CHAPTER 5

MAGNETISM AND MATTER

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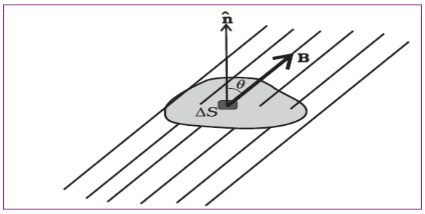
Gauss's Law in magnetism

- The law states that "**the net magnetic flux through any closed surface is zero**"

$$\phi_B = \sum_{'all'} \Delta\phi_B = \sum_{'all'} \mathbf{B}\cdot\Delta\mathbf{S} = 0$$



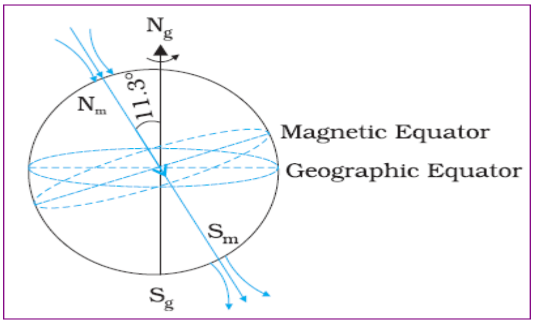
Earth's Magnetism

- Earth has an immense magnetic field surrounding it and is of the order of 10^{-5} T.
- The location of the north magnetic pole is at latitude of 79.74^0 N and a longitude of 71.8^0 W, a place somewhere in north Canada.
- The magnetic South Pole is at 79.74^0 S, 108.22^0 E in the Antarctica.

Source of Earth's Magnetism – Dynamo Effect

- Earth's magnetism is due to the electric currents produced by the convective motion of metallic fluids (consisting mostly of metallic iron and nickel) in the outer core of earth. This is known as **Dynamo Effect**.

Magnetic Meridian



- A vertical plane passing through the magnetic axis of a freely suspended magnet is called the magnetic meridian.

Geographic Meridian

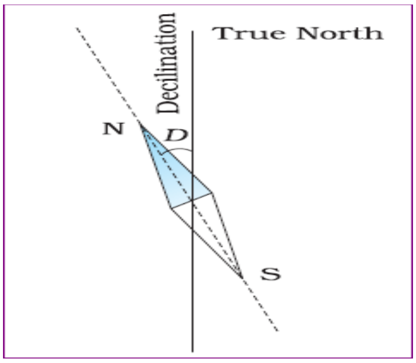
- The vertical plane passing through a place and the geographic north and south poles is called the geographic meridian at that place.

Elements of earth's magnetism

The three elements of earth's magnetic field are

- **Angle of declination (D)**
- **Angle of Dip or inclination (I)**
- **Horizontal component of earth's magnetic field (BH)**

Magnetic Declination



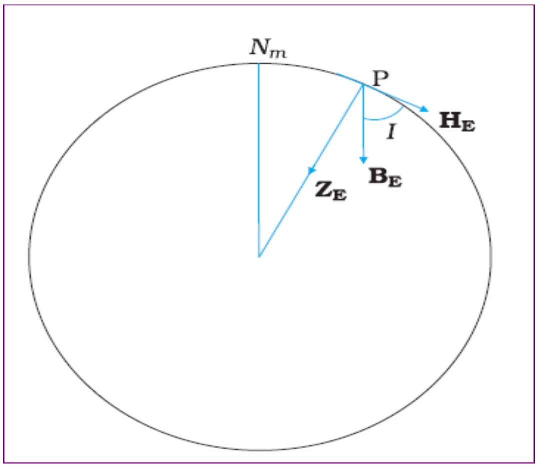
- The angle between the geographic meridian and magnetic meridian is called the angle of declination.
- The magnetic declination is different at different places on the surface of earth.
- The declination is greater at higher latitudes and smaller near the equator.

- The declination in India is small, it being $0^0 41'$ E at Delhi and $0^0 58'$ W at Mumbai.

Dip or Inclination

- Dip is the angle that the total magnetic field B_E of the earth makes with the surface of the earth.

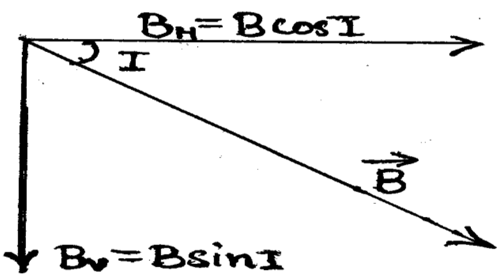
- The angle of dip is maximum (90 degree) at the magnetic poles and minimum (0 degree) at the magnetic equator.
- At other places its value lies between 0 degree and 90 degree.



- In most of the northern hemisphere, the north pole of the dip needle tilts downwards.
- In most of the southern hemisphere, the south pole of the dip needle tilts downwards

Horizontal Component of earth's magnetic field

- The total magnetic field at P can be resolved into *a horizontal component* B_H and a vertical component B_V.



Relation Connecting Horizontal component and vertical component

- We have $B_H = B \cos I$ and $B_V = B \sin I$
- Thus $\tan I = B_V / B_H$
- Also

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

Some Important Terms

Magnetistion or Intensity of Magnetisation (M)

- *Magnetisation M* of a sample is the net magnetic moment per unit volume, when the sample is subjected to magnetizing field.

$$\mathbf{M} = \frac{\mathbf{m}_{net}}{V}$$

- M is a vector with dimensions $L^{-1}A$ and is measured in a units of A m^{-1}.

Magnetic Intensity or Magnetising Field (H)

- When a magnetic material is placed in a magnetic field, magnetism is induced in the material. It is known as induced magnetism.
- The field which induces magnetism in a material is called magnetizing field and the strength of that field is called magnetic intensity (H).
- Its SI unit is ampere/ metre
- The magnetizing field is given by

$$\mathbf{H} = \frac{\mathbf{B}}{\mu_0} - \mathbf{M}$$

where, B – net magnetic field, M – Magnetistion, μ_0-permeability of free space

Relation connecting B , M and H

- The total magnetic field B is written as ,

$$\mathbf{B = \mu_0 (H + M)}$$

Relation connecting M and H

- The dependence of M on H is given by $M = \chi H$, Where χ – Magnetic susceptibility

Magnetic susceptibility

- *Magnetic susceptibility* is a measure of how a magnetic material responds to an external field.
- It is *small* and *positive* for *paramagnetic materials*
- *It is small and negative for diamagnetic* materials

Relation connecting B , μ and H

- We have $B = \mu_0 (H + M)$
- Substituting $M = \chi H$, we get

  $$B = \mu_0 (H + \chi H) = \mu_0 H(1+\chi) ,$$

- **Thus**

  $$\mathbf{B} = \mu_0 (1 + \chi)\mathbf{H} = \mu_0 \mu_r \mathbf{H} = \mu \mathbf{H}$$

- **where $\mu_r = 1 + \chi$, is a dimensionless quantity called the *relative magnetic permeability of the substance.***
- **The *magnetic permeability of the substance is μ and it has* the same dimensions and units as μ_0**

  $$\mu\ \mu = \mu_0 \mu_r = \mu_0 (1+\chi)$$

Magnetic permeability (μ)

- It is the ratio of magnetic field to the magnetizing field

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

- Its unit is tesla meter/ampere (TmA^{-1})

Relative permeability of medium

- Relative permeability of medium is the ratio of permeability of a medium (μ) to the permeability of air or vacuum (μ_0)

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

- Also $\mu_r = (1+\chi)$

Magnetic Flux (ϕ)

- It is the number of magnetic field lines passing normally through a surface.
- The SI unit is weber(Wb)

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