MATERIALS IN MAGNETIC FIELDS

A material, is said to be magnetic if $\chi_m \neq 0$, $\mu_r = 1$

A material is said to be non-magnetic if $\chi_m = 0$, $\mu_r = 1$.

The term 'Magnetism' is commonly discussed in terms of magnets with basic examples like north pole, compass needle, horse shoe magnets and so on.

Magnetic properties are described in terms of magnetic susceptibility and relative permeability of the materials.

Magnetic materials are classified into

1. Diamagnetic materials
2. Paramagnetic materials
3. Ferromagnetic materials

Diamagnetic Materials

A material is said to diamagnetic if its susceptibility, $\chi_m < 0$ and $\mu_r \leq 1.0$.

Examples are copper, lead, silicon, diamond and bismuth.

Characteristics of diamagnetic materials

- Magnetic fields due to the motion of orbiting electrons and spinning electrons cancel each other.
- Permanent magnetic moment of each atom is zero.
- These materials are widely affected by magnetic field.
- Magnetic susceptibility χ_m is (-)ve.
- $\mu_r = 1$
- $B = 0$
- Most of the materials exhibit diamagnetism.
- They are linear magnetic materials.
- Diamagnetism is not temperature dependent.
- These materials acquire magnetisation opposite to H and hence they are called diamagnetic materials.

Paramagnetic Materials

A material for which $\chi_m > 0$ and $\mu_r \geq 1$ is said to be paramagnetic.

Examples are air, tungsten, potassium and platinum.

Characteristics of paramagnetic materials

- They have non-zero permanent magnetic moment.
- Magnetic fields due to orbiting and spinning electrons do not cancel each other.
- Paramagnetism is temperature dependent.

- ☞ χ_m lies between 10^{-5} and 10^{-3}.
- ☞ These are used in MASERS.
- ☞ $\chi_m > 0$
- ☞ $\mu_r \geq 1$
- ☞ They are linear magnetic materials.

These materials acquire magnetisation parallel to H and hence they are called paramagnetic materials.

Ferromagnetic Materials

A material for which $\chi_m >> 0$, $\mu_r >> 1$ is said to be ferromagnetic.

Examples are iron, nickel, cobalt and their alloys.

Characteristics of ferromagnetic materials

- They exhibit large permanent dipole moment.
- $\chi_m >> 0$
- $\mu_r >> 1$
- They are strongly magnetised by magnetic field.
- They retain magnetism even if the magnetic field is removed.
- They lose their ferromagnetic properties when the temperature is raised.

- If a permanent magnet made of iron is heated above its curie temperature, 770°C, it loses its magnetisation completely.
- They are non-linear magnetic materials.
- $\mathbf{B} = \mu\mathbf{H}$ does not hold good as μ depends on **B.**
- In these materials, magnetisation is not determined by the field present. It depends on the magnetic history of the object.

BOUNDARY CONDITIONS ON H AND B

1. The tangential component of magnetic field, **H** is continuous across any boundary except at the surface of a perfect conductor, that is,

$$\mathbf{H}_{tan1} - \mathbf{H}_{tan2} = \mathbf{J}_s \qquad (3.9)$$

At non-conducting boundaries, $J_s = 0$.

2. The normal component of magnetic flux density, **B** is continuous across any discontinuity, that is,

$$\mathbf{B}_{n1} = \mathbf{B}_{n2} \qquad (3.10)$$

Proof: Consider Fig. 3.2 in which a differential rectangular loop across a boundary separating medium 1 and medium 2 are shown.

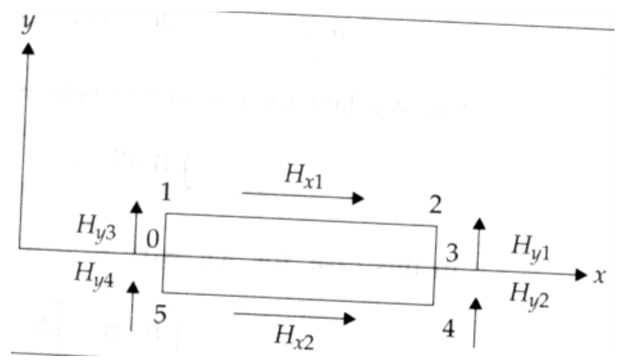

Fig. 3.2: A rectangular loop across a boundary

From Ampere's circuit law, we have

$$\oint H \cdot dL = \int_{50} + \int_{01} + \int_{12} + \int_{23} + \int_{34} + \int_{45}$$

$$= H_{y4}\frac{\Delta y}{2} + H_{y3}\frac{\Delta y}{2} + H_{x1}\Delta x - H_{y1}$$

$$\frac{\Delta y}{2} + H_{y2}\frac{\Delta y}{2} - H_{x2}\Delta x = I$$

As $\Delta y \to 0$, we get

$$\int H \cdot dL = H_{x1}\Delta x - H_{x2}\Delta x = I$$

or,

$$H_{x1} - H_{x2} = \frac{I}{\Delta x} = J_s \tag{3.11}$$

Here, H_{x1} and H_{x2} are tangential components in medium 1 and 2, respectively.

So, $$\mathbf{H}_{\tan 1} - \mathbf{H}_{\tan 2} = \mathbf{J}_s \tag{3.12}$$

Now consider a cylinder shown in Fig. 3.3.

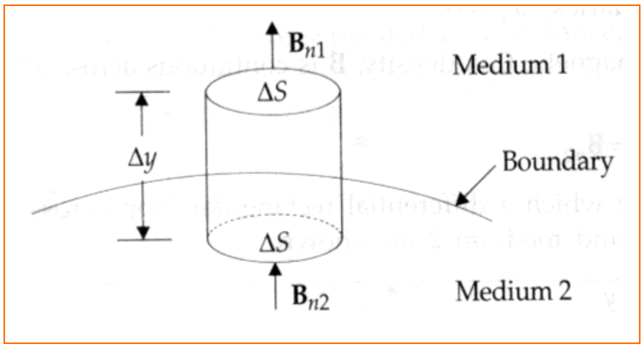

Fig. 3.3: A differential cylinder across the boundary

Gauss's law for magnetic fields is

$$\oint_s B \cdot dS = 0 \tag{3.13}$$

In this case, for $\Delta y \rightarrow 0$

$$\oint_s B \cdot dS = \int_s B_{n1} a_y \cdot dS \ a_y + \int_s B_{n2} a_y \cdot dS \ (-a_y) \tag{3.14}$$

that is, $B_{n1}\,\Delta S - B_{n2}\,\Delta S = 0$

Therefore, $$\mathbf{B}_{n1} = \mathbf{B}_{n2} \tag{3.15}$$

Problem 3:

Two homogeneous, linear and isotropic media have an interface at $x = 0$. $x < 0$ describes medium 1 and x > 0 describes medium 2. $\mu_{r1} = 2$ and $\mu_{r2} = 5$. The magnetic field in medium 1 is $150\mathbf{a}_x - 400\mathbf{a}_y + 250\mathbf{a}_z$ A/m.

Determine:

(a) Magnetic field in medium 2

(b) Magnetic flux density in medium 1

(c) Magnetic flux density in medium 2.

Solution:

The magnetic field in medium 1 is

$$\mathbf{H}_1 = 150\mathbf{a}_x - 400\mathbf{a}_y + 250\mathbf{a}_z \text{ A/m}$$

Consider Fig. 3.4.

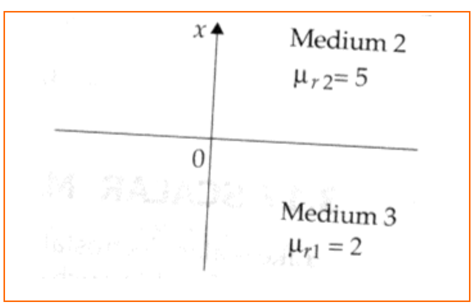

Fig. **3.4: Illustrative figure**

(a) $\mathbf{H}_1 = \mathbf{H}_{tan1} + \mathbf{H}_{n1}$

$H_{tanl} = -400\mathbf{a}_y + 250\mathbf{a}_z$ A/m

$H_{n1} = 150\mathbf{a}_x$

The boundary condition is

$H_{tanl} = H_{tan2}$

$H_{tan2} = -\, 400\mathbf{a}_y + 50\mathbf{a}_z$ A/m

The boundary condition on **B** is $\mathbf{B}_{n1} = \mathbf{B}_{n2}$

that is, $\mu_1 H_{n1} = \mu_1 H_{n2}$

$$H_{n2} = \frac{\mu_1}{\mu_2} H_{n1}$$

$$= \frac{2}{5} \times 150 a_x$$

$= 60\mathbf{a}_x$

$\mathbf{H}_2 = \mathbf{H}_{tan2} + \mathbf{H}_{n2}$

(b) $\mathbf{B_1} = \mu_1 \mathbf{H_1}$

$= \mu_0 \mu_r \mathbf{H_1}$

$= 4\pi \times 10^{-7} \times 2(150\mathbf{a}_x - 400\mathbf{a}_y + 250\mathbf{a}_z)$

$= (376.5\mathbf{a}_x - 1004\mathbf{a}_y + 627.5\mathbf{a}_z)\ \mu wb/m^2$

(c) $\mathbf{B}_2 = \mu_2 \mathbf{H}_2$

$= 4\pi \times 10^{-7} \times 5\ (60\mathbf{a}_x - 400\mathbf{a}_y + 250\mathbf{a}_z)$

$= (376.98\mathbf{a}_x - 2513.2\mathbf{a}_y + 1570.75\mathbf{a}_z)\mu wb/m^2$

INDUCTANCE

Inductor is a coil of wire wound according to various designs with or without a core of magnetic material to concentrate the magnetic field.

Inductance, L In a conductor, device or circuit, an inductance is the inertial property caused by an induced reverse voltage that opposes the flow of current when a voltage is applied. It also opposes a sudden change in current that has been established.

Definition of Inductance, L (Henry):

The inductance, L of a conductor system is defined as the ratio of magnetic flux linkage to the current producing the flux, that is,

$$L \equiv \frac{N\phi}{I}(Henry) \qquad (3.35)$$

Here N = number of turns

ϕ = flux produced

I = current in the coil

1 Henry ≡ 1 wb/Amp

L is also defined as $(2W_H/I^2)$, or

$$L \equiv \frac{2W_H}{I^2} \qquad (3.36)$$

where, W_H = energy in H produced by I.

In fact, a straight conductor carrying current has the property of inductance. Aircore coils are wound to provide a few pico henries to a few micro henries. These are used at IF and RF frequencies in tuning coils, interstage coupling coils and so on.

The requirements of such coils are:

- Stability of inductance under all operating conditions

- High ratio inductive reactance to effective loss resistance at the operating frequency
- Low self capacitance
- Small size and low cost
- Low temperature coefficient

STANDARD INDUCTANCE CONFIGURATIONS

Toroid

It consists of a coil wound on annular core. One side of each turn of the coil is threaded through the ring to form a Toroid (Fig. 3.6).

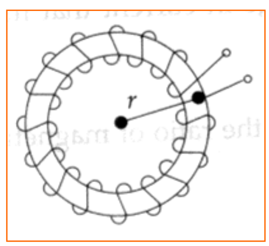

Fig. 3.6: Toroid

Inductance of Toroid, $L = \dfrac{\mu_0 N^2 S}{2\pi r}$ (3.37)

Here N = number of turns

r = average radius

S = cross-sectional area

Magnetic field in a Toroid, $H = \dfrac{NI}{2\pi r}$ (3.38)

I is the current in the coil.

Solenoid

It is a coil of wire which has a long axial length relative to its diameter. The coil is tubular in form. It is used to produce a known magnetic flux density along its axis.

A solenoid is also used to demonstrate electromagnetic induction. A bar of iron, which is free to move along the axis of the coil, is usually provided for this purpose. A typical solenoid is shown in Fig. 3.7.

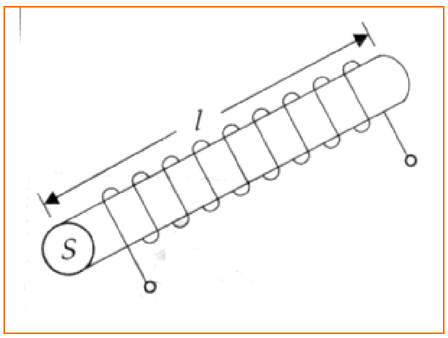

Fig. 3.7: Solenoid

The inductance, L of a solenoid is

$$L = \frac{\mu_0 N^2 S}{l} \qquad (3.39)$$

l = length of solenoid

S = cross-sectional area

N = Number of turns

The magnetic field in a solenoid is

$$H = \frac{NI}{l} \qquad (3.40)$$

I is the current