Chapter 1
Magnetic Circuits and Introduction

Basic Terms in Magnetic Circuits / Electromagnetism

i) Magnet

There are two types of magnets:
- artificial magnet
- natural magnet

Natural magnet does not have enough magnetic effect to be used in devices. In such devices, artificial magnet is used.

A substance that attracts or repel other magnetic material (iron, nickel, cobalt, etc) is called magnet.

(The material possessing this property is known as) magnetism.
↳ The property of the material

Types:

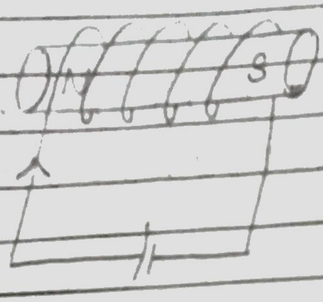
a) Natural magnets

Natural magnets are extracted from mines. Natural form of magnet is called magnetite (lodestone) b> artificial magnet

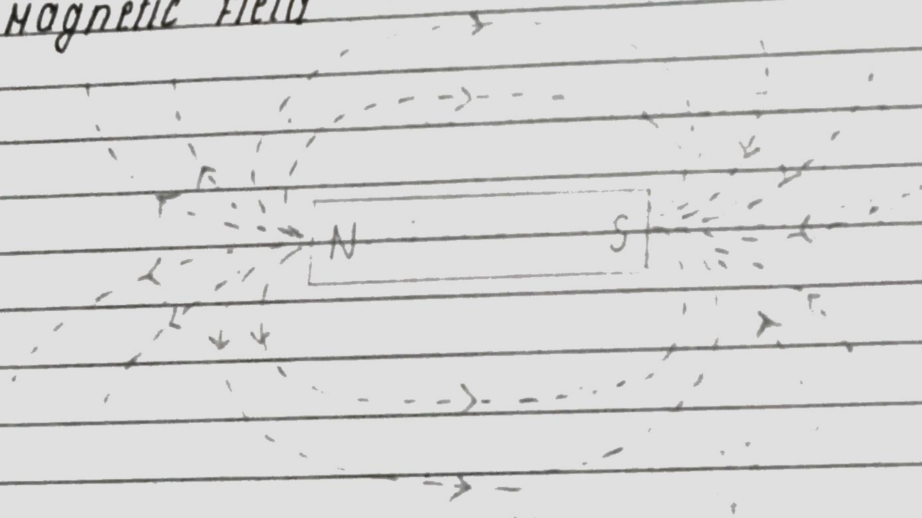
It can be prepared by rubbing an iron bar (magnetic pmaterial) with a magnet

OR

It can be prepaled by passing electric current through a coil wound on a iron bar(magnetic material).



ii> Magnetic Field

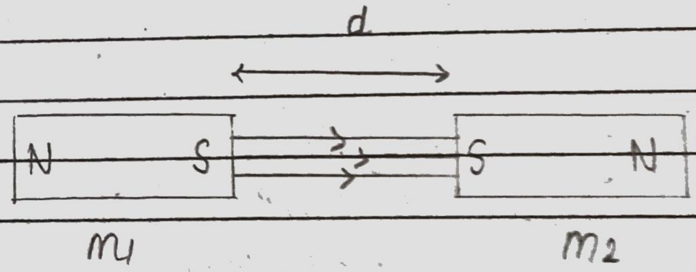


The space around the magnet upto which the magnetic force can be experienced is known as magnetic field

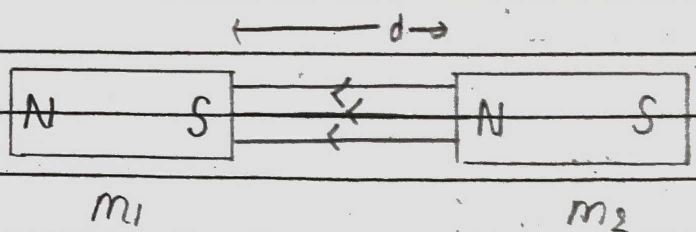
Magnetic field is made up of magnetic lines of force. The magnetic lines of force moves from north to south.

Properties of magnetic lines of force

- Magnetic lines of force always travel from north pole to south pole
- Magnetic lines of force forms a closed path
- Magnetic lines of force never intersect each other
- Magnetic lines of force repels sidewise but contracts longitudinally (lengthwise).



Force of repulsion



Force of attraction

iii) Magnetic force

The force exerted by one magnet on another magnet (magnetic materials) either of attraction or repulsion is known as magnetic force.

According to Coulomb's law (1st law), unlike poles attract each other and like poles repel each other.

According to Coloumb's 2nd law, "The magnetic force between two magnetic poles is directly proportional to the product of their pole strength and inversely proportional to the square of distance between them."

Mathematically,

$$F \propto \frac{m_1 m_2}{d^2}$$

where,

m_1 = pole strength of 1st magnet
m_2 = pole strength of 2nd magnet
d = distance between both magnets

$$F = \frac{1}{4\pi \mu_0 \mu_r}\left(\frac{m_1 m_2}{d^2}\right)$$

where,

μ_0 = absolute permeability, $4\pi \times 10^{-7}$ H/m
μ_r = relative permeability

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iv) Magnetic Field Intensity (H) or Magnetic Field Strength

Magnetic field intensity at any point in the magnetic field is defined as the force experienced by the unit north pole placed at that point.

$$H / F = \frac{1}{4\pi\mu_0\mu_r} \frac{m_1}{d^2}$$

v) Magnetic Flux (ϕ)

The total number of magnetic lines of force comprising the magnetic field is known as magnetic flux.

It is represented by ϕ.

It's unit is weber (Wb).

1 Wb = 10^8 magnetic lines of force

vi) Magnetic Flux Density (B)

$$\left[B = \frac{\phi}{A} \right]$$

It is defined as the ratio of flux per unit area. It is represented by B. It's unit is Wb/m^2.

Relation between Magnetic flux density (B) and Magnetic field intensity (H)

The magnetic flux density is directly proportional to magnetic field intensity, i.e

$$B \propto H$$

$$B = \mu H$$

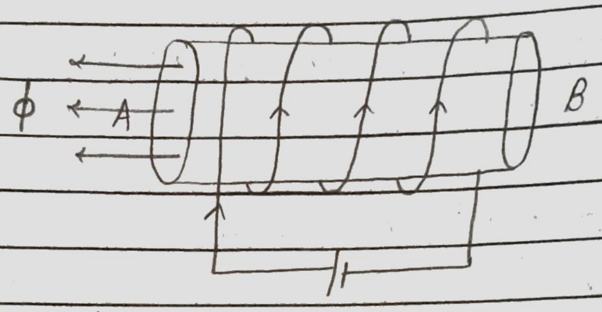
$$B = \mu_0 \mu_r H$$

Where,

μ_0 = absolute permeability

μ_r = relative permeability

Electromagnets



A current carrying conductor produces magnetic field around it. So when a conductor is wound with a coil having N turns and current is supplied through it, then, the conductor produces or develops magnetic properties and such magnet is known as electromagnets.

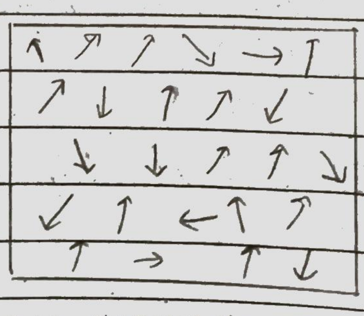
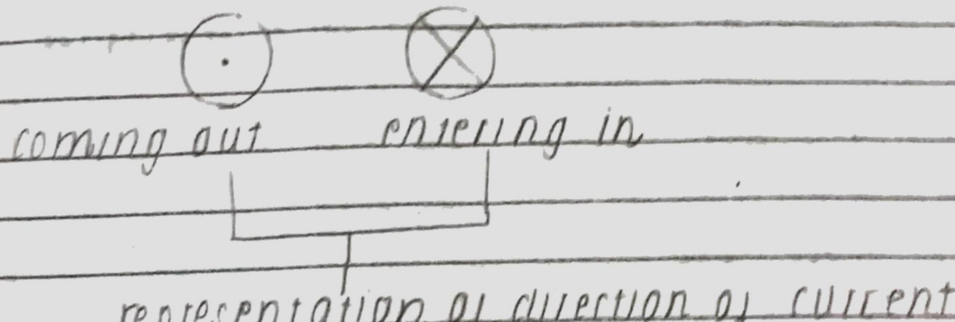


Fig: Random arrangement of atomic dipoles

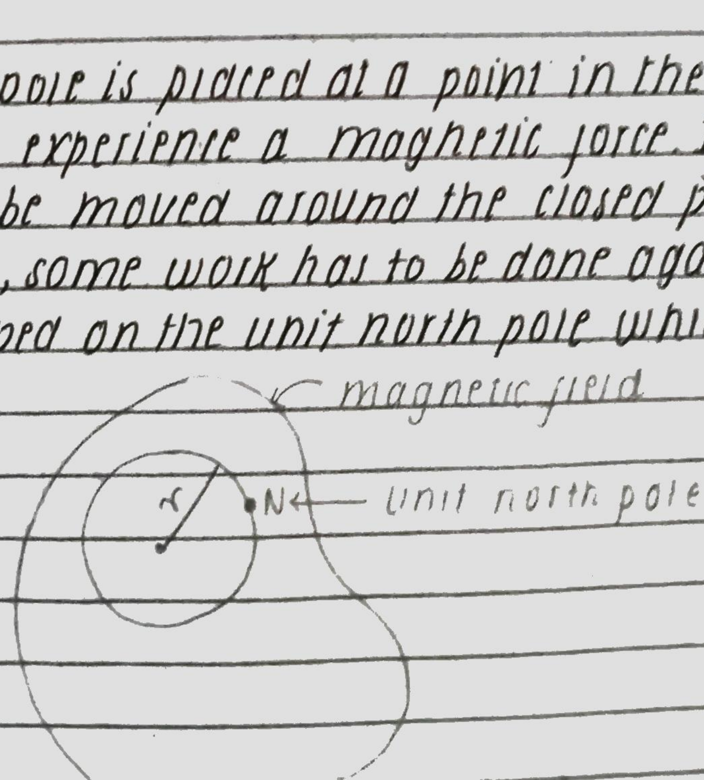
The direction of flux in electromagnets is determined by right hand thumb rule.

According to this rule, "If we use our right hand four fingers to hold the electromagnetic in such a way that the tip of the four fingers represent the direction of current, then the thumb will indicate the direction of flux."



Work law

If a unit north pole is placed at a point in the magnetic field, it will experience a magnetic force. If this unit north pole is to be moved around the closed path in the magnetic field, some work has to be done against the magnetic force developed on the unit north pole which is given by work law.



It states that, "The net work done by the unit north pole in moving around any closed path in a magnetic field is equal to the ampere turn enclosed by that closed path."

Consider a circular closed path of radius 'r' in the magnetic field around which the unit north pole is used to be moved. The amount of work done by unit north pole in moving one complete cycle is,

$$W = F * \text{distance}$$

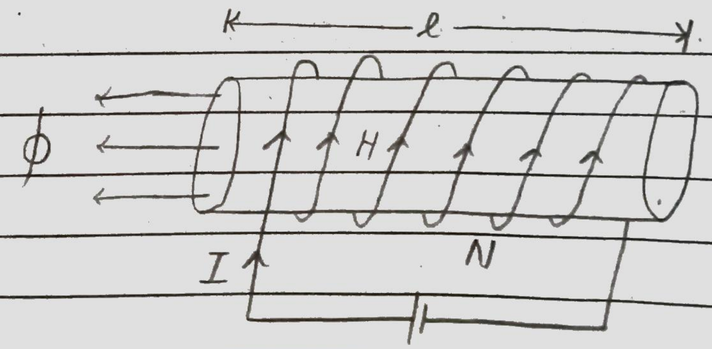
$$\Rightarrow W = H * 2\pi r$$

According to work law,

$$NI = H * 2\pi r$$

$$\boxed{\therefore H = \frac{NI}{2\pi r}}$$

Application of work law



consider an electromagnet having magnetic field intensity(H) inside. let it's length be 'l' on which a coil having N turns is placed through which current I is flowing.

Assumptions made:

- Magnetic field intensity inside the core remains constant throughout the length.

- Magnetic field intensity outside the core is negligible in comparison with magnetic field intensity inside the core.

since magnetic field intensity outside the core is negligible, so the work done in moving a unit north pole outside the core is also negligible. Therefore, the total work done will be equal to the work done along length or inside core.

$$W_{inside} = F * l$$

$$\Rightarrow W_{inside} = H * l \quad \text{---(i)}$$

According to work law,

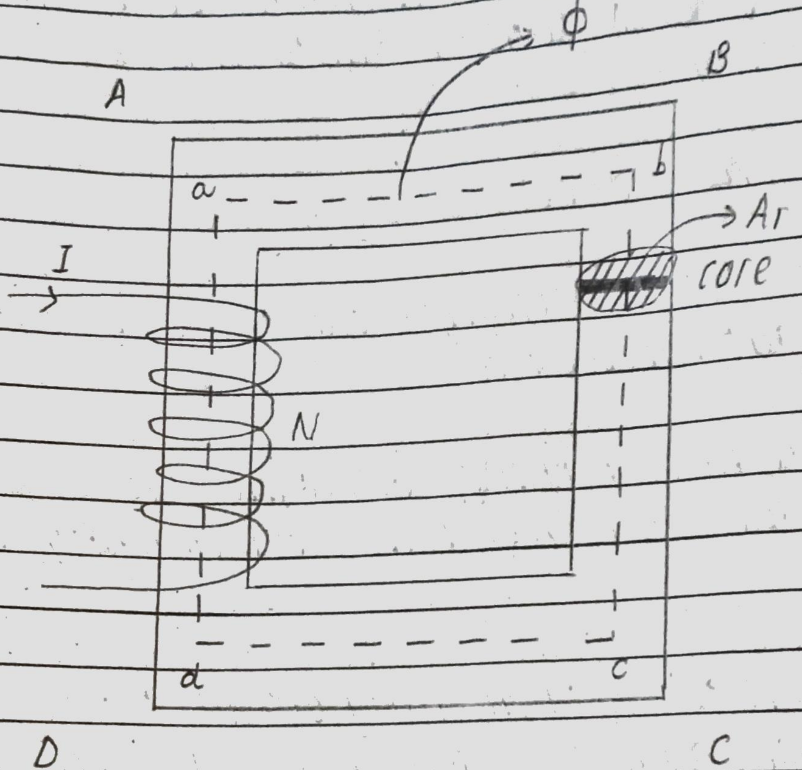
$$W = NI \quad \text{---(ii)}$$

From eqn(i) and (ii),

$$H * l = NI$$

$$\boxed{\therefore H = \frac{NI}{l}}$$

Magnetic circuits



consider a magnetic circuit having rectangular core as shown in figure. let A_r be the area of cross-section of the core and a winding having N turns is placed on the core through which current I is flowing, due to which flux ϕ is set up in the core. let the mean length of the magnetic circuit be 'l'.

then,

Magnetic flux density

$$B = \frac{\phi}{A} \ (Wb/m^2)$$

Magnetic field intensity inside the core is given by,

$$H = \frac{NI}{l}$$

Relation between B and H is,

$$B = \mu H$$

or, $B = \mu_0 \mu_r H$

or, $\dfrac{\phi}{A} = \mu_0 \mu_r \dfrac{NI}{l}$

or, $\phi = \mu_0 \mu_r \dfrac{NI}{l} A$

or, $\phi = \dfrac{NI}{\dfrac{l}{\mu_0 \mu_r A}}$

$$\boxed{\therefore \phi = \frac{mmf}{S}}$$

where,

NI = mmf (magneto motive force) which drives the flux in the magnetic circuit

$\dfrac{l}{\mu_0 \mu_r A} = S$ = Reluctance opposes the magnetic flux