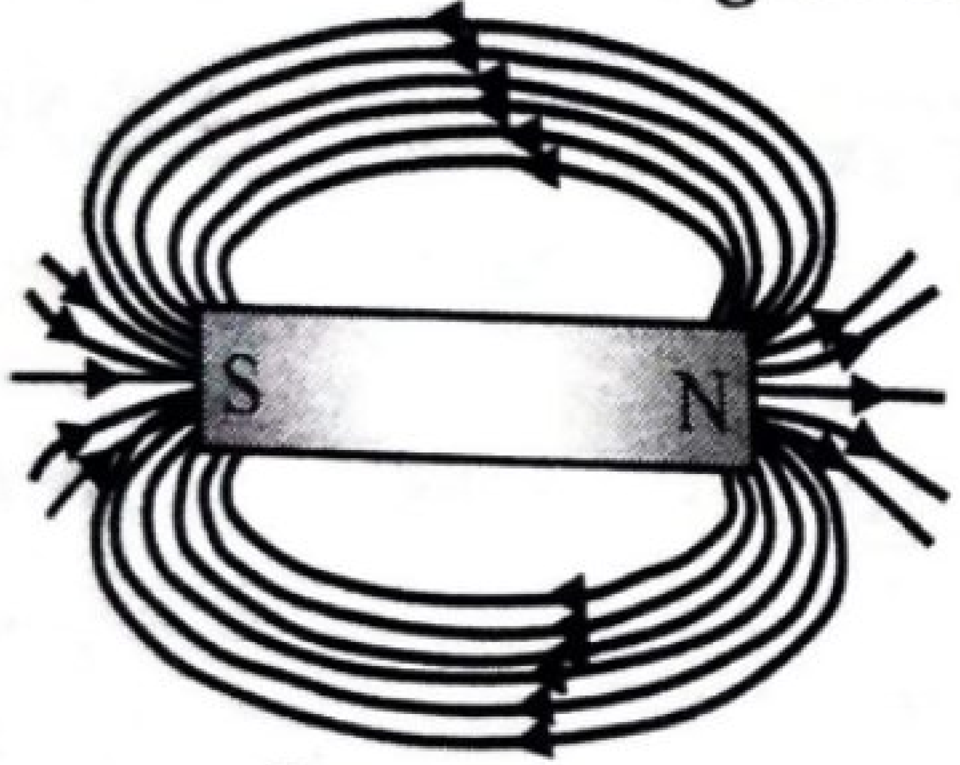
1. A freely suspended magnetic needle always stays along north- south direction.
2. Neutral points are obtained while drawing magnetic lines of force.
3. If an iron piece is buried in earth for sufficient time , it behaves as a weak magnet.

Magnetic meridian: **I**t is the vertical imaginary plane passing through the axis (N and S pole) of a freely suspended magnet

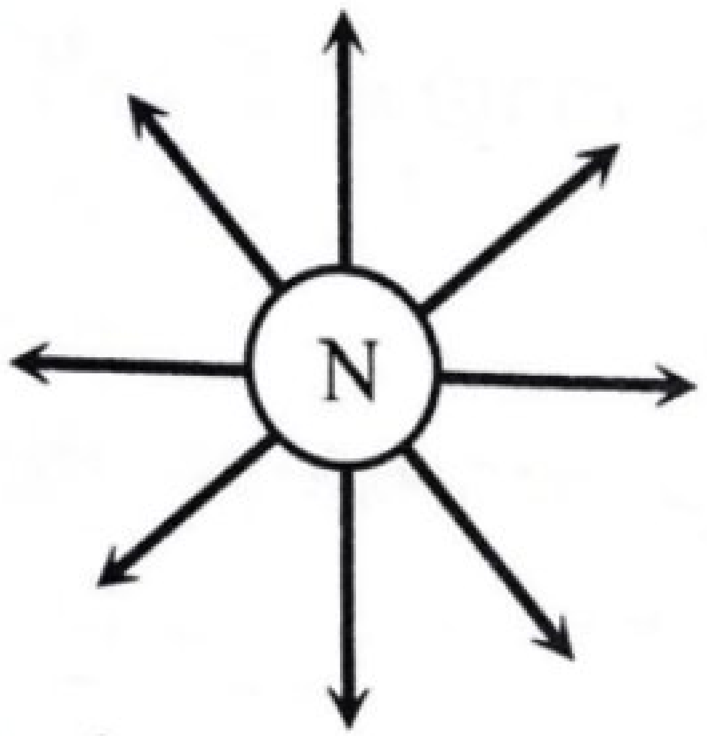
Geographical meridian : it is the vertical imaginary plane passing through the geographical axis of the earth

MAGNETIC FIELD LINES

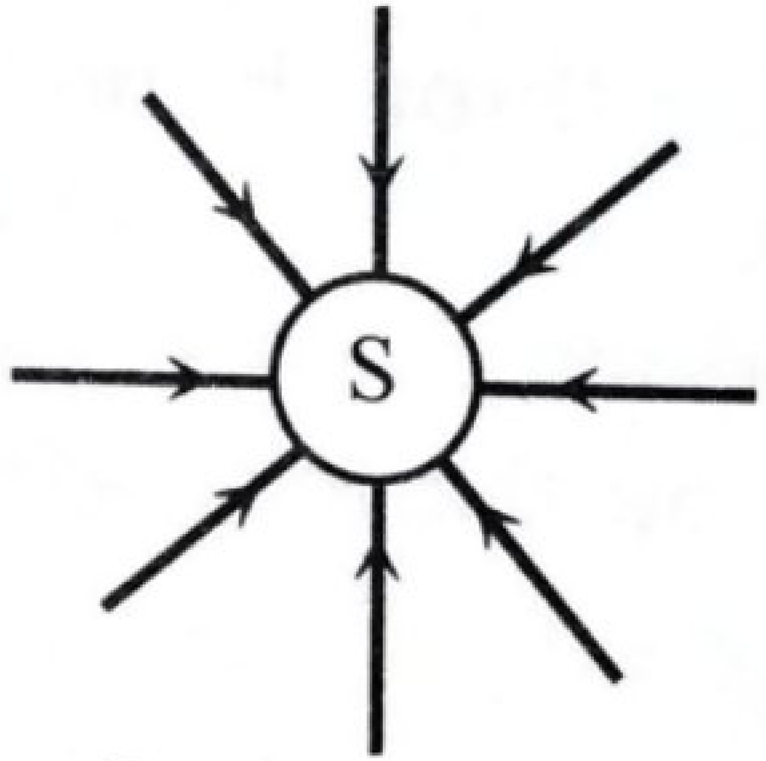
Magnetic field lines are the hypothetical closed curves through which a unit north pole would move if it were free to move and tangent at every point of the curve gives the direction of resultant magnetic field.



Bar magnet
(a)



Isolated North pole
(b)



Isolated South pole
(c)

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Properties

1. Magnetic field lines come out from N-pole and enter the S- pole but they go from S-pole to N-pole inside the magnet at any angle.
2. They are continuously closed curves.
3. They repel each other laterally (sideways). That is why, there is repulsion between like poles.
4. They never cross each other. If they cross each other then at the point of intersection there will be two tangents and hence two directions of the magnetic field, but magnetic field is a vector quantity. So it should not have two directions. That is why, two magnetic field lines never intersect each other. C is the point of intersection where two lines of force intersect and there are two tangents CA and CB which indicate the two directions of the magnetic field which is not possible.

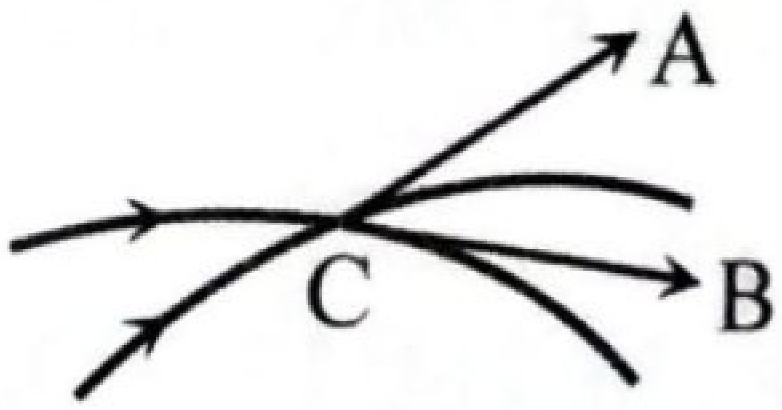
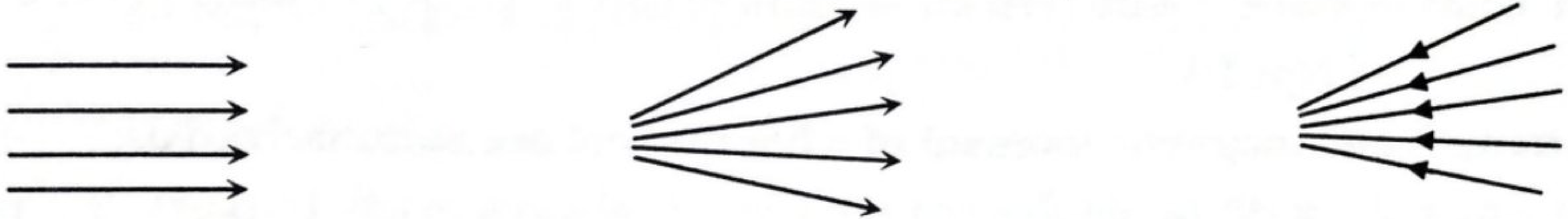


Fig. : field lines never cross each other

5. They are affected by earth's magnetic field.
6. They are like stretched elastic thread which tend to contract along their lengths. That is why, there is attraction between unlike poles.
7. Tangent at any point to magnetic field lines gives the direction of magnetic intensity at that point.
8. The strength of magnetic field increases as the number of magnetic field lines increases.

9. The parallel magnetic field lines represent the uniform magnetic field while converging or diverging or the curved magnetic field lines represent non-uniform magnetic field.



(a) Uniform magnetic field (b) Non-uniform magnetic field (c) Non-uniform magnetic field

Fig. : Magnetic field lines (a) Parallel lines of force (b) Diverging lines of force (c) Converging lines of force

Magnetic flux (φ)

Magnetic flux through any surface is defined as the number of magnetic lines of force crossing through that surface

Consider a small surface of area 'A'. let θ be the angle made by the normal drawn to that surface with uniform magnetic field B as shown in figure. The magnetic flux through the surface is $\phi = \vec{B} \cdot \vec{A}$

$$= B\,A\cos\theta$$

$$= B\cos\theta\, A$$

$$= B_n\, A$$

Where $B_n = B\cos\theta$ is the component of magnetic field normal to the surface .

Thus magnetic flux over a given surface is the product of the area of the surface and normal component of magnetic field

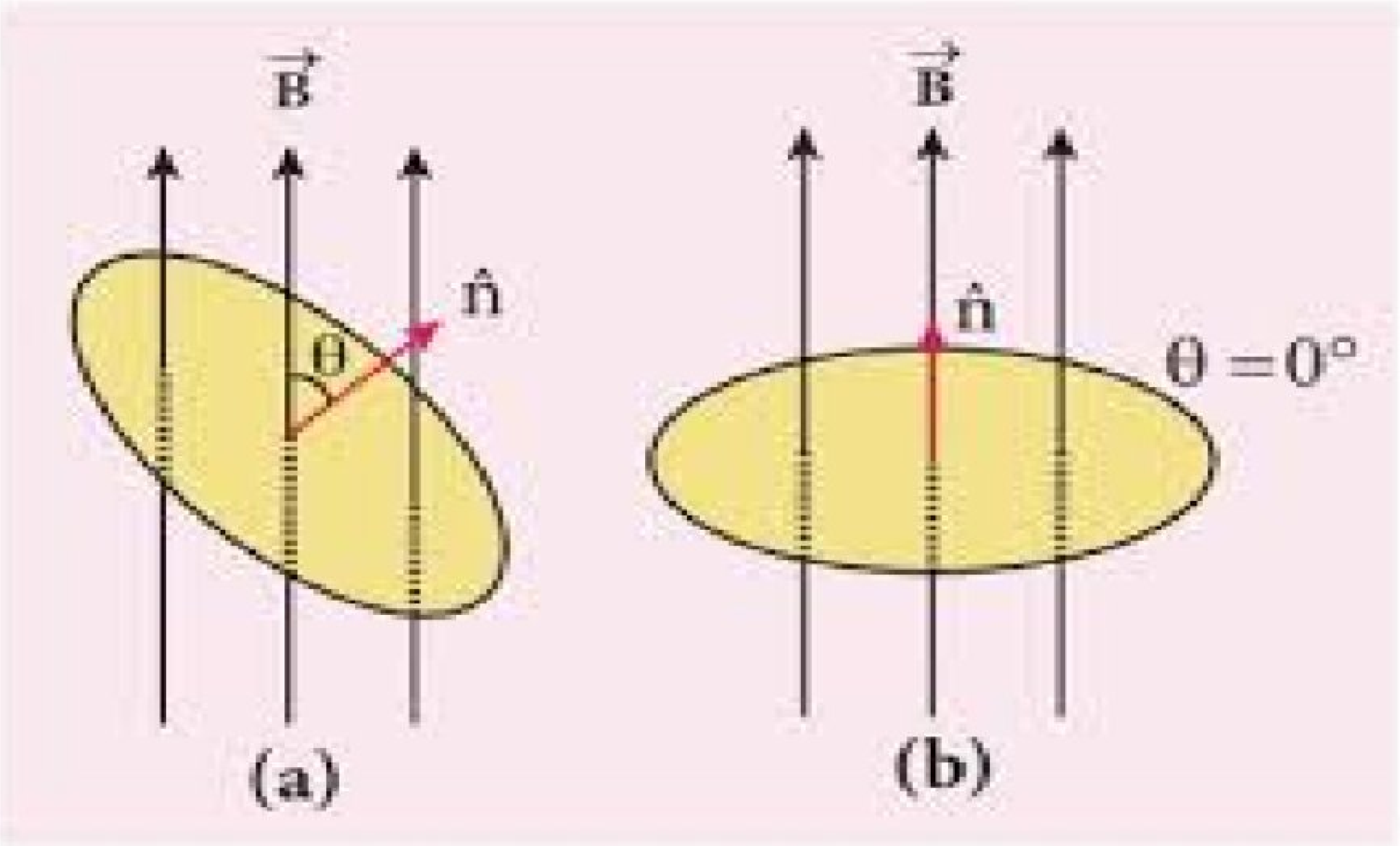


Figure 4.1 Magnetic flux

We have $\phi = \vec{B} \cdot \vec{A}$

$= B\,A \cos\theta$

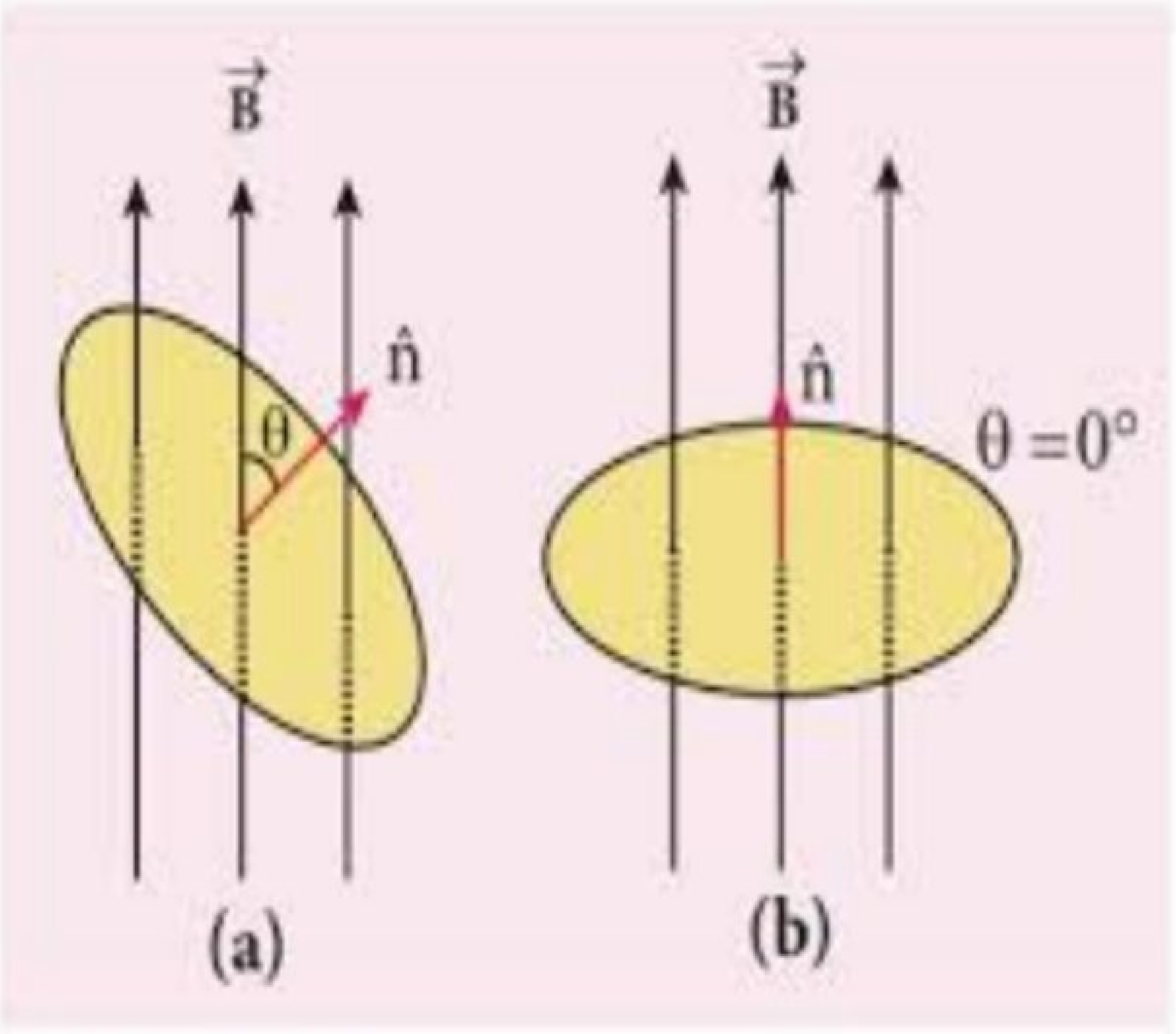


Figure 4.1 Magnetic flux

Special cases

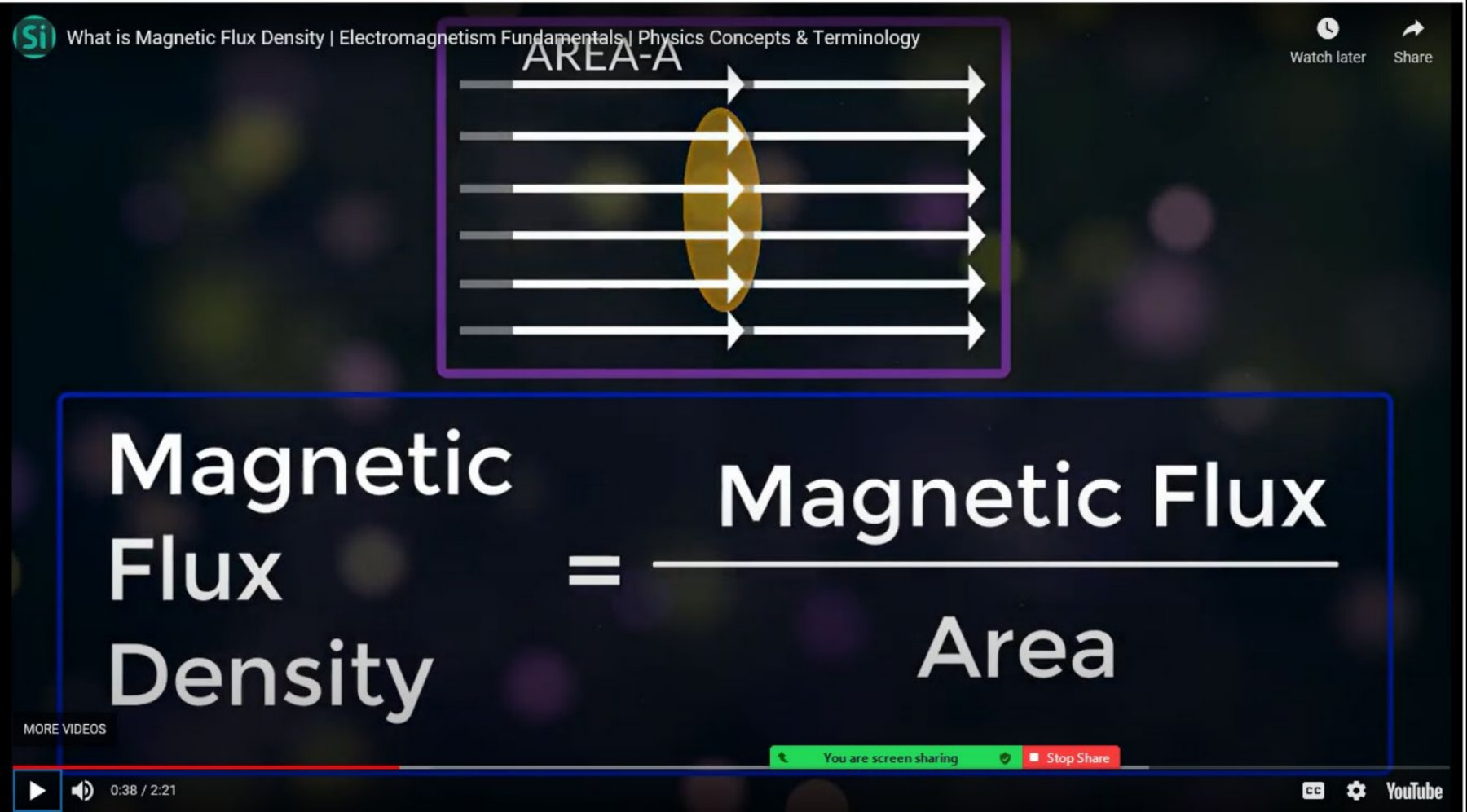
1. when $\theta = 0^0$, ϕ = B A (maximum)
2. when $\theta = 90$, $\phi = 0$

S I unit of ϕ is Weber =T m^2

in CGS it is measured in Maxwell = 10^{-8} Weber

What is Magnetic Flux Density?

Magnetic flux density is defined as the magnetic flux passing through unit area taken perpendicular to the field. B is also known as Magnetic Field Induction.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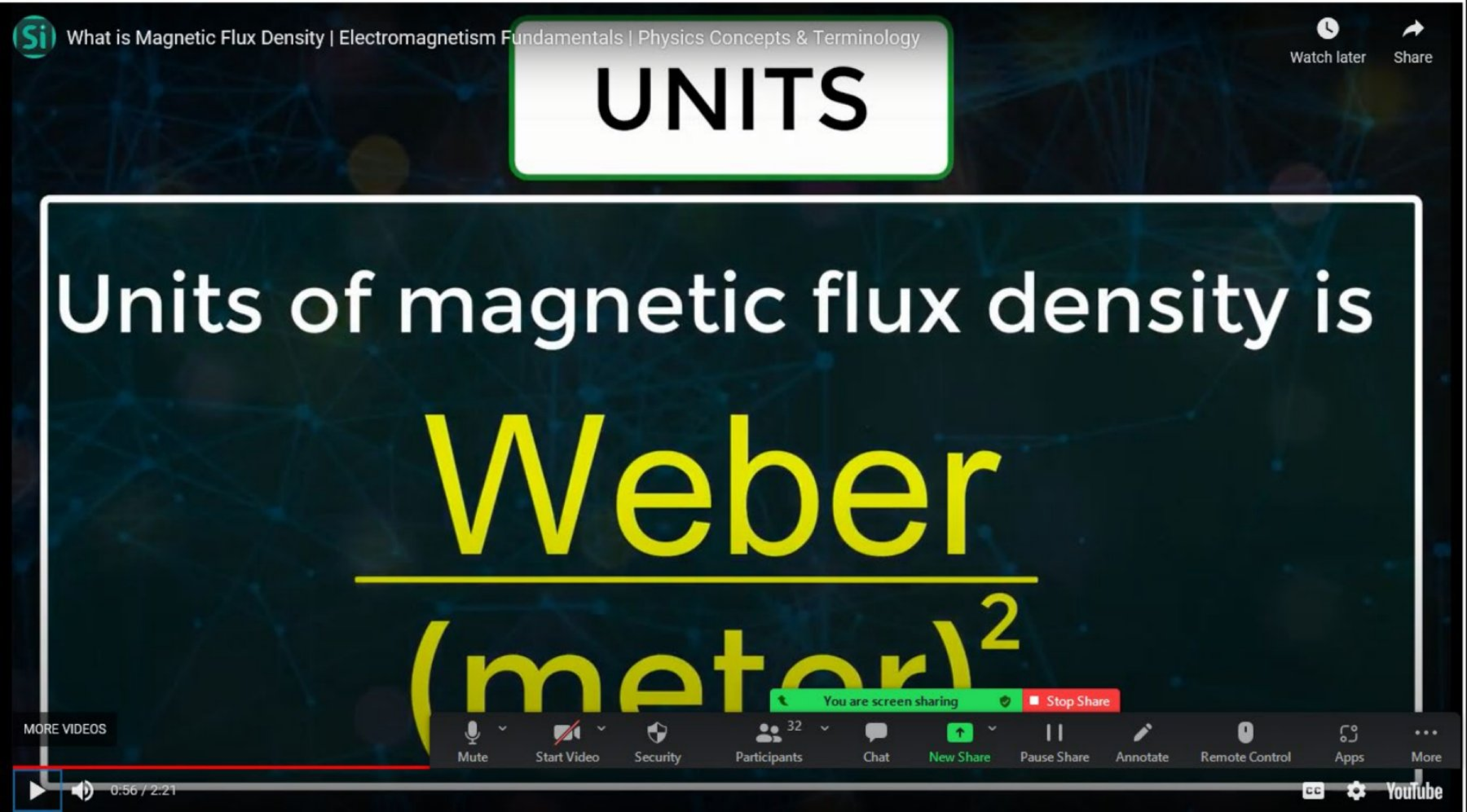
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Elements of Earth's magnetism

1. Angle of declination : The declination at a place is the angle between the magnetic meridian and the geographical meridian

2.Angle of dip: The angle made by the direction of resultant magnetic field with the horizontal is called the angle of dip. It is denoted by δ . Its value is maximum ie 90^0 at the poles and minimum ie 0^0 at the equator.

3. Horizontal component of Earth's magnetic field: The horizontal component of Earth's magnetic field His the component of the Earth's magnetic field along horizontal direction in the magnetic meridian at a place.

Induced magnetism

When a piece of magnetic substance is placed inside a magnetic field the substance gets magnetized, the magnetism so produced in the substance is called induced magnetism and this phenomenon is called magnetic induction.

The magnetic field which produces induced magnetism in a magnetic substance placed inside it is called magnetizing field (H).

Intensity of magnetization(I)

The magnetic moment per unit volume of substance is called the intensity of magnetization.

If M is the magnetic moment developed and V is the volume of the magnetic specimen then

$$\mathrm{I} = {}^{M}/_{V}$$

If A is area of cross section of the specimen and $2l$ be its length then

$$\mathrm{I} = {}^{m\,x\,2l}/_{A\,x\,2l}$$

$$\mathrm{I} = {}^{m}/_{A}$$

Hence intensity of magnetization may also be defined as the pole strength developed per unit area of cross-section of the specimen.

Its SI unit is weber/meter^2 or ampere meter^{-1}

Magnetic permeability(μ) :

the magnetic permeability of a medium μ is the ratio of

The magnetic field B (magnetic induction) to the magnetizing field H.

Ie $\mu = {}^{B}/_{H}$

The permeability of a free space is represented by μ_0 whose valueis $4\pi x 10^{-7}$H m^{-1}

The ratio of permeability of a material to that of free space is called relative permeability

Ie $\mu_r = {}^{\mu}/_{\mu_0}$ it is a unitless quantity.

Magnetic susceptibility(χ)

The magnetic susceptibility of a material is the ratio of intensity of magnetization to the magnetizing field. This is a dimensionless quantity.

Ie $\chi = I/H$

Relation between relative permeability and magnetic susceptibility

When a magnetic material is placed in a uniform magnetic field B_0 then the material magnetize and produce magnetic field B_M . now total magnetic field produce

$\therefore \quad B = B_o + B_M$

or, $\quad B = B_o + \mu_o I \qquad [\because B_M = \mu_o I]$

or, $\quad B = \mu_o H + \mu_o I \qquad [\because B_o = \mu_o H]$

or, $\quad B = \mu_o [H + I]$

or, $\quad B = \mu_o [H + \chi H] \qquad [\because \chi = \frac{I}{H}]$

or, $\quad B = \mu_o H [1 + \chi]$

or, $\quad \frac{B}{H} = \mu_o [1 + \chi]$

or, $\quad \mu = \mu_o [1 + \chi]$

or, $\quad \frac{\mu}{\mu_o} = 1 + \chi$

or, $\quad \mu_r = 1 + \chi$. This is the required relation.

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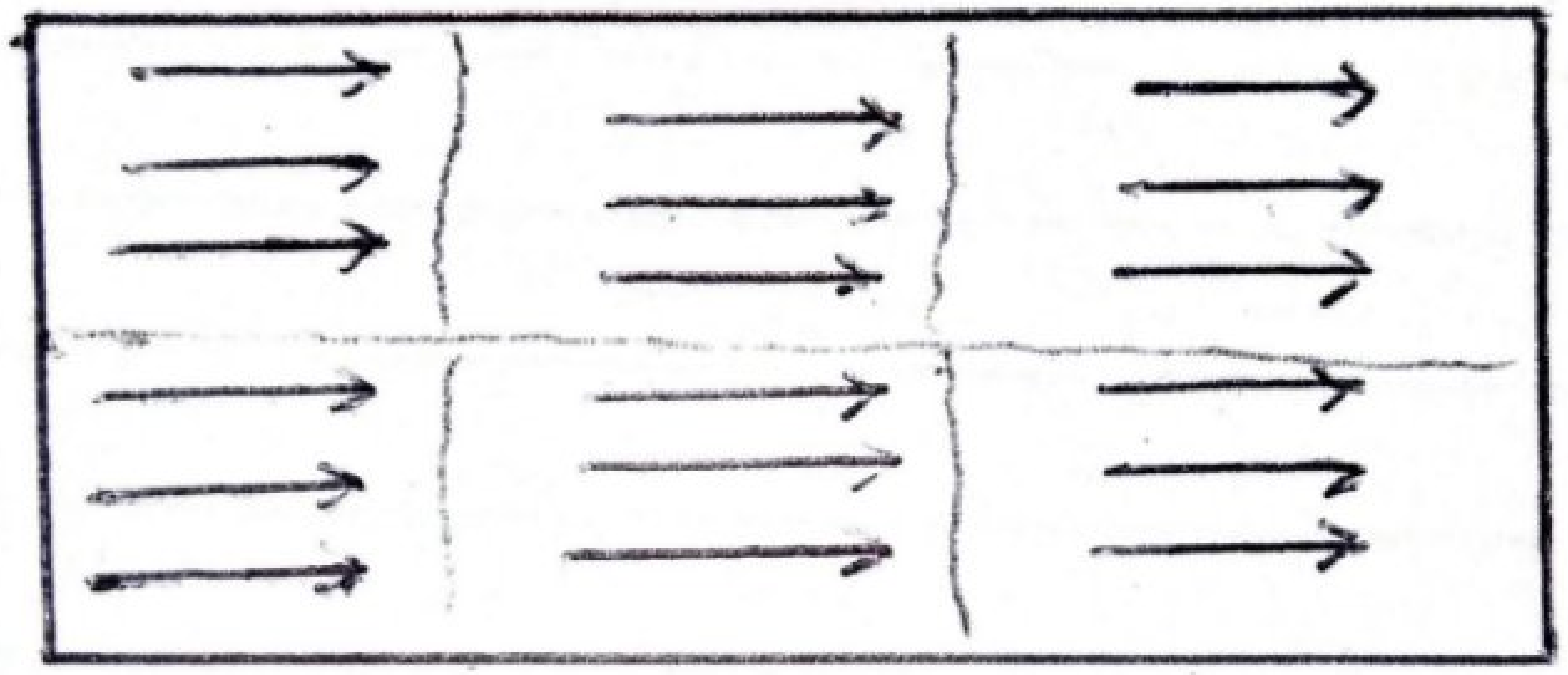
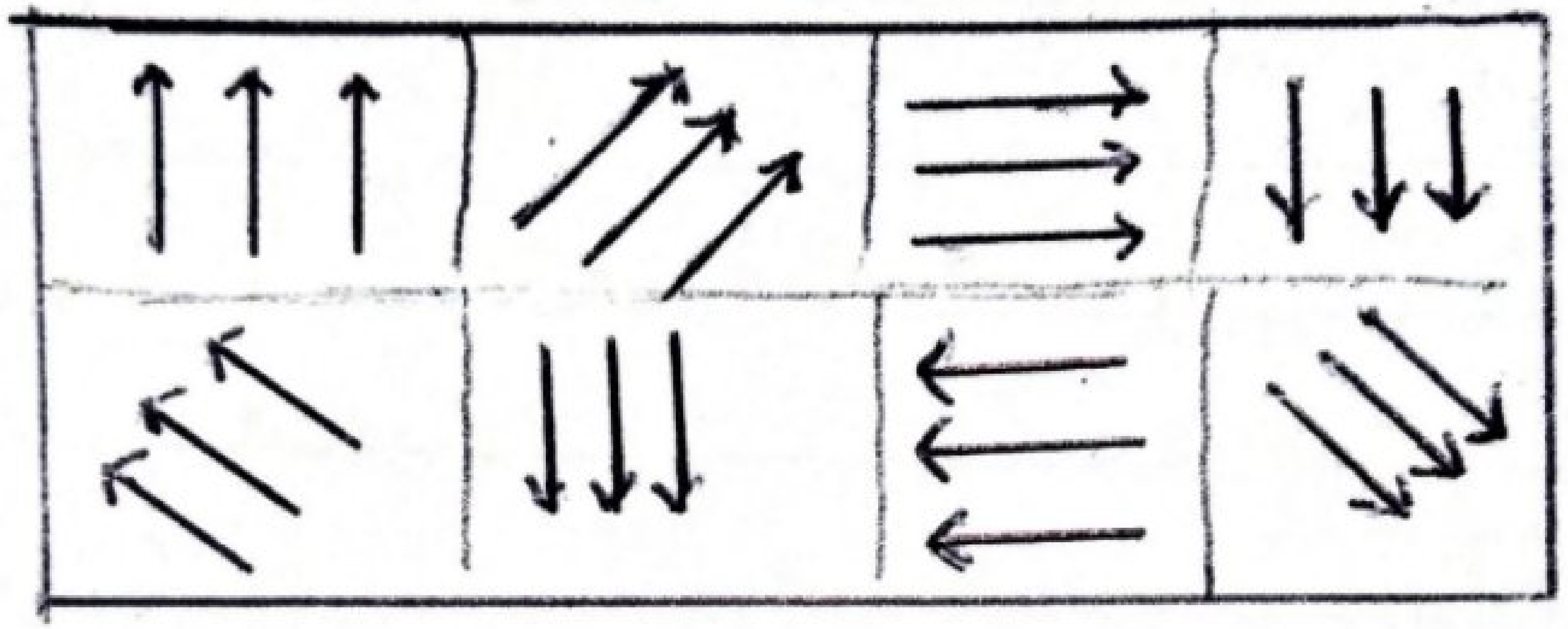
Which is the Relation between relative permeability and magnetic susceptibility

Domain theory

According to domain theory , it is assumed that magnetic materials are composed of tiny individual magnets called domains. A piece of magnetic substance (iron) is also made of domains which are randomly oriented inside it, but when it is placed near a magnet these domains are aligned in a direction of magnetic field . So it behaves as a magnet.



Domains of magnet



Domains of magnetic substance

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