Magneto Statics

Magnetic field: The space around in which its magnetic influence extends is known as magnetic field.

Intensity of magnetisation = $\frac{\text{Magnetic moment}}{\text{Volume}}$

$$I = \frac{M}{V}$$

for uniform cross section,

$$I = \frac{m}{a} \; wb/m^2$$ pole strength per unit area

Permeability:

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

B - magnetic induction

H - magnetising field

$\mu_a = \mu_0 \times \mu_r$

$\mu_a \rightarrow$ absolute permeability, $4\pi \times 10^{-7}$ Henry/metre

$\mu_0 \rightarrow$ permeability of free space

$\mu_r \rightarrow$ relative permeability of the medium

Flux density:

Total no. of lines of force per unit area due to the magnetising field and due the field induced in the substance

flux wb/m^2.

Magnetic Susceptiblity:

$I \propto H$ → magnetising field.

↓

intensity of magnetisation

$I = KH$

$$\boxed{K = \frac{I}{H}}$$

Magnetic potential:

* A magnetic field can be described in terms of magnetic field intensity. It is a vector quantity.

* To find the magnetic field intensity at a point due to a number of magnetic poles we have to find the field intensity due to individual pole and then to add intensities vectorially. To avoid this magnetic field can be represented using a scalar quantity called magnetic potential.

* Consider a magnetic north pole of strength m situated in free space. A magnetic field exists all around the magnetic pole.

* close to the pole, the field will be greater, and at a larger distance the field will be less. Beyond a certain distance from the pole, the field reduces to zero. This distance from the pole is considered as infinity in magnetism.

* Suppose it is required to take a unit north pole from infinity to a point inside, a certain amount of work has to be done against the repulsive force of the magnetic field.

The work done is the magnetic potential at that point.

* Magnetic potential is normally denoted by the symbol V and its unit is Joule/weber.

* If ω_A is the joule of work done in moving a unit north pole from infinity to a point A, the potential at A is ω_A Joule/weber.

* Similarly the potential at a point B is ω_B Joule/weber, if the workdone in moving north pole from infinity to B is ω_B joule. The difference in potential between the two points is $(\omega_B - \omega_A)$ joule/weber.

* Hence the magnetic potential at a point is defined as the amount of workdone in joule, in moving unit north pole from infinity to that point.

* The magnetic potential at any point is independent of the path taken in bringing the unit north pole from infinity to that point.

Magnetic properties of Materials

Faraday classified the magnetic material into three types according to their magnetic property. They are,

(i) Diamagnetic
(ii) Paramagnetic and
(iii) Ferromagnetic.

* When a magnetic material is placed in an intense magnetic field, it will experience a force. For a large number of ordinary substances the force observed is small. In addition, the force may be upwards for some substances and downward for some others. Some substances are pulled in the direction of increasing field intensity, others in the direction of decreasing field intensity, irrespective of the field direction.

* Substances like bismuth that are repelled from the high field region are called diamagnetic.

* Substances that are attracted towards the high field region are called Paramagnetic.

* Besides dia and para magnetic substances, there is another class of material like iron, nickel, cobalt etc., which experience a very strong force in the magnetic field. These substances are called ferromagnetic.

Diamagnetic substances:

* The substance which when placed in a magnetic field acquire feeble magnetisation in a direction opposite to that of the applied field are called diamagnetic substances.

* The phenomenon of diamagnetism is independent of the temperature of the substances.

* Bismuth, antimony, water, alcohol and hydrogen are diamagnetic substances.

Properties of diamagnetic substances:-

(i) When a diamagnetic substance is placed in a uniform magnetic field, it sets at right angle to the direction of the applied field.

(ii) When a diamagnetic substance is placed in a non-uniform magnetic field, it moves from stronger to weaker part of the field.

Properties of paramagnetic substances:

(i) When a paramagnetic substance is placed in a uniform magnetic field, they rotate until their longest axis is parallel to the field. When a paramagnetic gas is allowed to ascend between pole pieces of a magnet, it spread parallel to the field.

(ii) When a paramagnetic substance is placed in a non-uniform magnetic field, it moves from ~~stronger~~ weaker part of the field to stronger region of the field.

(iii) When a paramagnetic substance is placed in a magnetic field, the lines of force tend to concentrate through the body of the substance. Thus the permeability μ for a magnetic substance is slightly greater than one. For aluminium and platinum μ is 1.000022 and 1.000036 respectively.

(iv) The magnetic susceptiblity is small ~~positive~~ value. For aluminium and platinum k is 1.76×10^{-6} and 2.88×10^{-6} respectively.

(v) The susceptiblity varies inversely as the absolute temperature. Its value decrease with increase in temperature. At higher temperatures its value become negative and substances becomes diamagnetic.

(iii) When a bar of diamagnetic material is placed in a magnetic field, it develops induced poles in a direction opposite to the inducing field.

* These lines force thus try to avoid passing through the magnetic ~~field~~ material, but would pass through the surrounding air. Thus the permeability μ for a diamagnetic substance is less than one but positive.

(iv) Diamagnetic substances are repelled by a magnet. Thus they exhibit negative magnetic susceptiblity.

(v) The magnetic susceptiblity of diamagnetic material is independent of its temperature.

Paramagnetic substances:

The substance which when placed in a magnetic field acquire a feeble magnetism in the same sense as the applied field are called paramagnetic substances.

Platinum, aluminium, manganese, chromium and oxygen are all paramagnetic substances.

Ferromagnetic substances:

Ferromagnetic substances are characterised by the fact that they are strongly attracted by magnet. In comparison to the paramagnetic substances, they are distinguished by high degree of alligmment of atomic poles.

* The magnetisation of dia and paramagnetic exist only in the presence of an external field. The magnetisation of ferromagnetics is retained even in the absence of external field.

Iron, steel, nickel are examples of ferromagnetic materials.

Properties of Ferromagnetic substances:

(i) When a ferro magnetic substance is placed in a uniform magnetic field, the length side align parallel to the magnetic field.

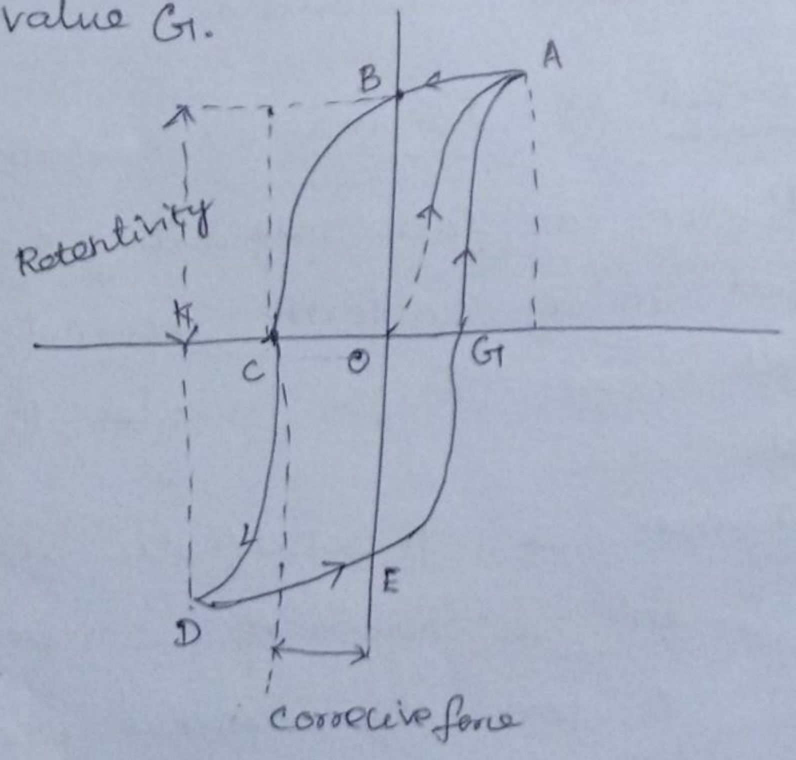
(ii) When a paramagnetic substance is placed in a non-uniform magnetic field, it moves from the weaker region to a stronger region.

(iv) The value of susceptiblity is very large and positive.

(v) The susceptiblity remains constant for small value of H and for moderate value of H, the value of I increases rapidly with H and for large value attains a constant value. Hence the value of K increases for moderate value of H and for large value of H, it decreases.

Hysteresis curves:

To take a specimen, through a cycle of magnetisation of H is gradually increased from O to G. Increased in reverse direction to K, decreased again to O and finally brought back to value G.



The initial magnetization is along the path OA. when H is changed from G to k and back again G the values of I changes along the path ABCDEFA which gives I-H' curve for the material.

Ballistic galvanometer method:

* In this method a specimen of the given magnetic material is taken in the form of a ring.

* The Primary winding P_1 on the specimen is an endless solenoid (toroid) and this winding is connected in series with a battery B, rheostat R and an Ammeter A through a reversing key k. The Primary winding has a number of resistances $R_1, R_2, R_3 \ldots$ etc. connected in series. Each of these resistances is provided with a short circuiting key

* the Secondary winding S_1 over the specimen consists of few turns of closely wound wire.

* This winding S_1 is connected in series with rheostat R_g, a ballistic galvanometer and the secondary winding S_2 of the standard solenoid. k_g is the damping key across the ballistic galvanometer. The Primary winding of the standard solenoid is connected in series with a battery B', a rheostat R', a battery B' and an Ammeter A' through a reversing key k'.

* Initially, before noting the readings, the key is closed, the resistances R_1, R_2 etc. are all short circuited and the position of the rheostat R is suitably adjusted so as to obtain full scale deflection. The position is kept fixed for the rest of the experiment. The position of R is kept fixed for the rest of the experiment.

* To bring the specimen to characteristic state, the current is reversed 20 to 30 times. The process is repeated by including the resistance R_1 R_2 etc in the circuit in succession until the current is

finally zero This initial diamagnetisation very essential.

Number of turns of primary windings = n_1 turns per metre

Total number of turns of the windings S_1 = n_1 turns

Number of turns of the windings P_2 = n_2 turns per metre

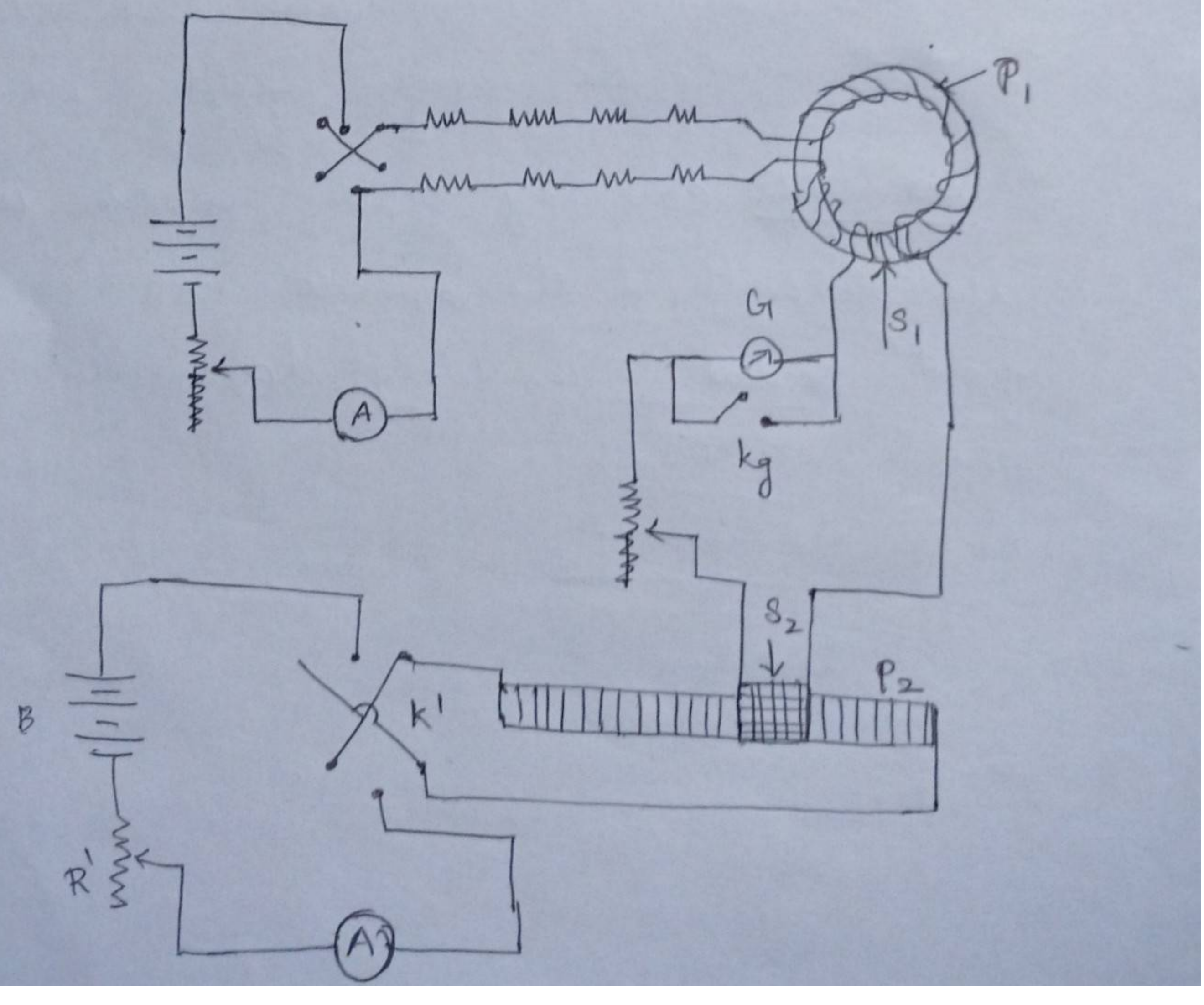
Total number of turns of the windings S_2 = n_2 turns

Area of cross-section of the specimen = A sq metre

Area of cross-section of the standard solenoid = a sq metre

Constant of the ballistic galvanometer = k

Logarthimic decrement = λ



Definitions:

(i) Hysteresis:

When a magnetic material is taken through a cycle of magnetisation, the intensity of magnetisation and magnetic induction lag behind the magnetising field. Thus, even if the magnetising field made zero the value of I and B are not zero and there is a tendency in the material to retain its magnetic property. This lagging of I and B behind H is called hysteresis.

(ii) Retentivity (or) remanence of a material is the residual intensity of magnetisation left in the specimen when the magnetic field is cut-off.

(iii) Corecivity: Coreivity of a material is the strength of the reverse magnetic field needed to completely diamagnetise the specimen.

Calculation of H:

The intensity of the magnetising field

$$H_0 = n_1 I_0 \text{ amp turns/metre} \rightarrow (1)$$

where I_0 amperes is the minimum current through the primary winding of the specimen. Different values of magnetising field H_1, H_2 etc. can be obtained by increasing the current in steps (ie) I_1, I_2 etc, This can be done by excluding the resistances R_1, R_2 etc, in the circuit session.

Calculation of B:

The magnetic induction of the specimen in the different values of H can be calculated as follows. To start with all the keys K_1, K_2 etc are removed so that the current I_0 through the circuit in minimum. The corresponding deflection θ_0 of the ballistic galvanometer is noted. If the magnetic ~~deflection~~ induction B_0 the change in flux $= B_0 A n_2$ and the charge that passes through the ballistic galvanometer

$$= \frac{B_0 A n_2}{R} = k_0 \theta_0 \left(1 + \frac{\lambda}{2}\right) \rightarrow (2)$$

where R is the total resistance of the galvanometer circuit.

Determination of galvanometer constant:

To determine the galvanometer constant, the key k is opened, and k' is closed. The rheostat R' is adjusted for a current I' ampere through the primary winding P_2 of the standard solenoid. Then the magnetic intensity along the axis of this solenoid = $n_2 I'$.

The change in magnetic flux produced when the current changes from 0 to I' through P_2

$= \mu_0 n_3 I' a \times n_4$

If θ' is the observed throw, then

The charge that passes through the galvanometer

$$= \frac{\mu_0 n_3 n_4 I' a}{R}$$

$$\therefore \frac{\mu_0 n_3 n_4 I' a}{R} = k\theta'\left(1+\frac{\lambda}{2}\right) \rightarrow (iii)$$

$$k = \frac{\mu_0 n_3 n_4 I' a}{R\theta'\left(1+\frac{\lambda}{2}\right)} \rightarrow (iv)$$

Substituting this value of k in eqn. (ii)

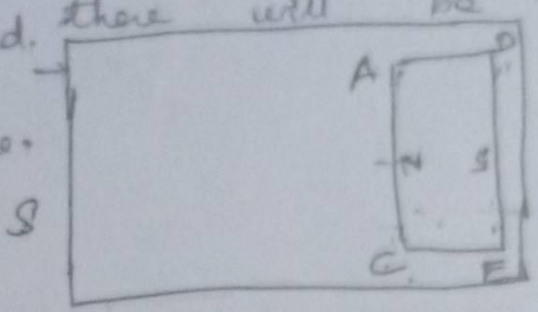
$$B = \frac{\mu_0 n_3 n_4 I' a}{A n_2}\left(\frac{\theta_0}{\theta'}\right) \text{ weber/metre}^2 \rightarrow (v)$$

$$\boxed{B = \mu_0 [H + I]}$$

From the above equation B values calculated and B-H can be drawn.

Releation between H, I and B

when a magnetic material is placed in a uniform magnetic field. there will be a redistribution of magnetic lines of force.



The cavity in the figure exhibits magnetic property due to magnetistion of the specimen.

let, I be the intensity of magnetisation

H - magnetising field.

then,

$$B = \mu_0 H a$$

↓ mag. induction

μ_0 - permeability of free space

lines of induction in this region

$$B = \mu_0 H a + I a$$

magnetic induction $B = \frac{\mu_0 H a + I a}{a}$

$$= \frac{a(\mu_0 H + I)}{a}$$

$$\boxed{B = \mu_0 H + I}$$

Relation b/w μ and K :

$$B = \mu_0 H + I$$

dividig bothsides by H

$$\frac{B}{H} = \frac{\mu_0 H}{H} + \frac{I}{H}$$

$$\frac{B}{H} = \mu_0 + \frac{I}{H}$$

$$\mu_a = \mu_0 + \frac{I}{H}$$

$$\boxed{\mu_a = \mu_0 + K}$$

$\div$ by μ_0

$$\mu_a = \mu_0 \times \mu_r$$

$$\mu_r = \frac{\mu_a}{\mu_0}$$

$$\frac{\mu_a}{\mu_0} = \frac{\mu_0}{\mu_0} + \frac{K}{\mu_0}$$

$$\boxed{\mu_r = 1 + \frac{K}{\mu_0}}$$

in vacum $K = 0$

$$\mu_r = 1$$