

Chapter - I Dielectric properties

Introduction The dielectrics are the substances which don't contain free electrons under normal conditions. Insulators do not have free electrons or conduction electrons so that dielectrics are basically electrical insulating materials.

The dielectric materials are considered as materials in which electrostatic fields can persist for a long time. The dielectrics are electrically insulators, because electrons are bound to their parent molecule.

Examples of Dielectrics: Mica, glass, plastic, natural rubber, paper, bakelite, polymer materials, vegetable oils, transformer oil.

Importance of Dielectrics: The dielectric materials play a vital role in many electronic applications such materials in capacitors, ferroelectric, antiferroelectric, piezoelectric and magnetic materials.

[1] Explain the polarization mechanism in dielectrics?

Dielectrics exhibit the phenomenon of electronic polarization in the presence of the electric field and have high resistivities.

When an electric field is applied on dielectrics then the positive charges displace in the direction of the field, while negative charges are displaced in the opposite direction. The displacement of charges produce local dipoles throughout the solid

Electric polarization: The process of producing dipoles by the influence of an applied electric field is electric polarization in case of dielectrics.

Due to the polarization the +ve and -ve ions displaced, then dipoles will exist. Due to applied field the dipole moment will present. The process of polarization is contribution of electronic, ionic and orientational polarization.

When a dielectric is placed in an external field the polarized charges produce dipole momentum. There exist dipole moment on the presence of Electric field.

$$\text{P} \text{ is dipole moment} \quad P = \frac{q_i b}{A b} \quad q_i b = \mu_e \text{ electric dipole.}$$

The induced charge produce polarization $A b = \text{volume of slab.}$

The polarization may also be defined as the electric dipole moment per unit volume

$$\text{i.e. polarization } P = \frac{\mu_e}{V}; \vec{E}, \vec{D}, \vec{P} \text{ are related by } D = \epsilon_0 E + P$$

Consider an isolated atom is placed under E , the light electrons move much more than the heavy nucleus. Hence the centre of the electron cloud shifts in the opposite direction of E .

Due to the effect of an applied electric field on dielectric there exist displacement in between centres of +ve and -ve charge. So that due to the displacement of charge each atom becomes a dipole. The local field will developed individually

$$\text{Total polarization } P = N \alpha_t E$$

$$\text{where } \alpha_t = \text{Total polarizability} \quad \therefore \alpha_t = \alpha_e + \alpha_i + \alpha_o$$

where α_e is electronic polarizability; α_i = ionic polarizability; α_o = orientational polarizability

Due to presence of external field dipoles are rotate and tend to align in line with field E .

dielectric constant depend

α_e & α_i are independent of Temperature; on temperature

Some important definitions : (a) permittivity : permittivity is a quantity which represents the dielectric property of medium. permittivity of a material indicates the easily polarisable nature of material. It is denoted by ϵ

For vacuum ϵ is called permittivity of free space i.e. $\epsilon_0 = 8.854 \times 10^{-12} \text{ F/m}$ [Farad/meter]

(b) Relative permittivity : It is the ratio between the permittivity of medium and permittivity of vacuum
Denoted by $\epsilon_r = \frac{\epsilon}{\epsilon_0}$ [ϵ_r is constant for isotropic material]

(c) Dielectric constant (K) : The dielectric constant is defined as the ratio between the permittivity of that medium and permittivity of free space $K = \frac{\epsilon}{\epsilon_0} = \epsilon_r$
 K has no units

(d) Dielectric strength : It can be defined as the minimum voltage required to produce dielectric breakdown unit volt/meter

(e) polarization : The process of producing electric dipoles which are oriented along the field direction is called polarization. This phenomena observed with the effect of external field

(f) Polar molecules They have unsymmetrical structures and have permanent dipole moment

Examples H_2O , HCl , CO , N_2 , NH_3 etc. In case of these molecules the centres of gravity of +ve and -ve charges are separated

(g) Non polar molecules : These are having zero electrical dipole moment [H_2 , O_2 , CO_2 , C_6H_6]

In case of these molecules the centres of gravity of +ve and -ve charges coincide.

(h) Dipole moment $\mu = qd$ [where q is the magnitude of charge]
units for μ is coulomb-metre due separation of +ve and -ve charge]

(i) Polarizability It can be defined as the ratio of average dipole moment to the electric field applied
It is denoted by ' α ' $\therefore \alpha = \frac{\mu}{E}$ units (Farad m³)

(j) Polarization vector P : It is defined as the average dipole moment present per unit volume of a dielectric. It is denoted by P units Coulomb/m²

$P = N \mu$ when N : number of atoms present per unit volume; μ is averagedipole moment

(k) Electric displacement vector D : The number lines of forces received by unit Area is called flux density is denoted by electric displacement vectors. $\therefore D = \frac{q}{4\pi r^2 \text{ Area}}$: charge

Relation between E and D & K $E = \frac{1}{4\pi\epsilon} \frac{q}{r} \therefore D = \frac{q}{4\pi r^2} \therefore \frac{E}{D} = \frac{\frac{q}{4\pi r^2}}{\frac{q}{4\pi r^2}} = \frac{1}{\epsilon}$

$$\therefore \frac{E}{D} = \frac{1}{\epsilon} \Rightarrow D = \epsilon E \quad (1)$$

$$\text{But } \epsilon_r = \frac{\epsilon}{\epsilon_0} \Rightarrow \epsilon = \epsilon_r \epsilon_0 \rightarrow (2) \text{ from (1) } D = \epsilon_r \epsilon_0 E$$

$$D = \epsilon_r \epsilon_0 E \rightarrow (3)$$

$$\text{But } K = \epsilon_r \text{ Sub in (3)} \therefore D = K \epsilon_0 E \text{ For isotropic materials}$$

[2] with usual notation show that $P = \epsilon_0 (\epsilon_r - 1) E$ (or) obtain a relation between D, P, E for dielectrics (or) obtain a relationship between electric displacement vector D ; polarization P , applied electric field strength E . In case of dielectric material

For many of the crystal D varies non linearly with E

$$\therefore D = \epsilon E \rightarrow (1) \text{ But } \epsilon = \epsilon_r \epsilon_0 \therefore D = \epsilon_r \epsilon_0 E \rightarrow (2)$$

ϵ_r is equal to dielectric constant i.e $\epsilon_r = K$

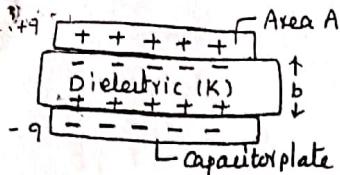
$$\therefore \text{eq(2) can be written as } D = K \epsilon_0 E \rightarrow (3)$$

$$\text{But polarization is defined as } P = \frac{(q_i)}{A} \hat{i} \rightarrow (4)$$

where q_i is the magnitude of the induced charge developed at and interior to the surface of Area 'A' of the dielectric

(14)

\hat{i} is a unit vector along the line joining negative and positive induced charges



Let us consider parallel plate capacitor placed by dielectric slab between the plates

Due to the external field exist dipole moment and the induced charges developed near the surfaces of parallel plates. There exist electric dipole moment (M_e)

The polarization $P = \frac{M_e}{V}$; D, E, P are related by $D = \epsilon_0 E + P$

$\therefore D = \epsilon_0 E + P \rightarrow (5)$ in this equation $D = K\epsilon_0 E$ substitute the value in (5)

$$\therefore K\epsilon_0 E = \epsilon_0 E + P \Rightarrow (K - 1)\epsilon_0 E = P \Rightarrow P = \epsilon_0(K-1)E \rightarrow (6)$$

But ϵ_r is equal to dielectric constant i.e. $\epsilon_r = K$.

$$\therefore \text{substitute } K = \epsilon_r \text{ in equation (6)} \therefore P = \epsilon_0(\epsilon_r - 1)E$$

Relation between electric polarization and electric susceptibility of the dielectric medium

$$\text{Electric polarization } P_e = NdeE$$

d is electron/c polarizability

N : is number of molecules per unit volume
in Dielectricity

The polarization generated by the separation

of the effective centre of the electron cloud from the nucleus of the atom is called the electronic polarization, it is denoted by P_e . $\therefore P_e = NdeE \rightarrow (1)$

$$\therefore \frac{P_e}{E} = \epsilon_0(K-1) \Rightarrow \left[\frac{P_e}{\epsilon_0 E} = (K-1) \right] \Rightarrow X_e = (K-1) \therefore P_e = \epsilon_0(K-1)E \rightarrow (2) \quad P_e = \epsilon_0(\epsilon_r - 1)E$$

$\therefore \frac{P_e}{\epsilon_0 E}$ is called the electric susceptibility of the dielectric medium

$$\therefore \left[\frac{P_e}{E} = \epsilon_0(K-1) \right] \text{ if } X_e \text{ is the electrical susceptibility of Dielectric material}$$

$$\therefore X_e = \{\epsilon(K-1)\} \therefore P_e = \epsilon(K-1)E$$

For vacuum $X_e = 0$

$$\therefore X_e = \{\epsilon(K-1)\} \text{ In case of vacuum } \epsilon = \epsilon_0$$

$$X_e = \{\epsilon_0(K-1)\} \rightarrow (3) \text{ but } K=1 \Rightarrow X_e = \epsilon_0[1-1] = 0$$

$$P_e = \epsilon_0 X_e E \rightarrow \text{Required Relation between } P_e \text{ & } X_e$$

Relation between susceptibility, Dielectric constant and ϵ_0 : $P = \epsilon_0(\epsilon_r - 1)E$

$$(or) \text{ Relation between } X, K, \epsilon_0 : X = \epsilon_0(K-1) \rightarrow (1) \quad \therefore P/E = \epsilon_0(\epsilon_r - 1)$$

$$K = \frac{\epsilon}{\epsilon_0} \text{ from definition}$$

$$X = \epsilon_0 K - \epsilon_0 \rightarrow (2)$$

$$\therefore K\epsilon_0 = \epsilon \text{ Substitute in eq(2)} \quad \therefore X = \epsilon - \epsilon_0 = \epsilon - \epsilon_0 + X \rightarrow (3)$$

$$\therefore \epsilon = \epsilon_0 + X \rightarrow (3)$$

dividing the eq(3) on both sides with ϵ_0

$$\therefore \frac{\epsilon}{\epsilon_0} = \frac{\epsilon_0 + X}{\epsilon_0} \Rightarrow \left[K = \frac{\epsilon_0 + X}{\epsilon_0} \right] = \left[K = 1 + \frac{X}{\epsilon_0} \right]$$

[3] Explain electronic polarization in atom and Obtain an expression for electronic polarizability in terms the radius of the atom?

Electronic polarization : The polarization generated by the separation of the effective centre of the electron cloud from the nucleus of the atom is called the electronic polarization.

It is denoted P_e $\therefore P_e = NdeE$

where de is electronic polarizability

N is number of atoms per unit volume of Dielectric material

E is applied electric field intensity

Consider a simple atom, it contains a light electron cloud of negative charge uniformly distributed over a sphere of radius ' a ' and positive charges concentrated at the centre of the sphere.

The polarization in atomic view gives the result that is the centres of the positive and negative charges in atom displaced by the applied field.

The applied electric field E separates the equal and opposite charge centers with in the atom so that the atom becomes a dipole. This happens to all the atoms in the material.

Consider an isolated atom is placed under electric field E , the light electrons

move much more than the heavy nucleus Atom without field ($E=0$) Atom with the field.

Hence the centre of the electron cloud shifts (displace) in the opposite direction of E



Consider an atom with atomic number Z then the charge on its nucleus is $+Ze$

By the application of external field the atom becomes a dipole and possess dipole moment when the atom is subjected to electric field the nucleus and the electron cloud are pulled apart by an amount x

Then the force along the direction of the field is

$$F_1 = Ze \cdot E \rightarrow (1)$$

The nucleus is surrounded by electron cloud of charge $-Ze$ distributed over a sphere of radius r . The charge density is given as $\rho = \frac{\text{Charge}}{\text{Volume}} = \frac{-Ze}{\frac{4}{3}\pi r^3} = -\frac{3}{4} \left(\frac{Ze}{\pi r^3} \right)$

Assuming uniform distribution of electron cloud, the

$$\text{Total charge in the electron cloud is } \frac{4}{3}\pi r^3 \rho = \left[\frac{4}{3}\pi r^3 \right] \left[-\frac{3}{4} \frac{Ze}{\pi r^3} \right] = -\frac{Ze r^3}{r^3} \rightarrow (2)$$

The coulomb force between the nucleus and the electron cloud is F_2

$$\therefore F_2 = \frac{Ze}{4\pi\epsilon_0 r^2} \left[-\frac{Ze r^3}{r^3} \right] = -\frac{Z^2 e^2 r}{4\pi\epsilon_0 r^3} \rightarrow (3)$$

In equilibrium condition, the forces F_1 and F_2 are equal i.e $ZeE = -\frac{Z^2 e^2 r}{4\pi\epsilon_0 r^3}$

$$\therefore r = \frac{4\pi\epsilon_0 r^3}{Ze} E \rightarrow (4)$$

Electronic dipole moment per atom $P_e = Ze(x) \rightarrow (5)$

$$\text{Substitute the value of } r \text{ in eq(5)} \therefore P_e = Ze \left[\frac{4\pi\epsilon_0 r^3}{Ze} \right] E$$

$$\therefore P_e = 4\pi\epsilon_0 r^3 E \rightarrow (6)$$

By definition $P_e = \alpha_e E \rightarrow (7)$ [P = αE]

$$\therefore \text{Comparing (6) and (7)} \quad \boxed{\alpha_e = 4\pi\epsilon_0 r^3}$$

α_e is known as electronic polarizability or ~~express~~ electronic polarizability is expressed in terms of radius of atom $[\alpha_e \propto r^3]$ where 'r' radius of atom

[4] Explain the ionic polarization?

Ionic polarization: The polarization produced by the relative displacement of the ions is called the ionic polarization

It is an additional polarization due to relative displacement of the atomic components of the molecule in the presence of Electric field

when an electric field E is applied to such a material, the opposite

Kind of ions are pulled apart and the normal separation of the ions increases

when a field is applied the original form of the molecule is disturbed, and dipoles are formed and polarized under E . So that this induced dipole moment is proportional to the applied field i.e. $\mu_i = \alpha_i E$ where α_i ionic polarizability ($\because \mu = \alpha E$)

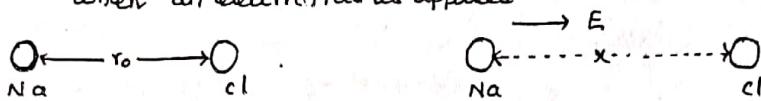
For most materials the ionic polarizability is less than the electronic polarizability i.e. $\alpha_i \ll \alpha_e$ where α_e is the electronic polarizability

$$\alpha_i \approx 0.1 \alpha_e$$

and $(\alpha_e + \alpha_i)$ is sometimes called as the deformation polarizability

The ionic polarizability is independent of temperature

Example The phenomena of ionic polarizability is observed in case of NaCl molecule when an electric field is applied



when a field E is applied the original form of the molecule is disturbed the dipoles are formed and polarized under E .

that is sodium(Na) and chlorine atoms are displaced in opposite directions until ionic binding forces stop the process, thus increasing the dipole moment

$$\mu_i = \alpha_i E \text{ so that this induced dipole moment is proportional to the applied field}$$

[5] what is orientational polarization? Derive an expression for the mean dipole moment when a polar material is subjected to an external field?

This type of polarization occurs in polar substances

Definition: The polarization arising due to the alignment of already existing but randomly oriented dipoles in the polar substance is called the orientational polarization (or) Dipolar polarization. The orientational polarizability is denoted by α_o . α_o depends on temperature T . It decreases with T

\therefore Total polarization in dielectrics is thus contributed by electronic, ionic and orientational polarizations i.e. $P = N \alpha_t E$

$$\text{where } \alpha_t = \alpha_e + \alpha_i + \alpha_o$$

polar substance [polyatomic molecules] like water, these molecules possess a permanent dipole moment. Even though dipoles will exist in such materials they orient randomly so that the net dipole moment in any specimen of the material is zero

when this specimen is placed in an external field E dipoles rotate and tend to align in line with the field E . This is resisted by the thermal agitations

The ~~other~~ orientational polarizability depend on temperature i.e. At higher temperature the thermal agitations are high that leads to lowering of polarizability

$$P = \epsilon_0 (\epsilon_r - 1) E \rightarrow (1) \quad \left. \begin{array}{l} \text{From (2) and (3)} \\ \epsilon_0 (\epsilon_r - 1) E = N \alpha_e E \end{array} \right\}$$

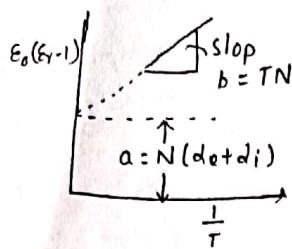
$$\text{But } \epsilon_r = K \quad \therefore P = \epsilon_0 (K - 1) E \rightarrow (2) \quad \left. \begin{array}{l} \epsilon_0 (K - 1) E = N \alpha_e E \\ \epsilon_0 (\epsilon_r - 1) = N \alpha_e \end{array} \right\} \rightarrow (4)$$

$$\text{But } \alpha_e = \alpha_t \quad \epsilon_0 (\epsilon_r - 1) = N \alpha_t \rightarrow (5)$$

ϵ_r is measured for different kinds of dielectrics at

at different temperatures : ϵ_r , d_i are independent of Temperature

ϵ_r depends on T & a of polar substance.



$b = TN d_o(T)$ ie The dielectric constant K is depend on the temperature in case of orientational polarization

$\therefore \epsilon_r$ is a function of Temperature $T \Rightarrow \epsilon = \epsilon_r(T)$

$$\therefore E_0(\epsilon_r(T) - 1) = N(d_e + d_i) + Nd_o(T)$$

$$E_0(\epsilon_r(T) - 1) = a + \frac{b}{T} \text{ where } a = N(d_e + d_i) \quad \frac{b}{T} = N d_o(T)$$

According to Langevin - Debye theory the polarization of

polar substances is a function of Temperature

$$\text{that is given by } P(T) = [N(d_e + d_i) + Nd_o(T)] E$$

$d_o(T)$ is orientational polarizability

$$d_o(T) = \frac{\mu m^2}{\pi(3k_B T)} \Rightarrow \mu m = \sqrt{\frac{3k_B T}{N}}$$

μm is called mean dipole moment of polar substance.

- [6] Obtain an expression for the internal field seen by an atom in an infinite array of atoms subjected to an external field.

[OR] Explain the concept of internal field in solids. [Local field],

The total electric field at the site of the atom within the dielectric is called the local field or the internal field. The internal field is denoted E_i .

The internal field is due to neighbouring dipoles in the specimen. The internal field is also called as Lorentz field.

In dense substance like liquids and solids the atoms or molecules are much closer to each other, when an external field E is applied to such a dielectric the dipoles are created.

Thus for an atom inside the dielectric it is effected by all the neighbouring dipole causes to interfield. The internal field (E_i) is different from the applied field E . For the calculation of polarization (P) internal field must be considered than applied field.

For denser dielectrics Polarization $P = N d(E_i - E)$

$$\text{But } D = \epsilon_0 E + P \rightarrow (2)$$

$$\text{Substitute the value } P = N d E_i \text{ in eq(2)} \Rightarrow D = \epsilon_0 E + N d E_i \rightarrow (3)$$

$$\text{But } D = \epsilon_0 E \text{ Sub in eq(3)} \therefore \epsilon_0 E = \epsilon_0 E + N d E_i \rightarrow (4)$$

$$\therefore \text{But } \epsilon_r = \frac{\epsilon_0}{\epsilon_r} \Rightarrow \epsilon = \epsilon_r \epsilon_0 \text{ Sub this value in equation (4)}$$

$$\therefore \epsilon_r \epsilon_0 E = \epsilon_0 E + N d E_i \rightarrow (5)$$

$$\epsilon_0 \epsilon_0 E - \epsilon_0 E = N d E_i \Rightarrow \epsilon_0 (\epsilon_r - 1) E = N d E_i$$

$$\therefore E_i = \frac{\epsilon_0 (\epsilon_r - 1) E}{N d} \quad \text{This represent the polarization due to the internal field.}$$

We can observe the internal field is due to the combined effect of external field E and polarization 'P' which itself is also due to E .

We know that $D = \epsilon_0 E + P \rightarrow (6)$

$$\text{divide by } \epsilon_0 \text{ on both sides of eq(6)} \Rightarrow \frac{D}{\epsilon_0} = \frac{\epsilon_0 E}{\epsilon_0} + \frac{P}{\epsilon_0} \Rightarrow \frac{D}{\epsilon_0} = E + \frac{P}{\epsilon_0}$$

thus $P = N Y \mu_a$ where Y is dimensionless constant that depend on the symmetry of the crystal (dielectric) structure. $\therefore Y = \frac{1}{3}$.

$$E_i = E + \frac{Y P}{\epsilon_0}$$

$$\therefore E \cdot \frac{D}{\epsilon_0} = E + \frac{N Y \mu_a}{\epsilon_0} \Rightarrow E_i = E + \frac{Y N \mu_a}{\epsilon_0}$$

$$E_i = E + \frac{P}{3 \epsilon_0}$$

(Q) Explain the phenomena of piezoelectricity? write the important applications of the piezoelectric materials:

The electrical charges induced on the surfaces of the crystals by the application of mechanical stress on the crystals this phenomenon is called piezoelectricity.

It is observed in case of piezoelectric materials. These materials are polarised when they subjected to mechanical deformation (it is possible for ionic solids).

All Ferroelectric crystals exhibit piezoelectricity but all piezoelectric materials need not exhibit ferroelectricity. Example Quartz - piezoelectric crystal not ferroelectric.

→ Piezoelectric materials are in form polycrystalline.

Applications of piezoelectric materials as (a) Sensors, (b) Transducers (c) amplifiers (d) detectors.

(e) oscillators (f) ultrasonic waves generator

Medical diagnostic: Ultrasonic Sources & Detectors.

Transducers: Piezoelectric materials are used as transducers for the conversion of electrical energy in mechanical energy and mechanical energy into electrical energy.

Example: Quartz crystal, ceramic, and ferroelectric material (BaTiO_3 , LiNbO_3)

Sensors: Piezoelectric materials used as sensors which measure pressures very accurately.

amplifiers: Piezoelectric semiconductor Gas, ZnO, CdS amplifiers of ultrasonic waves (MHz)

detectors: Quartz crystals are also used in selective band pass filters in submarines and in telephone industry, i.e. generation and reception of sound wave in nature.

oscillators: Most important material for such use being quartz, it has an extremely high dielectric strength. So that it is used frequently to control frequency in

Industrial application: Finds internal cracks, hidden defects.

Ultrasonic waves generator: we can employ the piezoelectric materials to produce the

ultrasonic waves [By specially prepared Quartz slices of the order of 0.1 nm]

[Or] Tourmaline crystal slices, frequency of about 1 MHz can be obtained by piezoelectric oscillatory circuit]

Electro optic modulator: LiNbO_3 material is used as electro optic modulator.

Space application: The T_c of LiNbO_3 is 1210°C so this is the suitable piezoelectric material for space application i.e. parametric oscillator & amplifier

(Q) Explain the phenomena of pyroelectricity? write the important applications of pyroelectric materials?

Pyroelectric effect: It is the change in spontaneous polarization when the temperature of the specimen is changed and also in PVDF, Triglycerine sulphate.

This effect was first discovered in minerals such as in Quartz, tourmaline and in other ionic crystals. (PVDF material)

Fact about pyroelectricity: By changing the temperature produces surface charges which attracts other charged materials.

All the ferroelectric materials are pyroelectric materials the converse is need not be true.

Example: Tourmaline crystal is pyroelectric material, but it is not ferroelectric.

The property of pyroelectricity is the measured change in net polarization P_s)

proportional to change in temperature $I_p = P_i A \frac{dT}{dt}$ $\frac{dT}{dt}$: Rate of heating.

I_p : pyroelectric current, P_i : pyroelectric coefficient, A : Area of cross-section

$\frac{dT}{dt}$ is rate of heating normally $3 - 5^\circ\text{C}/\text{m}$ ie 3°C to 5°C per minute

$P_i = \frac{J P_s i}{J T} =$ Spontaneous polarization At $T = T_c$ $P_i \approx 0$

Application of pyroelectric materials (a) Used in burglar alarms (b) detectors (c) Sensors

(d) Industrial applications (e) Domestic applications (f) infrared photography:

(a) Burglar alarms: Polyvinylidene di Fluoride (PVDF), Turmaline crystals used in burglar alarms that based on temperature changes

(b) Detectors [Detect Temperature change of a microdegree Change about 10^{-6}C because pyroelectrics are highly sensitive to temperature changes]

Industrial applications: pyroelectrics are used to monitor levels of pollution through IR detection.

→ Polycrystalline samples in thin film form (or) Ceramic discs (thin plates)
They are used in multilayer capacitors are employed.

Infrared photography: Pyroelectrics are excellent detectors of infrared radiation and they make excellent devices for infrared photography and Nightphotography in the dark.

Domestic applications: The pyroelectric materials are sensitive to infrared radiation

The pyroelectric materials are used in burglar's alarm.

(Variation of temperature functioning) ~~for laser~~

The pyroelectric detectors are useful in power meters for laser radiation and they are useful in microelectronics.

They make perfect devices for testing the level of IR radiation that passes through a gas sample.

Q Locate the trapped people Under rubble: Triglycine sulphate, It has pyrocoefficient

$-5.5 \times 10^{-4} \text{ C m}^{-2} \text{ K}^{-1}$ measured at 30°C . It is used in pyroelectric Vidicon

Pyroelectric vidicon is a device (or) a camera useful for thermal imaging.

This camera is highly helpful for disaster teams to locate the trapped people under rubble.

(Q) Explain the phenomenon of Ferro-electricity? write the applications of ferro-electric materials? (Or) Explain the characteristics of ferroelectric materials.

based on Hysteresis Curve? (Or) Mention the ferroelectric characteristics of Barium titanate (BaTiO_3)

Materials which exhibit electric polarization even in the absence of the applied electric field are known as Ferroelectric materials.



They have permanent dipole moment in each atom or molecule $P_{ex} \neq 0$.

Examples of ferroelectric materials BaTiO_3 , SrTiO_3 , PbTiO_3 , LiNbO_3 , (7)

LiTaO_3 , Rochelle salt ($\text{NaK(C}_4\text{H}_4\text{O}_6 \cdot 4\text{H}_2\text{O}$), phosphate (KH_2PO_4)

Ferroelectric materials exhibit piezoelectricity and pyroelectricity converse need not be true.

Ferroelectricity: It refers to the creation of enormous value of induced dipole moment

in a weak dielectric field as well as existence of electric polarization even in the absence of applied electric field.

Hysteresis effect: Ferroelectricity is a result of dielectric hysteresis. Since these materials exhibit hysteresis effects.

By observing hysteresis curve, they show the P_s value in the absence of External applied electric field.

* irreversal process: E increases the path BC - increasing order of P

E decreases then we observe the CAB path even $E=0 : P_s \neq 0$. This is important property of ferroelectric material.

$P_s \neq 0$: i.e. Ferroelectric materials possess Spontaneous polarization due to permanent electric dipoles.

All ferroelectric exhibit polarization reversal.

Characteristics of Ferroelectric materials

(i) They are easily polarized in a weak field.

(ii) They exhibit spontaneous polarization ($P_s \neq 0$) at $E=0$

(iii) They possess very high dielectric constants.

(iv) They exhibit piezoelectric & pyroelectric effects.

(v) They exhibit dielectric hysteresis (P-E curve).

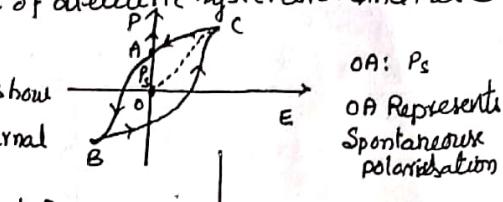
(vi) Centre of gravity of +ve & -ve charges do not coincide even in the absence of external field.

(vii) Hysteresis curve: P is not linear function of E

(viii) $T > T_c$ ferro — converted in paraelectric material.

$T > T_c$ P varies linearly with E .

(ix) The area of Hysteresis curve change w.r.t Temperature



Applications of Ferroelectric materials

(a) They exhibit Piezo, pyroelectric effects due to that they are used as detectors, sensors

(b) They are used as Transducers: $E_{\text{mech}} \leftrightarrow E_{\text{electr}}$

(c) They are used in multilayer capacitors.

(d) They are useful in microelectronics

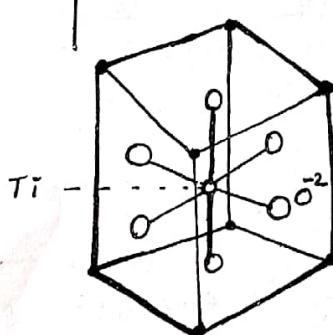
(e) Due to high dielectric constant they are useful for storing energy in small size capacitors in electrical circuits.

(f) Optical communications ferroelectric crystals are used for optical modulation

(g) Pressure transducers, microphones, ultrasonic transducers

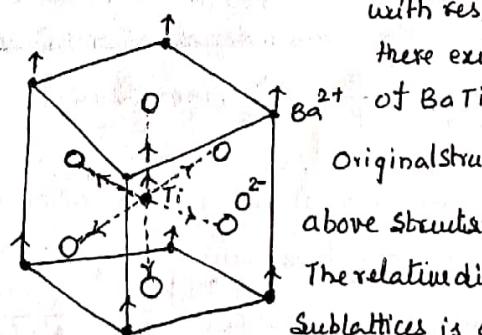
Explain the structural changes of ferroelectric materials

i.e. Behaviour of BaTiO_3 (ferroelectric material) with temperature. [$T = T_c$ & $T > T_c$]



(a) $T > T_c$

i.e. at high temperature



$T < T_c$

i.e. at low temperature

with respect to the temperature there exist a change in the structure of BaTiO_3

Original structure of BaTiO_3 perovskite

above structure change with temperature

The relative displacement of the two sublattices is 0.01nm . This is responsible

for the spontaneous polarization

i.e. At high temperature : BaTiO_3 - has cubic structure with Titanium ions at body centre. ($T > T_c$) Barium ions at the body corners and Oxygen ions at face centres

At low temperature (if the crystal is cooled) The Sublattice containing Ba^{2+} & Ti^{4+} ions shifts upward along c-axis w.r.t Oxygen sublattice

This displacement responsible for Spontaneous polarization [creates electric dipoles]

[7] Derive Classius - Mosotti relation? Explain Classius-Mosotti relation in dielectrics subjected to static fields?

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For an atom inside the dielectric it is effected by all the neighbouring dipoles causes to internal field. E_i be the internal field $\therefore E_i = E + \frac{Yp}{\epsilon_0} \rightarrow (1) \Rightarrow E_i = \frac{\epsilon_0 E + Yp}{\epsilon_0}$

$$\therefore E_i \epsilon_0 = E \epsilon_0 + Yp \Rightarrow E_i \epsilon_0 - Yp = E \epsilon_0 \rightarrow (2)$$

$$\text{But } p = N \alpha E_i \text{ substitute in eq(2)} \Rightarrow E_i \epsilon_0 - Y[N \alpha E_i] = E \epsilon_0$$

$$\therefore E_i [\epsilon_0 - YN \alpha] = E \epsilon_0 \Rightarrow E_i = \frac{\epsilon_0 E}{\epsilon_0 - YN \alpha} \rightarrow (3)$$

From (4) and (5)

$$\text{But } E_i = \frac{\epsilon_0 (\epsilon_r - 1) E}{N \alpha} \rightarrow (4) \quad Y \text{ is dimensionless constant.}$$

$$\frac{p_0 (\epsilon_r - 1) E}{N \alpha} = \frac{\epsilon_0 E}{\epsilon_0 - YN \alpha} \Rightarrow \frac{\epsilon_r - 1}{N \alpha} = \frac{1}{\epsilon_0 - YN \alpha}$$

$Y = \frac{1}{3}$ for an isotropic dielectric of cubic system

$$\therefore \frac{\epsilon_r - 1}{N \alpha} = \frac{1}{\epsilon_0 - \frac{1}{3} N \alpha} \Rightarrow \epsilon_r - 1 = \frac{3 N \alpha}{3 \epsilon_0 - N \alpha} \rightarrow (5)$$

Adding 3 on both sides of eq(5)

$$\Rightarrow \epsilon_r - 1 + 3 = \frac{3 N \alpha}{3 \epsilon_0 - N \alpha} + 3 \Rightarrow \epsilon_r + 2 = \frac{3 N \alpha + 9 \epsilon_0 - 3 N \alpha}{3 \epsilon_0 - N \alpha}$$

$$\therefore \epsilon_r + 2 = \frac{9 \epsilon_0}{3 \epsilon_0 - N \alpha} \rightarrow (6)$$

The equation (6) may be written

$$\epsilon_r + 2 = \frac{9 \epsilon_0 \times \frac{1}{3 N \alpha}}{3 \epsilon_0 - N \alpha \times \frac{1}{3 N \alpha}} \Rightarrow \epsilon_r + 2 = \frac{3 \epsilon_0}{N \alpha} \rightarrow (7)$$

$$\therefore \epsilon_r + 2 = \frac{3 \epsilon_0}{N \alpha} \times \left[\frac{3 N \alpha}{3 \epsilon_0 - N \alpha} \right] \rightarrow (8)$$

$$\text{in equation (8)} \quad \frac{3 N \alpha}{3 \epsilon_0 - N \alpha} = \left[\frac{1}{\epsilon_r - 1} \right] \quad \left[\because \text{from (5)} \quad \epsilon_r - 1 = \frac{3 N \alpha}{3 \epsilon_0 - N \alpha} \right]$$

$$\therefore \text{equation (8) becomes} \quad \epsilon_r + 2 = \frac{3 \epsilon_0}{N \alpha} \left[\epsilon_r - 1 \right] \Rightarrow \frac{\epsilon_r + 2}{\epsilon_r - 1} = \frac{3 \epsilon_0}{N \alpha} \rightarrow (9)$$

$$\text{From equation (9)} \Rightarrow \frac{\epsilon_r - 1}{\epsilon_r + 2} = \frac{N \alpha}{3 \epsilon_0} \rightarrow (10) \quad \begin{aligned} n &= \sqrt{\epsilon_r} \quad \therefore \frac{n^2 - 1}{n^2 + 2} = \frac{N \alpha}{3 \epsilon_0} \\ n^2 &= \epsilon_r \end{aligned}$$

This is known as the Classius - Mosotti relation

n is refractive index of medium

Explanation of Classius - Mosotti relation (Importance)

It gives the relation between ϵ_r and α
i.e It gives relation between the microscopic polarizability α
and the macroscopic dielectric ϵ_r of dielectric solid or liquid

From Classius - Mosotti relation the molar polarization (P_m) is calculated

$$\therefore P_m = \left[\frac{\epsilon_r - 1}{\epsilon_r + 2} \right] \frac{M}{P} = \frac{N_A}{3 \epsilon_0} [(\alpha_e + \alpha_i) + \alpha_o]$$

where $\alpha = (\alpha_e + \alpha_i) + \alpha_o$

Since α_o is orientational polarizability it is dependent on temperature i.e $\alpha_o = \frac{\mu_m}{3 K_B T}$

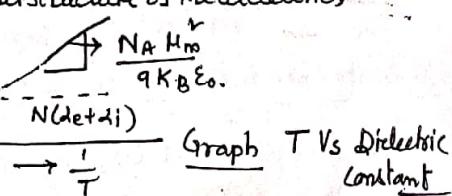
So that P_m is a function of temperature $\therefore P_m = \frac{N_A}{3 \epsilon_0} [(\alpha_e + \alpha_i) + \frac{\mu_m}{3 K_B T}]$ This is Debye's equations

with the help of Debye's equation we can determine the dipole moment per molecule.

Using Classius - Mosotti relation we can calculate the dielectric constant of materials.

and also gives the variation of Dielectric constant with temperature of substances
and helps to determine molecular structure of the dielectrics

$$\alpha_o = \frac{N_m^2}{3 K_B T} \quad M_m = 3 \sqrt{2 \alpha K_B \epsilon_0} \cdot \left(\frac{\epsilon_r - 1}{\epsilon_r + 2} \right) \frac{M}{P} \quad \begin{aligned} \uparrow & \quad \frac{N_A \mu_m}{3 K_B \epsilon_0} \\ M_m & \propto \sqrt{T} \end{aligned}$$



"Dielectric material is subjected to high frequency the dipole will no longer be able to rotate sufficiently rapidly. So that their oscillations will begin to lag behind those of the field.

So that the orientation of the dipoles will result the polarization will tend to reverse everytime, then the polarity of field changes.

As the frequency is further increased the dipoles will be completely unable to follow the field

Effect on orientational polarization By the increasing of frequency the orientational-

- polarizational ceases, this usually occurs in the range above 10^6 cycles/sec

At ultrahigh frequency heavy positives and negative ions can not follow the field variations

So that the contribution to the permittivity from the atomic (or) ionic polarizations ceases and only the electronic polarization remains

So that the permittivity of a dielectric material vary with increasing frequency this phenomenon is known as Anomalous Dielectric dispersion.

[10] Explain piezo electricity phenomena?

The electrical charges induced on the surfaces of the crystals by the application of mechanical stress on the crystals this phenomenon is called piezo electricity

Example Quartz (SiO_2) Lithium Niobate (LiNbO_3), Barium Titanate (BaTiO_3) ^{Barium} Titanate
Materials which are polarised when subjected to mechanical deformation are called

piezo electric materials. All ferroelectric crystals exhibit piezoelectricity but all piezo electric crystals need not exhibit ferroelectricity

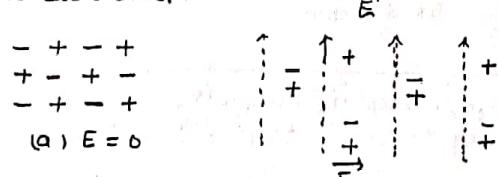
uses piezo electric materials are very important since they permit the conversion of the mechanical energy into electrical energy and vice-versa.

Explanation: Quartz crystal Suitably prepared slices of the quartz crystal we observe the piezo electric effect. Quartz crystal consist of three axes, x-axis is known as electrical axis, y-axis is known as mechanical axis and z-axis is known as optical axes.

In the absence of the external stress, all the charges are balanced, net polarization is zero.

But when external stress is applied to the crystal the balance is disturbed and the crystal is polarized. As a result, electrical charge is developed on the faces.

Electric field is inducing an electric dipole moment in a dielectric and displacements relative to each other.



If the dimensions of the crystal have increased in the field direction this physical property is called electrostriction.

$\begin{matrix} - & + & - & + \\ + & - & + & - \\ - & + & - & + \end{matrix}$
 $u_1 \downarrow$
 $u_2 \uparrow$
No Stress

$\begin{matrix} - & + & - & + \\ + & - & + & - \\ - & + & - & + \end{matrix}$
Tension

$\begin{matrix} - & + & - & + \\ + & - & + & - \\ - & + & - & + \end{matrix}$
 $u_1 + u_2 = 0$
Compression

If the crystal under study posses the centre of symmetry these crystals do not exhibit the piezo electricity.

On the other hand the stress will produce a dipole moment in a crystal whose charges do not possess the centre line of symmetry. Such crystals show the piezoelectric effect

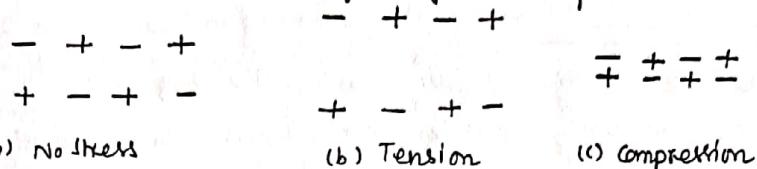


Fig Origin of the piezoelectric effect

[11] What is dielectric breakdown? Explain briefly the various factors contributing to breakdown in dielectrics?

For many materials there is a maximum field intensity beyond which damage occurs that results in breakdown phenomena.

At relatively high fields, the electrons in the dielectric gain enough energy to knock other charged particles and make them available for conduction.

Although many theories exist regarding the breakdown of solids, the failure of solid insulation in practice is almost always due to entirely different reasons. Electric strength of solid dielectrics depend on many extraneous factors.

- (i) defects and inhomogeneity of the material
 - (ii) thickness area and volume of the specimen
 - (iii) the surface conditions and the method of placing the electrodes
 - (iv) the type and application of test voltage and test duration
 - (v) moisture and other contaminations

A number of fundamental breakdown mechanisms in solids can be distinguished.

(i) Intrinsic breakdown : electronic in nature and depends on the presence of electrons capable of migrating through the lattice.

(ii) Thermal breakdown : when the local heat generated by losses exceeds that when the rate of heat generation is greater than the rate of dissipation.

(iii) Discharge breakdown Depends upon the presence of voids etc

(iv) Electrochemical breakdown : is cumulative in nature and gradually builds upto breakdown

[12] what is intrinsic breakdown in dielectric materials?

In a perfect dielectric there are no free electrons and the conductivity is almost zero. In general all crystals contain imperfections of one or more of the following types.

The impurity atoms (or) molecules traps for the conduction electrons upto certain ranges of field / temperature. By application external field the electrons jump from valency band to conduction band. For intrinsic breakdown : effect of increased temperature is to eject more electrons to the conduction band increasing the conductivity.

Low temperature breakdown under this condition, the number of electrons will be few and interaction of electrons with the lattice will be predominant.

when electric field is applied electrons gain energy after collision they will loss their energy.

Some important definitions:

Magnetic induction: It is defined as the number of magnetic lines of force passing perpendicularly through unit area $\therefore B = \frac{\Phi}{A}$ units weber/m² (or) Tesla

(or) It is defined as the magnetic force experienced by unit north pole placed at a given point in a magnetic field $\therefore B = \frac{F}{m}$ units Newton ampere-meter.

Magnetic field intensity: The magnetic field intensity at any point in the magnetic field is force experienced by an unit north pole placed at that point.

$$H = \frac{F}{\mu m} \Rightarrow H = \frac{B}{\mu} \text{ units } \frac{\text{ampere turn}}{\text{meter}}$$

Permeability (μ): Permeability of the medium is defined as the ratio between magnetic induction and magnetic field intensity at a given point in that medium.

$$\therefore \mu = \frac{B}{H} \quad \text{for free space } \mu \text{ becomes } \mu_0 \text{ and the value of } \mu_0 = 4\pi \times 10^{-7} \text{ Henry/m}$$

Relative permeability: It is defined as the ratio of the permeability of medium to the permeability of free space $\therefore \mu_r = \frac{\mu}{\mu_0}$

Magnetization (or) Intensity of magnetization: It is defined as the average magnetic moment present per unit volume in a system. $\therefore M = N \bar{\mu}$; where N = Number of atoms (or) molecules per unit volume

I & H have same units and dimensions $\bar{\mu}$ is the averaged dipole moment per unit volume

Susceptibility (χ): It may be defined as the ratio of intensity of magnetization to applied magnetic field intensity $\chi = \frac{M}{H}$ χ has no units

χ is a measure of magnetization produced in the specimen per unit field strength when a material has high susceptibility then it can be easily magnetized.

Relation between B & H : $H = \frac{B}{\mu} \Rightarrow \{B = \mu H\}$ But $\mu = \mu_0 \mu_r$ $\therefore B = \mu_0 \mu_r H$

$$\therefore \left\{ \begin{array}{l} B = \mu_0 \mu_r H + \mu_0 H - \mu_0 H \\ B = \mu_0 H + \mu_0 H (\mu_r - 1) \\ B = \mu_0 H + \mu_0 \{H(\mu_r - 1)\} \end{array} \right\} \text{ where } \mu_0 [H(\mu_r - 1)] = M$$

$$\therefore B = \mu_0 H + \mu_0 M \Rightarrow \boxed{B = \mu_0 [H + M]} \rightarrow (1)$$

$$\mu_r = \frac{\mu}{\mu_0} \quad \text{and} \quad \left[M = \frac{B}{H} \quad \& \quad \mu_0 = \frac{B}{H+M} \right]$$

$$\therefore \mu_r = \frac{B/H}{B/(H+M)} \Rightarrow \mu_r = \frac{M+H}{H} \Rightarrow \mu_r = \frac{M}{H} + 1 \quad \left(\frac{M}{H} = \chi \right)$$

$$\Rightarrow \mu_r = \chi + 1$$

$$\Rightarrow \boxed{\chi = \mu_r - 1} \rightarrow (2)$$

Relation between M and H

M and H are related by $M = \chi H$

$$\mu = \frac{B}{H} \Rightarrow B = \mu H \rightarrow (3) \quad \text{Comparing (3) and (4)}$$

$$\text{But } B = \mu_0 [H + M] \rightarrow (4) \quad \mu H = \mu_0 [H + M] \rightarrow (5)$$

Substitute $\mu = \mu_0 \mu_r$ in equation (5)

$$\mu_0 \mu_r H = \mu_0 [H + M]$$

$$\therefore \mu_0 \mu_r H = \mu_0 H + \mu_0 M$$

$$\mu_0 \mu_r H - \mu_0 H = \mu_0 M \Rightarrow \mu_0 [\mu_r - 1] H = \mu_0 M \Rightarrow M = [\mu_r - 1] H$$

$$\text{where } \mu_r - 1 = \chi \quad \therefore \boxed{M = \chi H} \rightarrow (6)$$

[1] Define magnetic moment? Explain the origin of magnetic moment at the atomic level; what is Bohr magneton?

The origin of magnetism is due to the orbital motion of electrons in their orbits
(ii) Spinning of electrons (spin motion)

The revolving and rotating electrons constitute current loops. Each loop is like a magnet with one face behaves as a north pole while the other face as a south pole. so that due to above reason there exist a dipole in the magnetic material and they will interact with the applied field gives more strength to the magnet.

The magnetic moment is mainly due to orbital magnetic moment and spin magnetic moment

- The atoms having incomplete electronic shells and so they do have resultant magnetic moment
- According to quantum mechanical concept the magnetic moment is being due to the rotation of electric charge about one of the diameters of the electron. In a manner similar to that spiral spinning motion around its north-south axis.

Bohr magneton : The quantity $\mu_B = \frac{e\hbar}{4\pi m}$ is an atomic unit called bohr magneton

According to modern atomic theory the angular momentum of an electron in the orbits is determined by the orbital quantum number 'l' which is

$$l = 0, 1, 2, \dots (n-1)$$

where 'n' is the principal quantum number which determines the energy of the orbit. It can accept only the integer values $n = 1, 2, 3, 4, \dots$. The corresponding electronic shells are called K, L, M, N, ... shells

The angular momentum of the electrons associated with a particular value of 'l' is given by $\frac{lh}{2\pi}$ ∵ The strength of permanent magnetic dipole is given by

$$\mu_{el} = -\frac{eh}{4\pi m} l$$

$$\therefore \mu_{el} = -\left[\frac{eh}{4\pi m}\right] l$$

$$\therefore \mu_{el} = -[\mu_B] l$$

∴ The quantity $\mu_B = \frac{eh}{4\pi m}$ is an atomic unit called Bohr magneton

$$\text{if } l = 0 \Rightarrow \mu_B = 0 \quad [l=0 \Rightarrow \mu_{el} = -\left(\frac{eh}{4\pi m}\right) 0 \Rightarrow \mu_B = 0]$$

[2] In hydrogen atom an electron having charge 'e' revolves around the nucleus at a distance of 'r' meter with an angular velocity 'ω' rad/sec. Obtain an expression for magnetic moment associated with it due to its orbital motion.

Let us consider the simplest atom of hydrogen

in which one electron revolves round the proton.

Electron revolves on a circular path of radius 'r'

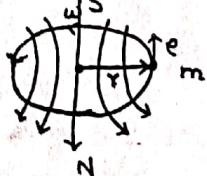
At any instant the electron at a point 'P' and

proton at centre form an electric dipole, the direction of dipole goes on changing as the electron moves.

Let 'e' and 'm' be respectively the charge and mass of the electron.

Also let its speed be 'v' in an orbit of radius

Then the area A of the orbit is πr^2 and its circumference is $2\pi r$



(Q) Classification of magnetic materials

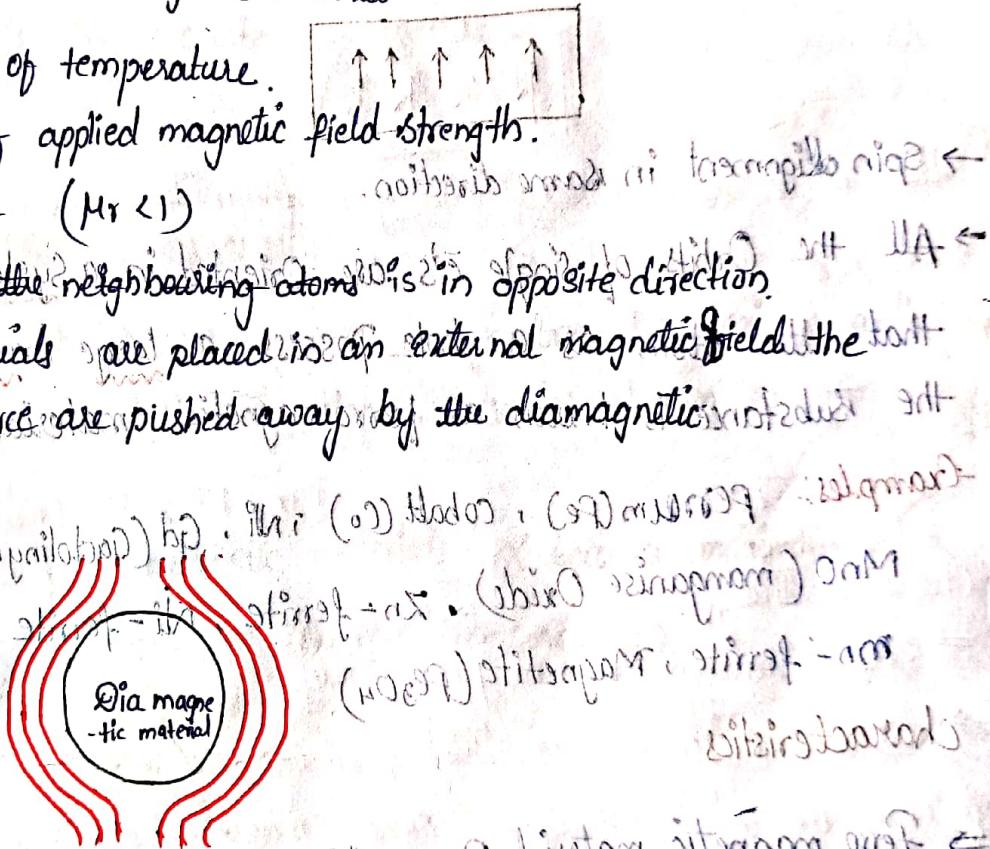
Diamagnetic Materials: It is a material which has no moment of dipole moment.

→ If the sum of magnetic moment of atoms is zero. These type of material is known as diamagnetic [due to opposite spin alignment of atoms the resultant magnetic moment is zero]

Examples of diamagnetic materials:

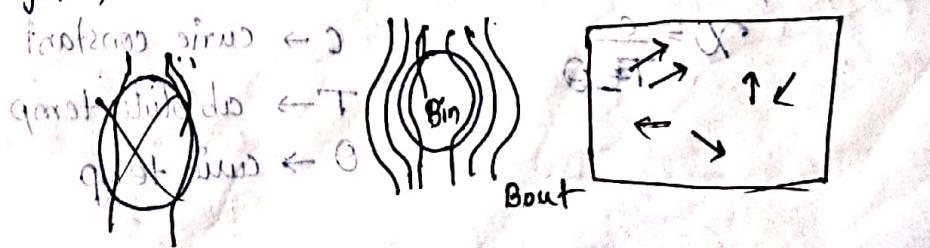
Bismuth (Bi), platinum (Pt), H₂O, Hg (mercury), NaCl, inert gases, Ag, Cu etc.

- ⇒ χ is negative for diamagnetic material
- ⇒ χ is independent of temperature.
- ⇒ χ is independent of applied magnetic field strength.
- ⇒ μ_r is less than 1 ($\mu_r < 1$)
- ⇒ Spin alignment of the neighbouring atoms is in opposite direction.
- ⇒ Diamagnetic materials are placed in an external magnetic field the magnetic lines of force are pushed away by the diamagnetic material.



Paramagnetic Materials: It is a material which has some moment of dipole moment.

e.g.: O₂, silver (Ag), CuCl₂ (copper chloride), soln of salts of Fe, platinum, manganise (Mn), N₂, tungsten



B in < B out

- The vector sum of magnetic moment is not equal to zero. These type of materials is known as Para magnetic material
- χ is positive
- χ is slightly greater than 'Y'
- μ_r is greater than 1
- χ depend on temperature $\left[\chi = \frac{c}{T}, \frac{\chi_1}{\chi_2} = \frac{T_2}{T_1} \right]$
- $B_{in} < B_{out}$ [when para magnetic material placed in external magnetic field]

Ferro Magnetic Materials-

- Spin alignment in same direction.
- All the orbits of single e's are oriented in a systematic manner such that the atom as a whole possess a large magnetic moment, then the substance is known as ferromagnetic material.
- Examples: Ferrom (Fe), cobalt (Co), Ni, Gd (Gadolinium), Dy (Dysprosium) (Strongest magnet)
- MnO (manganese Oxide), Zn-ferrite, Ni-ferrite
- Mn-ferrite, Magnetite (Fe_3O_4)

Characteristics

- Ferro magnetic material Possess "enormous" permanent dipole moment and permanent magnetic moment even in the absence of external field
- Ferro magnetic materials obeys Curie-Weiss law

$$\chi = \frac{C}{T - \Theta}$$

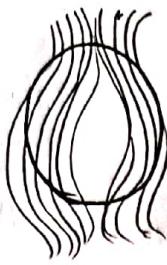


C → Curie constant

T → absolute temp

Θ → Curie temp

→ Ferro magnetic material placed under external magnetic field 21



$$B_{in} \gg B_{out}$$

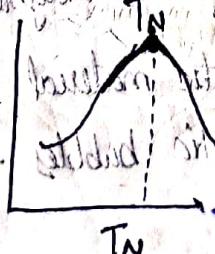
- It strongly attracts the magnetic lines of field.
- $\mu_r \gg 1$ with high magnetic flux in coil of given length X .
- $\chi \gg 1$, χ is always positive (χ depend on temperature).
- Ferro magnetic material behaves like para magnetic material when its temperature is greater than Curie temperature.

Anti Ferro Magnetic Materials:-



In some magnetic materials due to exchange forces, there exist a anti parallel alignment from neighbouring atoms, these are known as anti ferro magnetic materials.

Note: In case anti ferro magnetic materials χ becomes maximum at a particular temperature, is known as T_N (Neel Temperature).



Eg:-

Stegnopermal with $\chi = 10^{-3}$

antiferromagnetic χ

Antiferromagnetic χ

at T max χ

Antiferromagnetic χ

at T_c χ

Properties:-

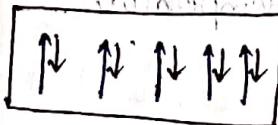
- ⇒ χ depend on temperature
- ⇒ spin alignment is anti parallel

$$\chi = \frac{C}{T+\theta}$$

⇒ electrons spin of neighbouring atoms are align anti parallel

⇒ χ increases up to the neel temperature, beyond the neel temperature decreases

Ferrimagnetic Materials



- distinct separation of moments.

This is a Special case of anti ferro magnetism. Even though there exist anti parallel alignment the net magnetic momentum is not equal to zero.

- ⇒ [Un equal magnetic moment in case of neighbouring atoms]

$$\Rightarrow \chi = \frac{C}{T+\theta}$$

Mn Fe₂O₄ (manganese ferrite)

Characteristics:

- ⇒ Spin alignment is anti parallel of different magnitudes
- ⇒ Above Curie temperature Ferrimagnetic material behaves as paramagnetic
- ⇒ Ferrimagnetic domains become magnetic bubbles to act as memory elements

⇒ These are possess net magnetic moment

⇒ χ depend on temperature

⇒ χ is large when $T > T_N$

χ is +ve when $T < T_N$

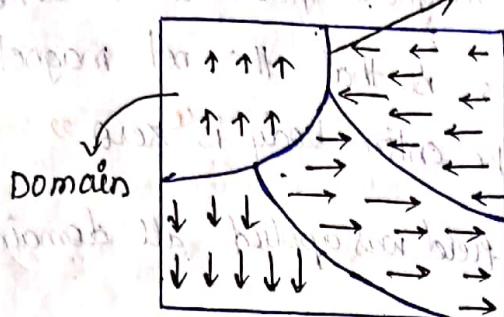
e.g. YIG (Yttrium Iron Garnet)

Ferrites composed of Iron oxides and other elements such as Al, Co, Ni, Mn, Zn



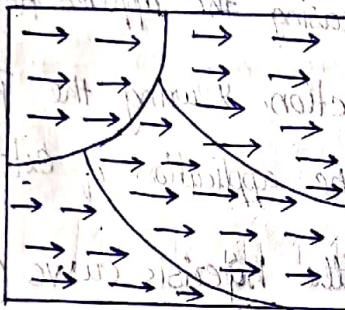
write a note on Ferromagnetic domains? write a note on hysteresis curve (B-H Curve)

Ferromagnetic domain :-



Ferromagnetic.

Substance with out any external magnetic field.



under external Magnetic field [Orientation is in same direction]

⇒ In 1907 P. Weiss Explain proposed the domain theory to explain the magnetic behaviour Ferromagnetic materials.

Domains:-

The entire Ferromagnetic material volume splits into a large no. of small regions. of Spontaneous magnetisation, the regions are called ferromagnetic domains.

⇒ Each domain shows the spontaneous magnetisation even in the absence of external magnetic field.

⇒ In each domain the alignment is in the same direction with respect to Spin of electrons in atoms. the neighbouring domains are having the different Orientations so that the net magnetisation is 'zero'

[Due to the opposite alignment of neighbouring domains] (contd) (Ans)

⇒ Effect of external magnetic field:-

In the absence of external magnetic field all the domains are oriented in all probable directions so that the net magnetic moment of the entire body is "zero".

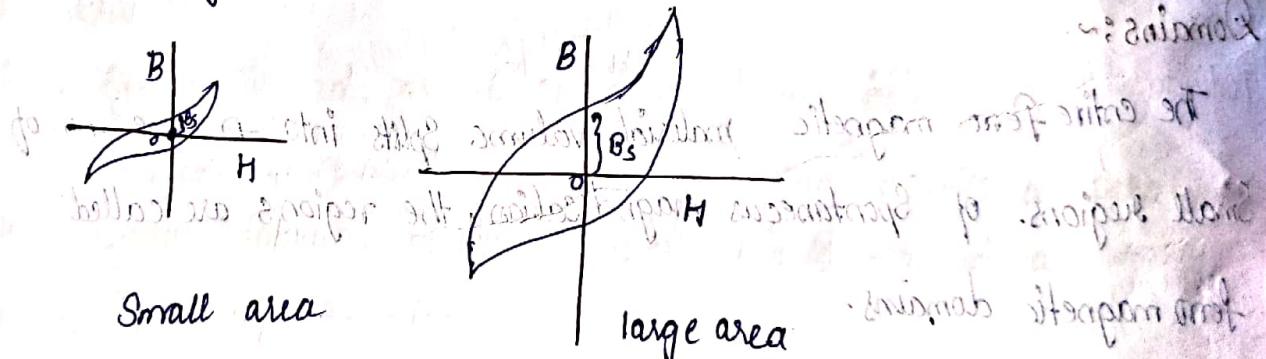
⇒ When an external field magnetic field was applied all domain are oriented in applied field direction.

⇒ By the application of external magnetic field some domains are unfavourable to change their direction, but by increasing the applied field intensity these domains are align in the field direction. During the process there exist a loss of internal energy. By the application of external field

⇒ The loss of energy is estimated by the hysteresis curve (B-H curve)

Note 1:- Hysteresis curve area is small, the loss of energy is small

2:- Hysteresis curve area is large, then the loss of magnetic energy is high.



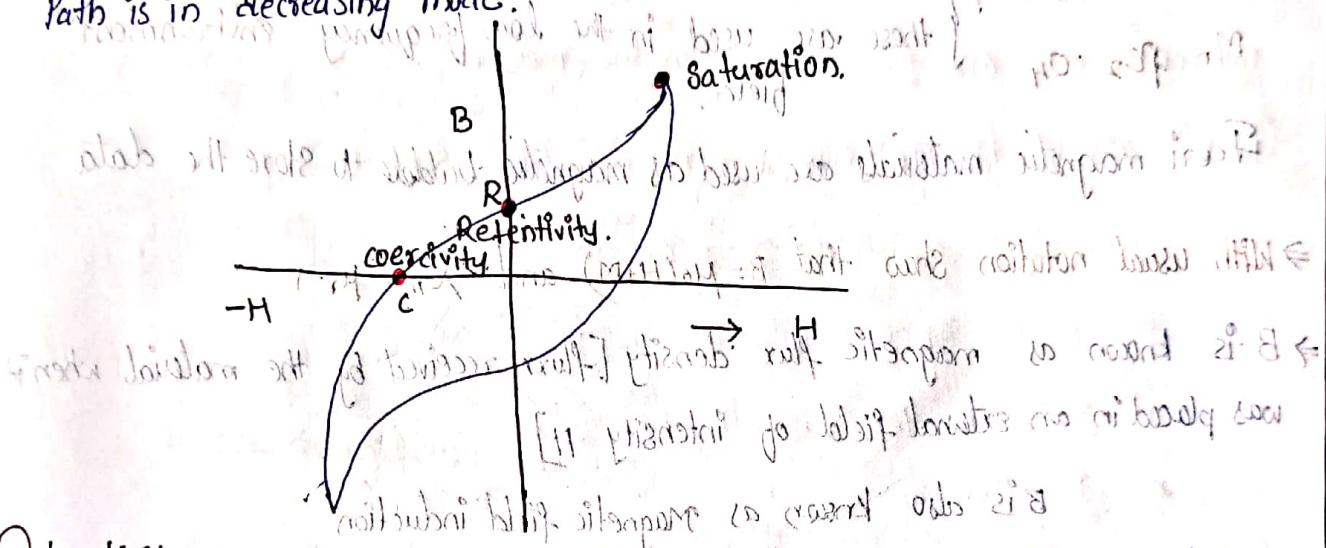
→ B & H are along x & y axis

→ H - applied external magnetic field intensity

→ B - magnetic field induction receiving flux

→ B_s - Spontaneous magnetisation

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- It is an irreversible curve which was exhibited by a ferromagnetic material under external magnetic field.
 - If the applied field intensity increases then B is also increases.
 - If the applied field intensity is reduced to minimum values B does not possess zero value.
 - $B-H$ curve has 2 paths one path is in increasing mode & another path is in decreasing mode.



Retentivity:- It is known as Ferromagnetic material's ability to retain a certain amount of residual magnetic field when the magnetising force is removed after achieving saturation.

Coercivity:- In the $B-H$ curve the value of H at the point "C" is known as coercivity [coercive force].

⇒ The amount of reverse magnetic field ($-H$) must be applied to a ferromagnetic material to make the magnetic flux return to "zero".

Applications of magnetic materials:- Because of the special properties of magnetic materials they are used in.

i) Digital computers in transducers

ii) they are used in magnetic tape

- ⇒ they are used for making permanent magnet
- ⇒ they are used in electro magnets
- ⇒ they are used in A/c current machinery. (toe~~r~~ manufacturer makes parts of the transformer)
- ⇒ they are used in communication System (communication equipment)
- ⇒ they are used in Audio & video transformers.
- ⇒ MgO , Fe_3O_4 , MnFe_2O_4 {these are used in the low frequency environment field.}

Ferri magnetic materials are used as magnetic bubble to store the data

- ⇒ with usual notation show that $B = \mu_0(H+M)$ and $\chi_m = \mu_r - 1$
- ⇒ B is known as magnetic flux density [flux received by the material when it was placed in an external field of intensity H]

B is also known as magnetic field induction

Units for B : "Weber/meter²" (or) "Tesla"

$$B = \frac{\Phi}{A} = \frac{\text{magnetic flux}}{\text{Area}}$$

$$\Rightarrow B = \mu H \quad \text{since } \mu = \frac{B}{H}$$

μ_r : Relative Permeability

$$\mu_r = \frac{\mu}{\mu_0} \quad \text{[}\mu_0 = \text{Permeability of free Space}]\text{}$$

* $\mu = \mu_0 \mu_r \quad \text{(3)}$

Rewrite Eqn ① as $B = \mu H + \mu_0 H - \mu_0 H \quad \text{(4)}$

Substitute Eqn(3) in Eqn(4) as follows

$$B = \mu_r \mu_0 H + \mu_0 H - \mu_0 H$$

$$B = \mu_r \mu_0 H - \mu_0 H + \mu_0 H$$

$$B = \mu_0 [(\mu_r - 1) H] + \mu_0 H$$

∴ we know that $(\mu_r - 1)H = M$

$$B = \mu_0 M + \mu_0 H$$

$$B = \mu_0 [H + M]$$

$$\begin{aligned} X_m &= \frac{M}{H} \\ X_m &= \mu_r - 1 \\ \frac{M}{H} &= \mu_r - 1 \\ M &= (\mu_r - 1) H \end{aligned}$$

20. 24

Prove that $X_m = \mu_r - 1$ depends with all material shapes?

$B = \mu H$ so that $\mu = B/H \rightarrow 0$ since it is uniform shape we

we know that $B = \mu_0(H + M) \rightarrow$ which will have no variation

$$\frac{\mu_0}{\mu} = \frac{B}{H + M} \rightarrow ③$$

$$\frac{\mu_0}{\mu} = \frac{H}{H + M} = \frac{H}{H + \frac{M}{H}} \underset{\text{since } M \text{ is constant}}{=} \frac{H}{H + 1}$$

$$\frac{\mu}{\mu_0} = 1 + \frac{M}{H} \rightarrow ④$$

as per definition

$$\frac{H}{\mu_0} = \mu_r \quad \frac{M}{H} = X_m$$

$$\mu_r = 1 + \frac{M}{H} \rightarrow ⑤ \rightarrow (\mu_r - 1)H = M$$

$$\frac{M}{H} = X_m \rightarrow ⑥$$

$$\mu_r = 1 + X_m$$

$$X_m = \mu_r - 1$$

Q) find the Relative permeability of a ferromagnetic material if a field of strength

220 A/m² produces a magnetisation 3300 A/m² in it.

Given data

$$\text{magnetisation } (M) = 3300 \text{ A/m}^2$$

magnetic field strength (or) Applied magnetic field intensity $H = 220 \text{ A/m}^2$

Let μ_r be the Relative Permeability.

$$\mu_r - 1 = \frac{M}{H} \rightarrow \mu_r = \frac{M}{H} + 1$$

$$M_r = \frac{220}{330} + 1, M_r = \frac{330\phi}{220} + 1$$

$$M_r = \frac{220}{330} + 1, M_r = \frac{330}{220} + 1$$

$$= \frac{16}{16} = 1.066 \quad \boxed{M_r = 16}$$

In a Magnetic material the field strength is found to be 10^6 A/m. If the magnetic Susceptibility is 0.5×10^{-5} , calculate the intensity of magnetisation and flux density in the material.

Given data $H = 10^6$ A/mtr = Magnetic field strength.

$$\text{magnetic Susceptibility } \chi_r = 0.5 \times 10^{-5}$$

Let M be the intensity of magnetisation = ?

Let B be the magnetic flux density = ?

from the formula $\chi_r = \frac{M}{H}$

$$M = \chi_r H = (0.5 \times 10^{-5}) \times 10^6 \frac{M}{H} + 1 = 0.5 \times 10^{-5} \times 10^6 = 5 \text{ A/mtr.}$$

$$B = \mu_0 (H + M)$$

$$\mu_0 = 4\pi \times 10^{-7} \text{ Henry/metr}$$

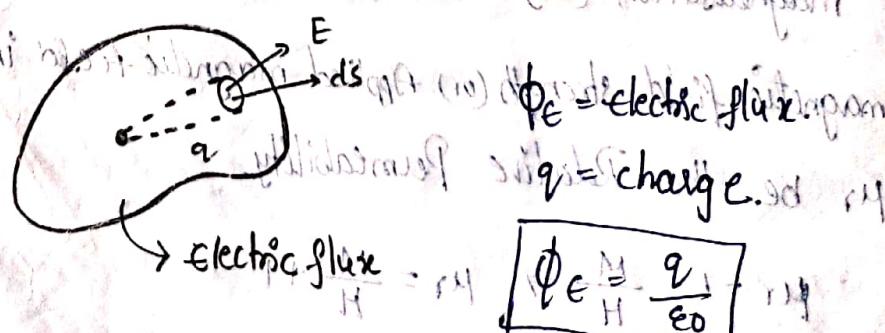
$$\mu_r M = \chi_r M$$

$$B = 4\pi \times 10^{-7} (5 + 10^6) = 1.257 \times 10^{-6} \text{ Weber/m}^2 \text{ (0.1 Tesla)}$$

Ques

State & Explain the laws of Electrostatics

Gauss law :-



\Rightarrow It defines the relation b/w charge enclosed by the closed surface $\frac{q}{\epsilon_0}$ and the electric flux [electric lines of force]

Gauss law statement:- The total electric flux through a closed surface enclosing a charge is equal to $\frac{1}{\epsilon_0}$ times the magnitude of charge enclosed.

$$\phi_E = \frac{1}{\epsilon_0} [q] \rightarrow (1)$$

Let us consider the small area "ds" the flux through the small area

$$ds = d\phi_E = \vec{E} \cdot \vec{ds} \rightarrow (2)$$

Total flux through the Surface $S + q$

$$\int_S d\phi = \oint \vec{E} \cdot \vec{ds} \rightarrow (3) \quad \begin{array}{l} \text{represent.} \\ S \rightarrow \text{closed surface} \end{array}$$

$$\phi_E = \oint \vec{E} \cdot \vec{ds} = \frac{q}{\epsilon_0} \rightarrow (4)$$

$$\text{Rewrite Eqn (4) w.r.t } \frac{q}{\epsilon_0} \rightarrow (4) = 0 \cdot \nabla \quad (0) \cdot \frac{q}{\epsilon_0} = 0 \cdot \nabla$$

$$\phi_E = \oint \vec{E} \cdot \vec{ds} \quad \epsilon_0 = q \quad 0 \cdot \nabla$$

$$\oint (\epsilon_0 \vec{E}) \cdot \vec{ds} = q \quad \frac{\partial}{\partial t} = \frac{0}{0} = 0 \cdot \nabla$$

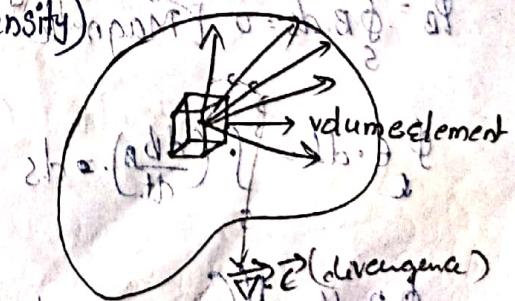
$$\oint (\vec{D}) \cdot \vec{ds} = q \quad \frac{\partial}{\partial t} = \frac{0}{0} = 0 \cdot \nabla$$

\Rightarrow Gauss law in differential form

Let us consider ρ : volume charge density

$$\text{electric flux} \quad \nabla \cdot \vec{E} = \frac{\rho}{\epsilon_0} = \frac{1}{\epsilon_0} (\text{volume charge density})$$

$$\nabla \cdot \vec{E} = \frac{\rho}{\epsilon_0} \quad (1) \quad \boxed{\nabla \cdot \vec{D} = \rho} \quad (2)$$



Gauss law in magnetism:-

The magnetic flux from a closed surface is equal to zero ("0")

It was represented in the form of equation $\oint_B = \oint B \cdot ds$

In differential form

$$\nabla \cdot B = 0$$



(Divergence of magnetic flux is always zero in case of closed surface)

→ State & Explain Maxwell's equation

Maxwell's frame the relation b/w electric field and magnetic field & the explains that variation electric & magnetic fields.

→ Maxwell's equations are linked with $\{E, D, J, E_0\}$ → electric field
 $\{B, H, \mu_0\}$ magnetic field

J: current density

$$J = \frac{I}{A} \quad \text{current density}$$

Maxwell's equations In differential form:-

$$\nabla \cdot E = \frac{P}{\epsilon_0} \quad (\text{or}) \quad \nabla \cdot D = P \quad (\text{known as Gauss law in electrostatics})$$

$$\nabla \cdot B = 0 \quad (\text{Gauss law in magnetism})$$

$$\nabla \times E = -\frac{\partial B}{\partial t} = \frac{\partial B}{\partial t} \quad \text{Amperes law} \rightarrow \text{Maxwell's Faraday's law}$$

$$\nabla \times B = \mu_0 J + \mu_0 \epsilon_0 \frac{\partial E}{\partial t} \quad \text{Maxwell - Amperes law.}$$

Maxwell's equations In Integral form:-

$$\Phi_E = \oint E \cdot dL = \frac{q}{\epsilon_0}$$

$$\Phi_B = \oint B \cdot dS = 0 \quad [\text{Magnetic flux is } 0] \quad \Phi_B \text{ magnetic flux}$$

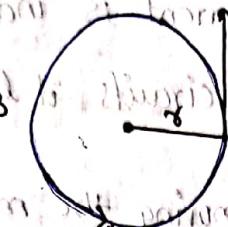
$$\oint_E E \cdot dL = \int_S \left(\frac{dB}{dt} \right) \cdot dS \quad \left[\begin{array}{l} \text{Rate of change of magnetic flux related to} \\ \text{Emf (e)} \end{array} \right]$$

$$\oint_C B \cdot dL = \int_S \left(\mu_0 J + \mu_0 \epsilon_0 \frac{dE}{dt} \right) \cdot dS$$

$$\oint_C B \cdot dL = \oint_C \text{current} \cdot dL \quad \text{with respect to time}$$

State and Explain Amperes law?

Amperes law gives the relation b/w current and magnetic field induction while current is passing through a conductor.

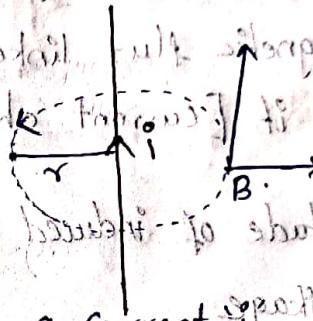


dI

Amperes law Statement: - the magneto motive force Around a closed path.

is equal to the Current Enclosed by the Path.

$$B = \frac{\mu_0 i}{2\pi r}$$

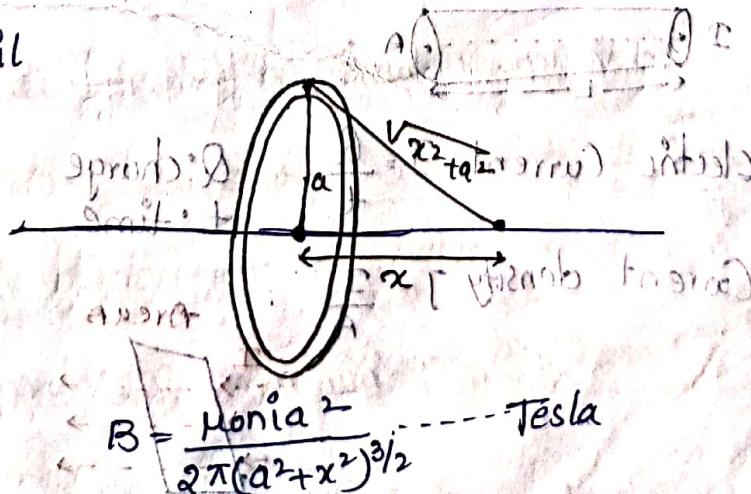


⇒ let us consider a conductor carrying a current i , there exist a magnetic field around the current carrying conductor which is \perp to the electric field

According to the amperes law $\oint B \cdot dL = \mu_0 i$

Amperes law in Integral form: $\oint B \cdot dL = \mu_0 i$ for all i

Special case of Amperes law: Amperes law is also used to calculate magnetic field along the horizontal axis of circular coil



$$B = \frac{\mu_0 i a^2}{2\pi(a^2+x^2)^{3/2}} \text{ Tesla}$$

State and explain Faraday's law?

Faraday's law gives the relation b/w Emf (Electro motive force) and Rate of change of magnetic flux
→ By changing the magnetic flux the current is induced i.e.

- By changing the magnetic flux in the circuits it leads to the changes Emf in the circuit

→ magnetic flux can be changed by moving the magnet in away/below/towards the circuit, By introducing the no. of turns in the coil

I law of faraday's law of electro magnetic induction:-

Whenever the magnetic flux linked with a circuit changes, an Emf is always induced in it [current changes]

I law :- The magnitude of induced emf is equal to the time rate of change of the flux linkage

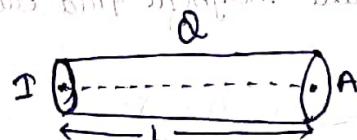
$$\text{induced Emf} = -\frac{d(\phi_B)}{dt} \quad \phi_B : \text{Magnetic flux}$$

$\frac{d(\phi_B)}{dt}$ Rate of change of magnetic flux

$$I = -N \frac{d(\phi_B)}{dt} \quad N = \text{No. of circular loops associated with electric circuit}$$

What is electric current derive the continuity equation:

Electric Current :-

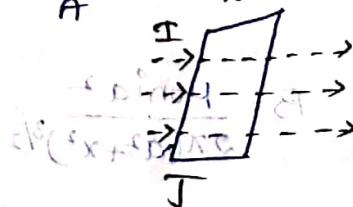


$$\text{Electric Current } I = \frac{Q}{t}$$

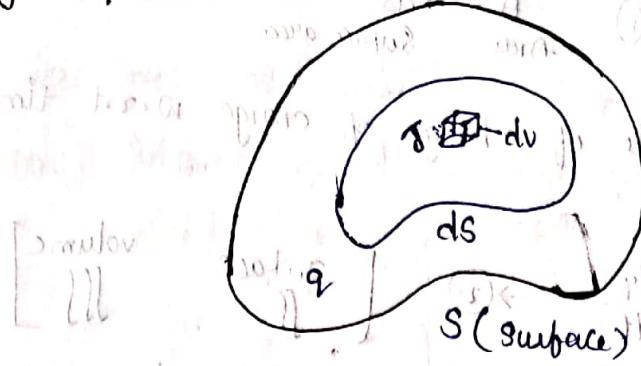
Q: charge
t: time

$$\text{Current density } J = \frac{I}{A}$$

Area A



continuity equation



27.

$ds \rightarrow$ Small Surface
 $dv \rightarrow$ Small volume
element.

⇒ The external electric field accelerates the charges, due to the displacement of charges there exist a current

⇒ The phenomenon of drifting of charges is known as drift current or electric current under external electric field.

continuity:-

$$\nabla \cdot J + \frac{d\rho}{dt} = 0$$

J: Current density.

ρ : charge density.

$\frac{d\rho}{dt}$ Rate of change of ρ with time t

⇒ Let us consider a closed Surface S, with in the Surface dv s be the.

Small area.

$$J = \frac{Q}{t} + I \cdot V$$

Let us consider dv s be the small volume in ds .

Let q be the total charge enclosed by the surface.

due to the displacement of charges there exist a current density in Volume element (ds) and strength of current is I

∴ Current $I = J \cdot A$

Total Current through the Surface

$$I = \iint_S J \cdot ds \rightarrow ① \quad \begin{array}{c} A \rightarrow ds \\ \text{Area} \end{array} \quad \begin{array}{c} \text{Surface area} \\ \text{Volume} \end{array}$$

we know that the rate of change of charge w.r.t time is

equal to current

$$I = -\frac{dq}{dt} \rightarrow ② \quad \begin{array}{c} \text{Surface} \\ \iint \end{array} \quad \begin{array}{c} \text{volume} \\ \iiint \end{array}$$

$$\therefore q = \iiint_V \rho dv \quad \rho: \text{charge density with in } dv$$

$$I = -\frac{d}{dt} (\iiint_V \rho dv) = -\int \left(\frac{\partial \rho}{\partial t} \right) dv$$

$$I = -\iiint_V \left(\frac{\partial \rho}{\partial t} \right) dv \rightarrow ③$$

$$\text{We know that } I = \iint_S J \cdot ds \rightarrow ④ = \iiint_V (\nabla \cdot J) dv \rightarrow ④$$

Because From Gauss divergence theorem

$$\iint_S J \cdot ds = \iiint_V (\nabla \cdot J) dv$$

from eqn ③ & ④ By comparison of R.H.S

$$\iiint_V (\nabla \cdot J) dv = -\iiint_V \left(\frac{\partial \rho}{\partial t} \right) dv$$

$$\iiint_V \left((\nabla \cdot J) + \left(\frac{\partial \rho}{\partial t} \right) \right) dv = 0 \quad ⑤$$

$$\nabla \cdot J + \frac{\partial \rho}{\partial t} = 0$$

Volume integral is arbitrary therefore $\iiint_V dv \neq 0$ so that in Order

$$\nabla \cdot J + \frac{\partial \rho}{\partial t} = 0 \quad \text{so that } \nabla \cdot J \text{ and } \frac{\partial \rho}{\partial t} \text{ must be zero}$$

charges are displaced from one surface to another surface constitute electric current. This continuity equation enables conservation of

charge i.e. electric charge can neither be created nor be destroyed

and the net charge in an isolated system remains constant

significance of continuity equation;

charge can not flow away from a given volume without diminishing the amount of charge existing within the volume.

diminishing means decreasing.

so if we consider a small volume element

$$\frac{dQ}{dt} = \rho A v = \rho A \frac{dx}{dt}$$

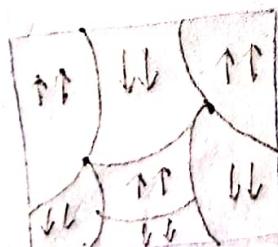
displacement current

(a) understand

Wavy path

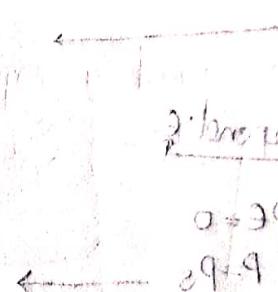


$\Delta t \rightarrow 0$



displacement current (d) p

current density $J = I/A$



$dQ = \epsilon_0 E dx$

per unit length

(a) understand

p

q

r

s

t

u

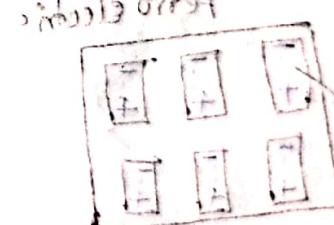
v

w

x

y

z

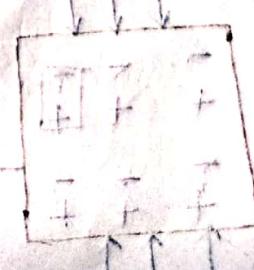


$I = \sigma A (0.1)^{0.7}$

time interval p

constant working M

: 223 dB



$I = \sigma A$

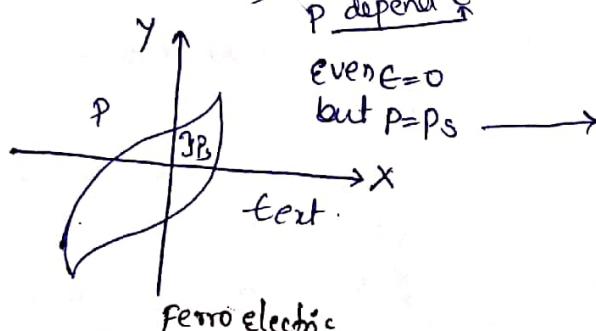
Polarization

$$P = \text{Density of dipole moment}$$

$$\epsilon_r = \frac{\epsilon}{\epsilon_0} \longrightarrow$$

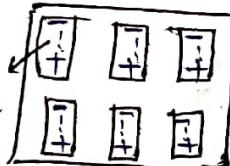
$$f_{ext} \longrightarrow$$

$$P = \epsilon_0 (\epsilon_r - 1) E \longrightarrow$$

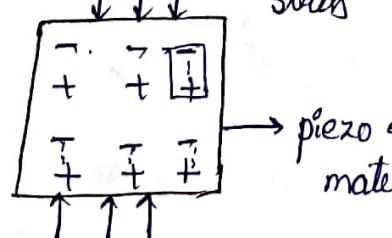
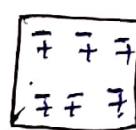
Ferro ElectricSpontaneous (P_s)

Ferro electric

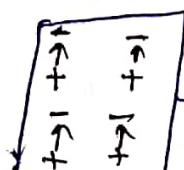
Electric dipole

Fig 1(a) $\epsilon_{r2}=0$ Piezo electric effect.Mechanical Stress:

Stress:

 $S_{eff}=0$

piezo electric material



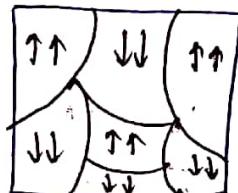
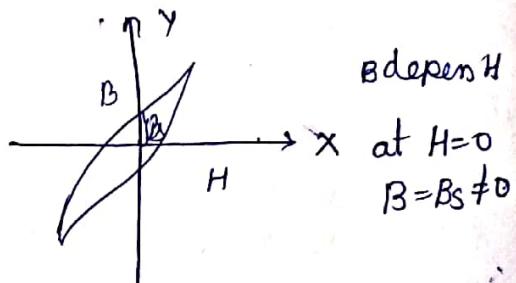
polarization

 f_{ext} magnetizationB = $\mu_r \cdot \mu_0$

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

Hext

$$B = \mu_0 (H + M) \cdot \frac{\chi - \frac{1}{\mu_r} - 1}{\chi - \frac{M}{H} - 1}$$

Ferro magneticSpontaneous (B_s)Fig 1(b) Ferromagnetic Domain
 $H=0$

Dipole

Para

Ferro

antiferro

Fermi magnet