UNIT3

Chapter1 **DIELECTRIC PROPERTIES**

Dielectrics are non metallic materials of high specific resistance, negative temperature coefficient of resistance and large insulation resistance.

Dielectrics are of two types

(i) Polar dielectrics

(ii) Non polar dielectrics

(i) **Polar dielectrics:** these dielectric molecules will not have centre of symmetry here the centers of positive and negative charges will not coincide and hence it possess a net dipole moment in it.

Ex: H_2o, N2o, Hcl

Effect of electric field:

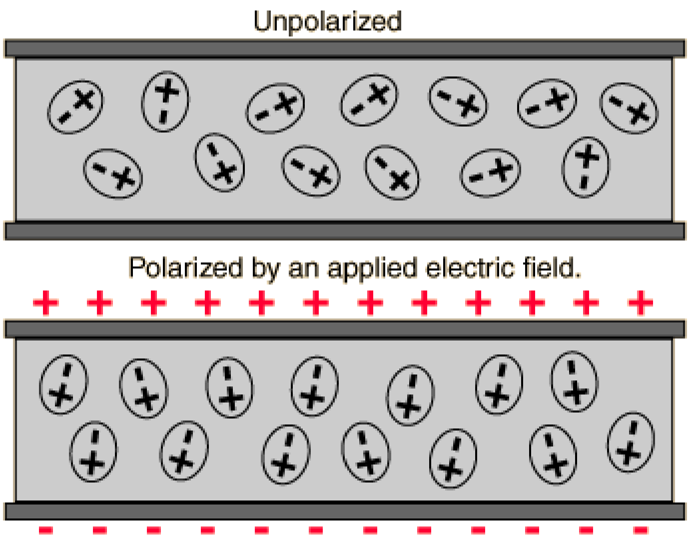
In the absence of electric field: in the absence of electric field the polar dielectric molecules themselves posses some dipole moment .but since these dipole are randomly oriented they cancel each other and the net dipole moment will be very very less

In the presence of electric field: now when an external electric field is applied to the polar dielectric molecule the dipole will align themselves parallel to the field direction and produce a net dipole moment.

(ii) **Non polar dielectricss:** these dielectric molecule posses centre of symmetry and hence the centres of positive and negative charges coincide. Therefore the net charges and net dipole moment of these molecule will be zero hence these non polar molecules will not posses any dipole moment in it.

Ex: $N_{2,}$ H2, O2, CO2

Effect of electric field: when non polar molecule is placed in an external electric field a force is exerted on each charge particle within the molecule i.e. the positive charges are pushed along the field direction and the negative charges are pushed opposite to the filed direction. Hence the positive and negative charges separated by some distance from their equilibrium position, creating a dipole and therefore net dipole moment will be produced in non polar molecule.



Electric dipole:two equal and opposite charges small in magnitude and separated by a small distance constitute a electric dipole.

Dipole moment: if two charges +q and –q are separated by a distance l than the dipole moment can be defined as product of magnitude of charges and distance between them.

μ =q.l

- it is a vector quantity
- the direction of μ is from negative to positive

Dielectric constant ε_r: dielectric constant is the ratio between the permittivity of the medium and the permittivity of the free space

$\varepsilon_r = \frac{\varepsilon}{\varepsilon_o}$

- since it is the ratio of same quantity ε_r has no units

Electric polarization : let us consider an atom placed inside an electric field the centre of positive charge is displaced along the applied field direction while the centre of negative charge is displaced in the opposite direction.thus a dipole is produced when a dielectric material is placed inside an electricfield such dipoles are created .

This process of producing electric dipoles which are oriented along the field direction is called polarization in dielectrics.

Polarizability(α) when the strength of the electric field E is increased the strength of the induced dipole μ is also increases . thus the induced dipole moment is proportional to the intensity of the electric field

μ =αE where α the constant of proportionality is called polarizability.

It is defined as induced dipole moment per unit electric field.

$$\alpha = \frac{\mu}{E}$$

Polarization vector (P) :the dipole moment per unit volume of the dielectric material is called polarization vector P

$$P = \frac{\mu}{V}$$

If μ is the average dipole moment per molecule and N is the number of molecules per unit volume the polarization vector

$$P = N\mu$$

The diple moment per unit volume of the solid is the sum of all the individual dipole moment with in that volume and is called polarization P of the solid.

Electric displacement vector (D) or electric flux density

The electric displacement vector is a quantity which is a very convenient function for analyzing the electrostatic field in the dielectrics and is given by

$\vec{D} = \frac{Q}{4\pi r^2}$ ------------- 1

We know that electric field intensity

$\vec{E} = \frac{Q}{4\pi r^2}$ -----------------2

From 1 and 2

$\vec{D} = \varepsilon \vec{E}$

D=$\varepsilon_0 \varepsilon_r$E--------------------3

Relation between P and E

D=ε_oE+P----------------------4

From 3 D=$\varepsilon_O \varepsilon_r$E

Therefore equ 4 becomes

$\varepsilon_O \varepsilon_r$E=$\varepsilon_o$E+P

P=$\varepsilon_O E(\varepsilon_r$- 1)

Electricsusceptability$\boldsymbol{\varphi}$ The polarization vector (P) is proportional to the applied electric field (E) and is in the same direction of E

P=$\varepsilon_O \boldsymbol{\varphi}$E------------1

Where the constant $\boldsymbol{\varphi}$ is refered as the electric susceptibility

From 1 $\boldsymbol{\varphi}=\frac{\boldsymbol{P}}{\varepsilon_O E}$

But P=$\varepsilon_O E(\varepsilon_r$- 1)

$\boldsymbol{\varphi}=\frac{\varepsilon_O E(\varepsilon_r -)}{\varepsilon_O E}$ = $\boxed{\boldsymbol{\varphi} = (\varepsilon_r - 1)}$

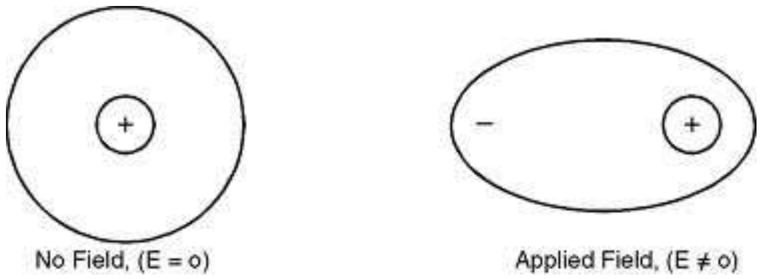
Various polarization process

Polarization occurs due to several atomic mechanisms. When the specimen is placed inside d.c electric field polarization is due to four types of process

1. Electronic polarization
2. Ionic polarization
3. Orientational polarization
4. Space charge polarization

Electronic polarization and calculation of electronic polarizability

Electronic polarization occurs due to the displacement of positively charged nucleus and negatively charged electron in opposite direction when an external field is applied and there by creates a dipole moment in the dielectric



Therefore induced dipole moment μ=α_eE

Where α_e is the electronic polarizability

- Electronic polarizability is proportional to the volume of atoms
- Electronic polarizability is independent of temperature.

Calculation of electronic polarizability

(i)Without field

Let us consider a classical model of an atom .assume the charges of the nucleus of that atom is

+Ze the nucleus is surrounded by an electron cloud of charge –Ze which is distributed in sphere of radius R

The charge density of the charged sphere = $\frac{-Ze}{\frac{4}{3}\pi R^3}$

Charge density $\rho = \frac{-3}{4}\frac{Ze}{\pi R^3}$-------------------1

(II) with field

When the dielectric is placed in a d.c electric field E two phenomena occur

(a) Lorentz force due to the electrc field tends to separate the nucleus and the electron cloud from their equilibrium position.
(b) After the separation an attractive coloumb force arises between the nucleus and electron cloud which tries to maintain the original equilibrium position.

Let x be the displacement made by the electron cloud from the positive core .since the nucleus is heavy it will not move when compared to the movement of electron cloud here $x<<R$, where R is the radius of the atom.

Since the Lorentz and coloumb forces are equal and opposite in nature equilibrium is reached.

At equilibrium lorentzforce =coulomb force

Lorentz force = charge × field

$$= -ZeE \text{--------------} 2$$

The negative sign indicates the repulsive forces

Coulomb force=charge × field

$$= +Ze\times\frac{Q}{4\pi\varepsilon_O\ x^2}$$ the positive sign indicates the attractive force

Therefore coloumb force= charge $\times\frac{total\ negative\ charges(Q)enclosed\ in\ the\ sphere\ of\ redius\ x}{4\pi\varepsilon_O\ x^2}$------------3

Here the total number of negative charges (Q) encloses in the sphere of radius

X=charge density of the electron × volume of the sphere ---------------4

Substitute ρ from 1 and 4 we get

$$Q=\frac{-3}{4}\ \frac{Ze}{\pi\, R^3}\times\frac{4}{3}\ \pi x^3$$

(a) $Q=\frac{Zex^3}{R^3}$ -------------------------------5

Substitute Q from 5 in 3 we get

$$\text{Coloumb force} = \frac{Ze}{4\pi\varepsilon_O\ x^2}\left(\frac{Zex^3}{R^3}\right) \text{----------} 6$$

At equilibrium Lorentz force= coulomb force

-ZeE= $\frac{Z^2 e^2 x}{4\pi\varepsilon_o R^3}$

X= $\frac{4\pi\varepsilon_o R^3 E}{Ze}$---------------------------------7

Therefore the displacement of electron cloud x is proportional to the applied electric fieldE

Dipole moment:now the two electrc charges +Ze and –Ze are displaced by a distance under the influence of the field and form a dipole.

Induced dipole moment =magnitude of charge $\times$ displacement

= Zex-----------8

Substitute the value of x from 7 in 8 we have

μ_e= Ze $\times \frac{4\pi\varepsilon_o R^3 E}{Ze}$

$\mu_e = 4\pi\varepsilon_o R^3 E$

$\mu_e = \alpha_e$E--------------------------------9

$\alpha_e = 4\pi\varepsilon_o R^3$ is called electronic polarizability

Chapter4 **MAGNETIC PROPERTIES**

Magnetic dipole moment:A system having two opposite magnetic poles separated by a distance d is called as a magnetic dipole.If m is magnetic pole strength and l is the length of the magnet then its dipole moment is

$$M = m \times l$$

Magnetic induction (or)Magnetic flux density(B)=The magnetic induction in any material is the number of lines of magnetic force passing through unit area perpendicularly.

Its nits is weber/m^2or tesla

Magnetic field intensity(or)strength(H)=Magnetic field intensity at any point in the magnetic field is the force experienced by an unit north pole placed at thet point.

Its units is ampere m^{-1}

The magnetic induction B due to a magnetic field of intensity (H) applied in vaccum is related by

$$B = \mu_0 \mathrm{H}$$

Where μ_0 is the permeability of free space (vaccum)=$4\pi \times 10^{-7}$H m^{-1}

Instead in vaccum if the field is applied in a medium the magnetic induction in the solids is given by

B=μH where μ is permeability of the solid material through which the magnetic lines of force pass.

Magnetic permeability(μ)=magnetic permeability of any material is the ratio of the magnetic induction in the sample to the applied magnetic field intensity.

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

relative permeability(μ_r)=it is the ratio between the permeability of the medium to permeability of the free space

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

Magnetization (or)intensity of magnetization(I)=the term of magnetization is the process of converting a non magnetic material into a magnetic material .it measures the magnetization of the magnetized

It is also defined as the magnetic moment per unit volume

$I = \frac{\mathrm{M}}{\mathrm{V}}$ Its units is ampere m^{-1}

Magnetic susceptibility(x)=the ratio of intensity of magnetization (I) produced to the magnetic field strength (H) in the which the material is placed

$x = \frac{\mathrm{I}}{\mathrm{H}}$ Type equation here.

Relation between μ_r and x

B=μH or $B = \mu_0\mu_r \mathrm{H}$

$B = \mu_0\mu_r \mathrm{H} + \mu_0\mathrm{H} - \mu_0 \mathrm{H}$

$$B = \mu_0 \mathrm{H} + \mu_0 \mathrm{H}(\mu_r - 1)$$

$B = \mu_0\mathrm{H} + \mu_0\mathrm{I}$ where I= $\mathrm{H}(\mu_r - 1)$

So $B = \mu_0(\mathrm{H} + \mathrm{I})$

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

Relative permeability $\mu_r = \frac{\mu}{\mu_0}$

$= \frac{\mathrm{B}}{\mathrm{H}} \times \frac{\mathrm{H+I}}{\mathrm{B}}$

$= 1 + \frac{\mathrm{I}}{\mathrm{H}}$

$$\boxed{\mu_r = 1 + \mathbf{x}}$$

Classification of magnetic materials:

By the application of magnetic field some materials will not show any effect that are called non magnetic materials and those which show some effects are called magnetic materials

All magnetic materials magnetized in an applied external magnetic field.

Depending on the direction and magnitude of magnetization and also the effect of temperature on magnetic properties,all magnetic materials are classified into dia,para and ferromagnetic materials.

Two more classes of material have structure very close to ferro magnetic materials,but posses quiet different magnetic properties.They are anti-ferro magnetic and ferromagnetic materials.

Diamagnetism:

The number of orientations of electronic orbits in an atom be such that vectoe sum of magnetic moment is zero

The external field will cause a rotation action on the individual electronic orbits this produces an induced magnetic moment which is in the direction opposite to the field and hence tenda to decrease the magnetic induction present in the substance.Thus the diamagnetic is the phenomena by which the induced magnetic moment is always in the opposite direction of the applied field.

Properties of diamagnetic materials

1 Diamagnetic material get magnetized in a direction opposite to the magnetic field.

2 Weak repulsion is the characteristic of diamagnetism

3 permanent dipoles are absent

4 Relative permeability is less than one but positive

5 The magnetic susceptibility is negative and small.It is not effected by temperature.

6 Diamagnetism is universal i.e all materials when exposed to external magnetic fields,tend to develop magnetic moments opposite in the direction to the applied field.

7 When placed inside a magnetic field, magnetic lines of force are replaced as

Paramagnetism

The number of orientations of orbital and spin magnetic moments be such that he vector sum of magnetic moment is not zero and there is a resultant magnetic moment in each atom even in the absence of applied field.

The net magnetic moments of the atoms are arranged in random directions because of thermal fluctuations ,in the absence of external magnetic field.Hence there is no magnetization.

If we apply the external magnetic field there is an enormous magnetic moment along the field direction and the magnetic induction will be increase.Thus induced magnetism is the source of paramagnetism.

Preperties of paramagnetism materials:

1 paramagnetic materials get magnetized in the direction of the magnetic field.

2 Weak attraction is characteristic of paramagnetism

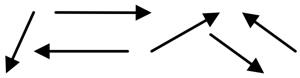
3 paramgnetic material posses permanent magnetic dipoles.

4 Relative permeability is greater than one but small i.e this indicate that when paramagnetic substance is placed in a uniform magnetic field the field inside the material will be more than the applied field.

5 The magnetic susceptibility is small and positive the magnetic susceptibility of paramagnetics is inversely proportional to absolute temperature

i.e x=C/T this is called curie law ,c is calles curie constant

6 Paramagnetic susceptibility is independent of the applied field strength.

7 Spin alignment is random 

8 When placed inside a magnetic field it attracts the magnetic lines of force

9 Some of the material which exhibit the paramagnetism are aluminium,manganese ,oxygen.

Ferromagnetism:

Ferromagnetism arises when the magnetic moments of adjacent atoms are arranged in a regular order i.e all pointing in the same direction .The ferromagnetic substance thus posses a magnetic moment even in the absence of the applied magnetic field ,this magnetization is known as the spontaneous magnetization

There is a special form of interaction called “exchange “coupling occurring between adjacent atoms ,coupling their magnetic moment together in rigid parallelism.

Properties of ferromagnetic materials

1 In ferromagnetism materials, large magnetization occurs in the direction of the field.

2 Strong attraction is the characteristic of ferromagnetism.

3 They posses spontaneous magnetization.

4 The relative permeability is very high for Ferro magnetic.

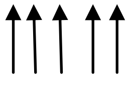
5 The magnetic susceptibility is positive and very high.

6 Magnetic susceptibility is fairly high and constant up to a certain temperature according the equation

X=$\frac{C}{T-T_C}$ C= curie constant T_C = Curie temperature

7 Ferromagnetism is due to the existence of magnetic domains which can be spontaneously magnetized.

8 Exhibit hysteresis.

9 Spin alignment is parallel in the same direction

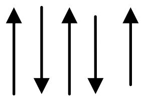
10 When placed inside a magnetic field it attracts the magnetic lines of forces very strongly

11 Permanent and electro magnetic are made using ferromagnetic materials.

12 Example iron, nickel, cobalt.

Antiferro magnetism

Anti ferromagnetism arises when the spin magnetic moment of neighbouring atoms are oriented in an antiparllel order



In the absence of external external magnetic field the magnetization of anti ferro magnetic specimen will be zero,because of anti parallel and equal spin magnetic moment.

By the application of the external magnetic field a small magnetization in the direction of the applied magnetic field takes place this magnetization varies with temperature as shown

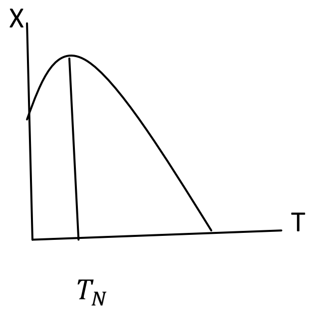
The susceptibility increases with an increase of temperature upto T_N called as neel temperature

At neel temperature the magnetization or susceptibility is maximum and above it the magnetization decreases with increasing temperature according to the relation

X= $\frac{C}{T+\theta}$,C =is curie constant θ=paramagnetic curie temperature

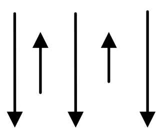
The decrease of magnetization with an increase of temperature is a property of of the paramagnetic substance,therefore the specimen becomes paramagnetic above T_N

Examples Mno,Nio,Feo,Mns etc



Ferrimagnetism and property of ferromagnetic materials(ferrites)

Ferrimagnetic substance are those in which the atomic or ionic dipoles in one diection are of unequal magnitudes ,this alignment of dipole gives a net magnetization and is the property of those magnetic substance which have two or more different kind of atoms.



In ferri magnetic materials there may be large net magnetization as compared to anti Ferro magnetic materials, due to the resultant of anti parallel alignment of neighboring dipoles of unequal magnitudes.

Ferrimagnetic materials generally known as ferrites consist of two or more different kind of atoms their formula is $M_e^{++}Fe_2^{++}O_4^{--}$

Where M_e^{++} stands for a suitable divalent metal ion such as Fe^{++}, CO^{++}, Ni^{++}, Mg^{++}, etc, Fe_2^{++} is a trivalent ferric ion. The magnetization of ferromagnetic material material can be understood by taking one of the materials as an example say ferrous ferrite

(i) In ferrous ferrite we have two types of ions i.e. Fe^{+3} , Fe^{+2}

(ii) hereFe^{+2} iona has six electrons in 3d sheels out of 6 electrons two electrons are paired with each other and hence left with 4 unpaired electrons
Therefore Fe^{+2} gives rise to 4 Bohr magneton

(iii) Fe^{+3} ions has five electrons in 3d shell and hence all these 5 are unpaired electrons

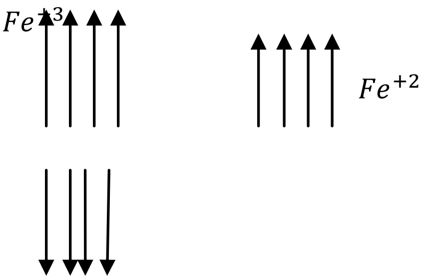
Therefore Fe^{+3} give rise to 5 Bohr magneton

Since we have two Fe^{+3},totally the Fe^{+3} give rise to 2x5=10 bohe magneton

Therefore total magnetization of Fe^{+3} + Fe^{+3}=4+10+14 bohr magneton.

Theoretically we get 14 μB(bohr magneton) but experimentally the total magnetic moment is only 4.08μB.The reason is if all the spins are aligned parallel then we get the total magnetization as 14μB

But in ferrites half of the magnetic spins of Fe_2^{3+} ions are parallel to one direction and the remaining half of Fe_2^{3+} ions are parallel in opposite direction as shown in fig hence they cancel each other.



Therefore net magnetic moment is only due to Fe^{+2} ions alone i.e .hence we get the total magnetization as 4μB which is a good agreement with the experimental value.

Application of ferrites(ferromagnetic substance)

1 They are used to produce ultrasonics by magnetization principle.

2 Ferrites are used in audio and video transformers.

3 Ferrites rods are used in radio receivers to increase the sensitivity.

4 They are also used for power limiting and harmonic generation.

5 Ferrites are used in computers and data processing circuits

6 ferrites are used in switching circuits and in storage devices of computers.

7 Ferrites are not metals but their resistivity lies in the range of insulators or semiconductors.

Explanation of hysteresis curve based on domain theory of ferromagnetism:

Domain theory of ferromagnetism

According to Weiss a virgin specimen of ferromagnetic material consist of a number region or domains which are spontaneously magnetized .In each domain spontaneous magnetization is due to parallel alignment of all magnetic dipoles

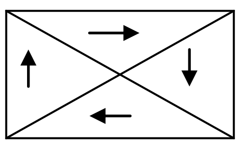
The direction of spontaneous magnetization varies from domain to domain

The resultant magnetization may hence br zero or nerly zero

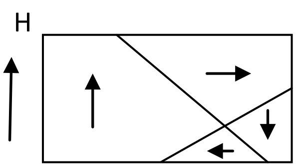
When an external field is applied there are two possible ways of alignment of domains

(i)**By motion of domain walls:** the volume of domains that are favourably oriented with the respect to the magnetizing field increases at the cost of those that are unfavourably oriented fig(b)

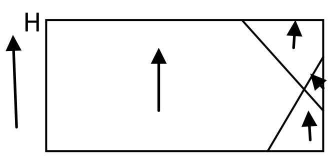
(ii)**By rotation of domains**:when the applied magnetic field is strong rotation of the direction of magnetization occurs in the direction of the field.fig(c)



Fig(a)

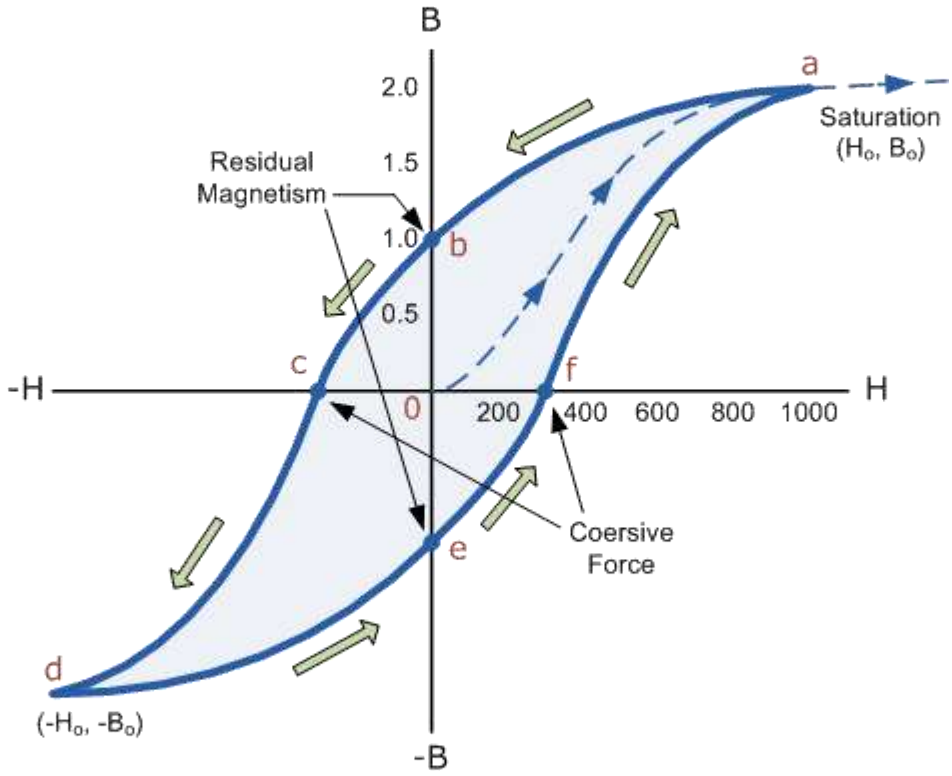


fig(b)



fig(c)

Hysteresis curves



Hysteresis : lagging of magnetization behind the magnetizing field(H)

We know when the ferro magnetic material is subjected to external field ,there is increase in the value of the resultant magnetic moment due to two process

(i)the movement of domain walls

(ii)rotation of domain walls

When a weak magnetic field is applied the domains are aligned parallel to the field and in the easy direction of magnetization grow in size at the expense of the less favourably oriented domains.

This result in the bloch wall (or)domain wall movement and when the weak field is removed the domains reverse back to their original state .this reversible wall displacement is indicated by OA the magnetization curve.

When the field becomes stronger han the domain wall movement continues and it is mostly reversible movement .this is indicated by path AB of the graph .the phenomena of hysteresis is due to the irreversibility.

At the point B all domains have got magnetized along their easy direction

Application of still higher field rotates the domains into the field direction indicated by BC.

Once the domains rotation is complete the specimen is saturated denoted by C.

Thus the specimen is said to be attain the maximum magnetization .at this position if the external field is removed (H=0),the magnetic induction B will not fall rapidly to zero ,but falls to D rather than O this shows that even when the applied field is zero the material still posses some magnetic induction(OD)which is called residual magnetism or retentivity.

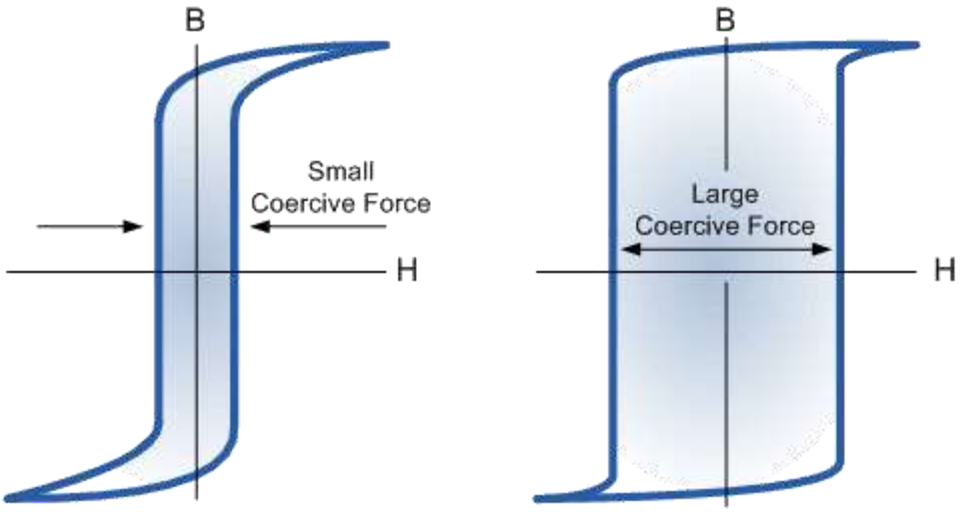
Actually after the removal of the external field the specimen will try to attain the original configuration by the movement of domain wall .But this movement is stopped due to the presence of impurities, lattice imperfections.

Therefore to overcome this a large amount of reverse magnetic field (H_c) is applied to the specimen .the amount of energy spent to reduce the magnetization (B) to zero is called “coercitivity” represented by OE in the fig.

HSTERESIS: lagging of magnetization (B) behind the magnetizing field (H) is called hysteresis.

Hysteresis loss: It is the loss of energy in taking a ferromagnetic body through a complete cycle of magnetization and this loss is represented by the area enclosed by the hysteresis loop.

Hard and soft magnetic materials: Based on the area of hysteresis, magnetic materials can be classified into hard and soft magnetic materials.



"Soft" Ferromagnetic Material

"Hard" Ferromagnetic Material

s

Hard magnetic materials	Soft magnetic materials
(i) Hard magnetic materials have large hyster- due	(i)Soft magnetic materials have low hysteresis loss
esis loss due to large hysteresis is loop area	to small hysteresis loop area.
(ii)in these material the domain wall movement relati-	(ii) in these materials the domain wall movement is

is difficult because of presence of impurities and crystal imperfection and it is irreversible in nature	vely easier .even for small changes in the magnetizing field magnetization changes by large amount.
(iii) The coercitivity and retentivity are large Hence these materials cannot be easily magne- Tised and demagnetized	(iii))the coercitivity and retentivity aresmall .these materials can be easily magnetized and demagnetized.
(iv)In these materials because of the presence of impuroties and crystal imperfection the mechanical strain is more hence magnetost atic energy is loss .	(iv)since these materials free from irregular the magnet ostatic energy is very small.
(v)these materials have small values of permea Bility and susceptibility.	(v)these materials have large values of permeability and Susceptibility.
(vi)they are used to make permanent magnets.	(vi)there are used to make electromagnets.
(vii)eample copper nickel iron alloys,copper nickel Cobalt alloys.	(vii)examples:iron silicon alloys,ferrous nickel alloys, Ferrites.
(viii)applications:for production of magnetic Detectors ,microphones,damping devices.	(vii)mainly used in electromagnetic machinery and And transformer cores.used in switching circuits ,microwave isolators.

Origin of magnetic moment.

In atoms the permanent magnetic moments can arises due to the following.

1 the orbital magnetic moment of the electrons

2 the spin magnetic moment of the electrons.

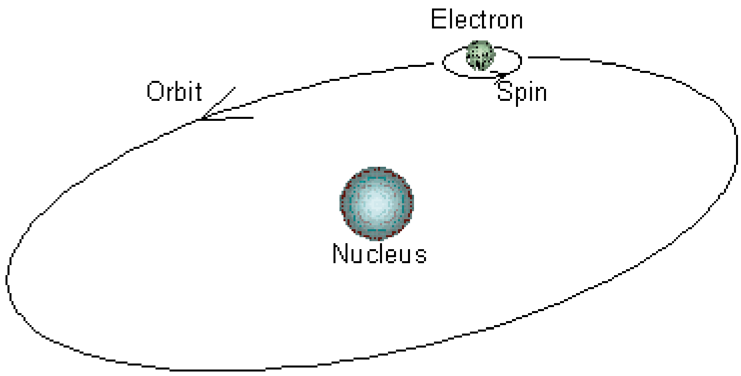
3 the spin magnetic moment of nucleus.

Orbital magnetic moment of the electrons and bohr magneton:

We know that in an atom electrons revolve round the nucleus in different circular orbits.let m be the mass of the electron and r the radius of the orbit in which it moves with angular velocity w

We can calculate the electric current due to the moving electron.

Current I=charge flow/unit time



= -e/T

Where T is the time taken for one revolution

I = $\frac{-e\omega}{2\,\pi}$ $\quad (T = \frac{2\pi}{\omega})$

We know that the current flowing through a circular coil produces a magnetic field in a direction perpendicular to the area of the coil and it is identical to a magnetic moment produced by such a dipole is

μ_m = I.A

$= \frac{-e\omega}{2\,\pi} \times \pi r^2$

$= \frac{e\omega r^2}{2} = \frac{e\omega r^2}{2} \times \frac{m}{m} = \frac{-e}{2m}$ L

Where L= mwr^2 is the orbital angular moment of the electron

The possible orientation of the angular momentum vector when placed in an external magnetic field

$L_{l,B} = m_l \times \frac{h}{2\pi}$

$\mu_m = \frac{-e}{2m} \times m_l \times \frac{h}{2\pi}$

$= \frac{-\,eh}{4\pi m} \times m_l =$

$\mu_m = -\,\mu_B \times m_l \qquad \mu_B = \frac{eh}{4\pi m}$ = bohr magneton.