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AP MODULE 4 SOLUTIONS

TYPED NOTES

RAJESHWARI | UJJWAL | VAIBHAV | MANEESH | ABHIRAM

Engineered Electric and Magnetic Materials

Applied Physics Module 4 Part A Solutions

@ Ujjwal Acharya

1. Explain the different types of solid dielectric materials and their polarization process.

> Dielectrics are insulating materials where all electrons are bound to their parent molecules and there are no free charges. Even when Voltage is applied, no current can pass through these materials. There are 2 types of Dielectric Materials:
> **1. Non-Polar Dielectrics:**
> The center of mass of positive particles and negative particles coincides with the non-polar dielectrics. They do not have any dipole moment. These molecules are in the form of symmetry.
> Ex: H_2, O_2, N_2
> **2. Polar Dielectrics:**
> The center of mass of positive particles in polar dielectrics doesn't coincide with the center of mass of negative particles. There's a dipole moment here. The shape of the

> molecules is asymmetrical.
> Ex: H_2O, CO_2

2. Write Lorentz relation for internal field or local field in a dielectric material.

> The internal field or a local field can be written in the form of Lorentz Relation as:

$$E_i = E_1 + E_2 + E_3 + E_4$$

$$E_i = (E + \frac{p}{\varepsilon_o}) - \frac{p}{\varepsilon_o} + 0 + \frac{p}{3\varepsilon_o}$$

$$E_i = E + \frac{p}{3\varepsilon_o}$$

3. How ferro-electric material is different from normal dielectric material.

> Some materials below a certain temperature possess spontaneous polarization even when an electric field is not applied. These materials have acquired electric dipole moment even no field is applied. Such materials are known as Ferro-electric materials.
> 🧲 The Ferroelectrics have a high dielectric constant and are used in small-sized capacitors to produce large capacitance.
> 🧲 As they satisfy Dielectric Hysteresis property, they can be used as memory devices in computers.

> 🧲 Piezo-electric transducers are used to produce & detect sound waves.
> 🧲 Pyroelectric behavior in Ferroelectrics is used to detect infrared radiation and they are used in electro mechanical filters.

4. Write the Clausius - Mosotti equation associated with a dielectric material.

> The Clausius - Mosotti Equation is a relation between the polarizability α of a molecule and the dielectric constant ε of a dielectric substance made up of molecules with this polarizability. The Clausius-Mossotti equation can be written in the form:
> Here, N is the number of molecules per unit volume.

$$\frac{\varepsilon_{ro} - 1}{\varepsilon_{ro} + 2} = \frac{N_e \alpha_e}{3\varepsilon_o}$$

5. Name different types of polarizations that occur in dielectric materials in the presence of external electric field.

> Polarization is the process of inducing dipole moment in a molecule.
> There are four types of dielectric polarization:
> **1. Electronic polarization**
> **2. Ionic polarization**
> **3. Orientational polarization**
> **4. Space charge polarization**

6. When an electric field is applied, how does the phenomenon of polarization takes place?

> Polarization is the process of inducing dipole moment in a molecule. When an electric field is applied on a dielectric material then all the positive nuclei of atoms move in the field direction and all the negative electron cloud of atoms move in opposite directions, hence dipoles are formed to produce dipole moment.
> The electron cloud readily shifts towards the positive end of the field. The extent of shift by electrons is proportional to field strength. Hence dipole moment is the product of charge and shift distance.

7. What is the difference between local electric field and applied electric field?

> In dielectric solids, the atoms or molecules experience not only the external applied electric field but also the electric field produced by the dipoles. The resultant electric field acting on the atoms or molecules of the dielectric substance is called the local field or an Internal Field.
> When a dielectric material is placed in an electric field, electric charges do not flow through the material as they do in an electrical conductor, but instead only slightly shift from their average equilibrium positions, causing dielectric polarization. This is called Applied Electric Field.

8. Recall about polar and non-polar molecules. Give two examples for each.

> Write any 3 to 4 points with examples from the below table.

Polar dielectrics	Nonpolar dielectrics
These are material which have inherent dipole moment	These materials do not have dipole moment.
In presence of electric field, positive and negative charges are separated by small distance.	In presence of electric field, positive and negative charges are not separated by small distance
These materials show the property of polarity.	These materials do not show the property of polarity.
Polar dielectrics are the polar compounds that do not conduct electricity.	Non polar dielectrics are the non-polar compounds that do not conduct electricity.
Shape of these dielectrics are asymmetric.	Shape of the dielectrics are symmetric.
Polar dielectrics are polar.	Non polar dielectrics are non-polar.
Example: ammonia and water	Example: benzene and methane

9. Write the relation between electric susceptibility and dielectric constant.

> The relation is as follows:

$$D = \varepsilon_0 (E + P)$$

Also,

$$D = \varepsilon E \quad \text{and} \quad P = X_e E$$

$$\varepsilon E = \varepsilon_0 E + X_e E$$

$$\varepsilon = \varepsilon_0 + X_e$$

$$\varepsilon / \varepsilon_0 = 1 + X_e / \varepsilon_0$$

↳ Dielectric Constant (K)

$D \rightarrow$ ε^- displacement

$P \rightarrow$ Polarization density

$X_e \rightarrow$ ε^- Susceptibility

$E \rightarrow$ Electric Field

10. Why is a capacitor known to be an energy storing device?

> A capacitor is a passive two-terminal electrical component used to store energy electrostatically in an electric field. They store electrical energy in the form of electrical charges accumulated on their plates. When a capacitor is connected to a power source, it accumulates energy which can be released when the capacitor is disconnected from the charging source. This is how it stores energy in itself and releases, similar to a battery.

11. How do you account for the magnetic properties of materials?

> There are 5 important magnetic properties of materials:
> **Property 1: Intensity of magnetization (I) -**
> When a material is magnetized, it develops a net magnetic moment. The magnetic moment per unit volume is called the Intensity of magnetization.
> $$Magnetization(M) = \frac{MagneticMoment}{Volume}$$
> **Property 2: Magnetic Field (H) or Magnetic intensity -**
> When a medium is exposed to a magnetic field of intensity 'H', it causes an induction 'B' in the medium.
> $B = \mu_0 H$
> **Property 3: Magnetic susceptibility -**
> When a material is placed in an external magnetic field, the material gets magnetized. For a small magnetizing field, the intensity of magnetization (I) acquired by the material is directly proportional to the magnetic field (H).

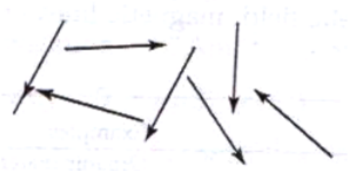
> $I = X_m H$
> **Property 4: Retentivity -**
> The ability of a material to retain or resist magnetization is called retentivity.
> **Property 5: Coercivity -**
> The coercivity of a material is the ability to withstand the external magnetic field without becoming demagnetized.

12. What is curie temperature? Is it unique for all substances?

> The Ferroelectric materials possess spontaneous polarization below a certain temperature. As temperature increases the spontaneous polarization decreases and at a particular temperature, the spontaneous polarization vanishes. This temperature is called Curie temperature. It is defined as the temperature at which Ferroelectric material converts into a Para electric material.
> The curie temperature depends on the magnetic moments and material parameters of the materials such as susceptibility, dipole moments, permeability, permittivity, etc of the given material. Hence, the value of Curie is different and unique for every substance.

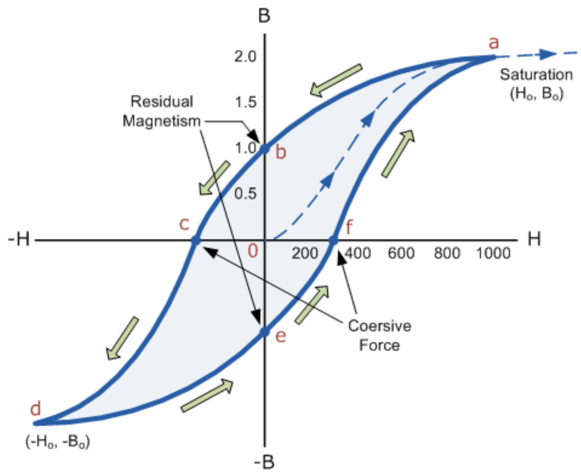
13. Mention the types of magnetic materials based on electron spins.

> There are 3 types of magnetic materials based on electron spins:

Diamagnetic materials	Paramagnetic materials	Ferromagnetic materials
1.Diamagnetism: It is the property of the material which has repulsive nature (or) opposing magnetization.	*1.Paramagnetism:* It is the property of the material which has weak attractive force.	*1.Ferromagnetism* It is property of the material which has strong attractive force.
2. The property is due to orbital motion of electrons.	2. The property is due to spin of electrons.	2. The property is due to spin of electrons.
3.There is no spin	3.Spin is random 	3.Spin is parallel 
4. These materials are lack of magnetic dipoles.	4. These materials have permanent dipoles.	4. They have permanent magnetic dipoles.
5. They do not possess permanent dipole magnetic moment (it is zero). Hence spontaneous magnetization is zero.	5. They possess permanent magnetic dipole moment. But there is no spontaneous magnetization in the absence of external field, due to random spin.	5. They possess permanent magnetic dipole moment. Also in the absence of field they have spontaneous magnetization even in the absence of external field due to parallel spin.

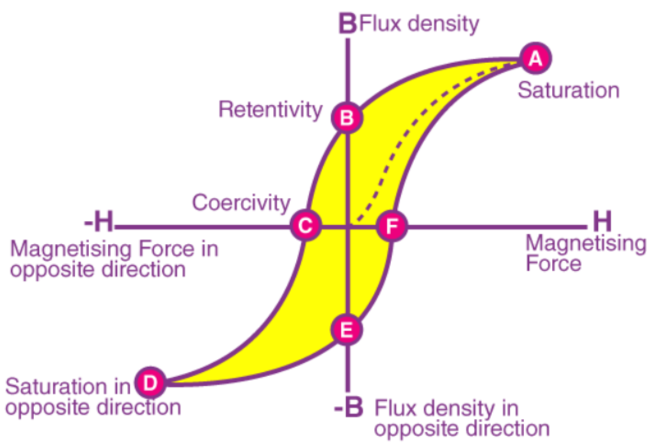
14. Sketch neatly hysteresis loop observed in ferromagnetic materials.

> Ferromagnetic Materials are materials that have the property of strong attractive force. Their spin is parallel and they have permanent magnetic dipoles. The Magnetic Hysteresis loop below shows the behavior of a ferromagnetic core graphically as the relationship between B and H is non-linear.



15. What is hysteresis? What does the area of hysteresis curve represent?

> Hysteresis means the lagging of magnetization 'B' behind the applied magnetizing field 'H'. The energy supplied to the specimen during magnetization is not fully used. The balance of energy left in the material is produced as heat i.e. loss of heat called Hysteresis Loss.
> The area of the Hysteresis curve of any substance represents the energy loss in magnetizing a substance.



16. Define diamagnetic, paramagnetic and ferromagnetic materials.

Diamagnetic materials	Paramagnetic materials	Ferromagnetic materials
1.Diamagnetism: It is the property of the material which has repulsive nature (or) opposing magnetization.	*1.Paramagnetism:* It is the property of the material which has weak attractive force.	*1.Ferromagnetism* It is property of the material which has strong attractive force.
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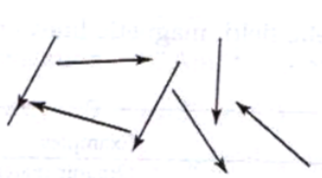
3.There is no spin	3.Spin is random 	3.Spin is parallel 
4. These materials are lack of magnetic dipoles.	4. These materials have permanent dipoles.	4. They have permanent magnetic dipoles.
5. They do not possess permanent dipole magnetic moment (it is zero). Hence spontaneous magnetization is zero.	5. They possess permanent magnetic dipole moment. But there is no spontaneous magnetization in the absence of external field, due to random spin.	5. They possess permanent magnetic dipole moment. Also in the absence of field they have spontaneous magnetization even in the absence of external field due to parallel spin.

17. Give two examples for each diamagnetic, paramagnetic and ferromagnetic material.

> **Diamagnetic Materials:**
> Those substances which are weekly magnetized when placed in an external magnetic field, in a direction opposite to the applied field are called diamagnetic substances.
> Examples: hydrogen, nitrogen, etc.
> **Paramagnetic Materials:**
> Those substances which are weekly magnetized when placed in an external magnetic field in the same direction as the

> applied field are called Paramagnetic substances. They tend to move from the weaker to the stronger part of the field.
> Examples: sodium, oxygen, etc.
> **Ferromagnetic Materials:**
> Those substances which are strongly magnetized in an external magnetic field in the same direction as the externally applied field and retain their magnetic moment even after the removal of the external field are Called Ferromagnetic substances. They have a very strong tendency to move from weaker to the stronger parts of the external field.
> Examples: Iron, cobalt, etc.

18. Define coercivity and retentivity of a ferromagnetic material.

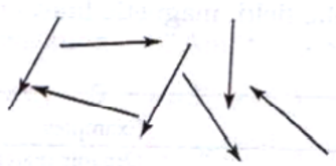
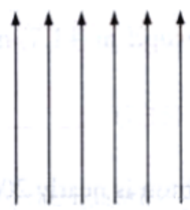
> **Coercivity in Ferromagnetic Materials:**
> In ferromagnetic substances, when the applied magnetic field is increased in the reverse direction, then at some point H_c the substance completely loses its magnetization. This point is known as Coercivity.
> **Retentivity in Ferromagnetic Materials:**
> When the applied magnetic field is decreased to zero after meeting the saturation point of magnetization, then the remaining magnetization shown by the substance is known as Retentivity.

19. Discuss in detail about Bohr magneton. Also mention its value.

> The Bohr magneton μ_B is a physical constant and the natural unit for expressing the magnetic moment of an electron

> caused by either its orbital or spin angular momentum. It is also the fundamental unit of the magnetic moment.
>
> $\mu_B = \frac{e\hbar}{2m_e}$
>
> where e is the elementary charge, $\hbar$ is the reduced Planck's constant, me is the electron rest mass.
>
> The value of Bohr magneton in SI units is $9.27400968 \times 10^{-24} JT^{-1}$

20. Compare the relative permeability values of diamagnetic, paramagnetic and ferromagnetic material.

Diamagnetic materials	Paramagnetic materials	Ferromagnetic materials
1.Diamagnetism: It is the property of the material which has repulsive nature (or) opposing magnetization.	*1.Paramagnetism:* It is the property of the material which has weak attractive force.	*1.Ferromagnetism* It is property of the material which has strong attractive force.
2. The property is due to orbital motion of electrons.	2. The property is due to spin of electrons.	2. The property is due to spin of electrons.
3.There is no spin	3.Spin is random 	3.Spin is parallel 
7. The relative permeability $\mu_r<1$.	7. The relative permeability $\mu_r>1$.	7. The relative permeability $\mu_r>>1$.

MODULE 4 PART B SOLUTIONS

@ Rajeshwari

1.) What do you understand about dielectric materials? Establish a relationship between D, E and P.

A.) A dielectric material is a substance that is a poor conductor of electricity, but an efficient supporter of electrostatic fields. When dielectrics are placed in an electric field, practically no current flows in them because, unlike metals, they have no loosely bound, or free, electrons that may drift through the material.

Let us derive the relation between polarization vector (P), displacement (D) and electric field (E):

The effect on dielectric is placed in an external electric field E_0 and there will be electric field due to polarized charges, this field is called electric field due to polarization (E_p).

$$E = E_0 - E_p \quad (1)$$

Polarization vector, P = P is equal to the bound charge per unit area or equal to the surface density of bound charges (because surface charge density is charge per unit area),

$$\text{Thus } P = q_b/A = \sigma_p \quad (2)$$

Where q_b is bound charge and σ_p is surface density of bound charges.

P is also defined as the electric dipole moment of material per unit volume.

$$P = np$$

where n is the number of molecules per unit volume.

Displacement vector, D= D is equal to the free charge per unit area or equal to the surface density of free charges,

Thus $D = q/A = \sigma$ (3)

where q is free charge and σ is surface density of free charges.

As for parallel plate capacitor

$$E = \sigma / \varepsilon_0 \quad (4)$$

$$E_p = \sigma_p / \varepsilon_0 \quad (5)$$

By substituting equations 4 and 5 in equation 1, we get

$$E = \sigma / \varepsilon_0 - \sigma_p / \varepsilon_0$$

$$\text{Or } \varepsilon_0 E = \sigma - \sigma_0$$

By putting equations 2 and 3 in above equation, we get

$$\varepsilon_0 E = D - P$$

$$\text{or } D = \varepsilon_0 E + P$$

This is the relation between D, E and P

2.) Explain in detail, the terms: (a) Dielectric constant (b) Electric susceptibility (c) Displacement vector

A.) DIELECTRIC CONSTANT: The dielectric constant is a measure of the amount of electric potential energy, in the form of induced polarization that is stored in a given volume of material under the action of an electric field. It is expressed as the ratio of the dielectric permittivity of the material to that of a vacuum or dry air.

Dielectric Constant

||

Relative Permittivity

Permittivity of the material

$$\kappa = \varepsilon_r = \frac{\varepsilon_m}{\varepsilon_0}$$

Permittivity of Vacumm

8.85418782 x 10^{12} Farads/meter

ELECTRIC SUSCEPTIBILITY:

Electric Susceptibility: When a dielectric material is placed in air electric field. It becomes electrically polarized. For most material the polarization is proportional to electric field E i.e.

$$P \propto E$$

$$P = XeE \qquad \ldots(1)$$

Where Xe is constant, characteristic of material called the electric susceptibility

$$Xe = \frac{P}{E}$$

That is, the electric susceptibility may be defined as the ratio of polarization to electric field strength in the dielectric

The units of electric susceptibility are

$$\frac{\mathrm{C/m^2}}{\mathrm{N/C}} = \mathrm{C^2/N{-}m^2}$$

DISPLACEMENT VECTOR: In physics, the electric displacement, also known as dielectric displacement and usually denoted by its first letter D, is a vector field in a non-conducting medium, a dielectric. The displacement D is proportional to an external electric field E in which the dielectric is placed.

In SI units the proportionality is,

$$\mathbf{D}(\mathbf{r}) = \epsilon_0 \epsilon_r \mathbf{E}(\mathbf{r}),$$

Another auxiliary field is the electric polarization P of the dielectric,

$$\mathbf{P} \equiv \mathbf{D} - \epsilon_0 \mathbf{E} = \epsilon_0(\epsilon_r - 1)\mathbf{E} \qquad \text{(SI)}$$

$$\mathbf{P} \equiv \frac{1}{4\pi}(\mathbf{D} - \mathbf{E}) = \frac{1}{4\pi}(\epsilon_r - 1)\mathbf{E} \qquad \text{(Gaussian)}$$

3.) Derive a relation between electronic polarization and electric susceptibility of the dielectric medium?

Electric Susceptibility Formula

The formula of electric susceptibility is derived as follow:

$P = \varepsilon_0 X_e E$

Where,

P = It is considered as the polarization density.

ε_0 = It is considered as the electric permittivity of free space.

X_e = It is considered as the electric susceptibility.

E = It represents the electric field.

The susceptibility is proved to be related to its relative permittivity, also known as dielectric constant ε_r by:

$X_e = \varepsilon_r - 1$

Therefore in the case of vacuum,

$X_e = 0$

During this time, the electric displacement D also becomes equal to the polarization density P by:

$D = \varepsilon_0 E + P = \varepsilon_0(1 + X_e) E = \varepsilon_r$

Where,

$\varepsilon = \varepsilon_r \varepsilon_0$

$\varepsilon_r = (1 + X_e)$

The dielectric constant is mathematically expressed as

$k = \varepsilon/\varepsilon_0$

Where,

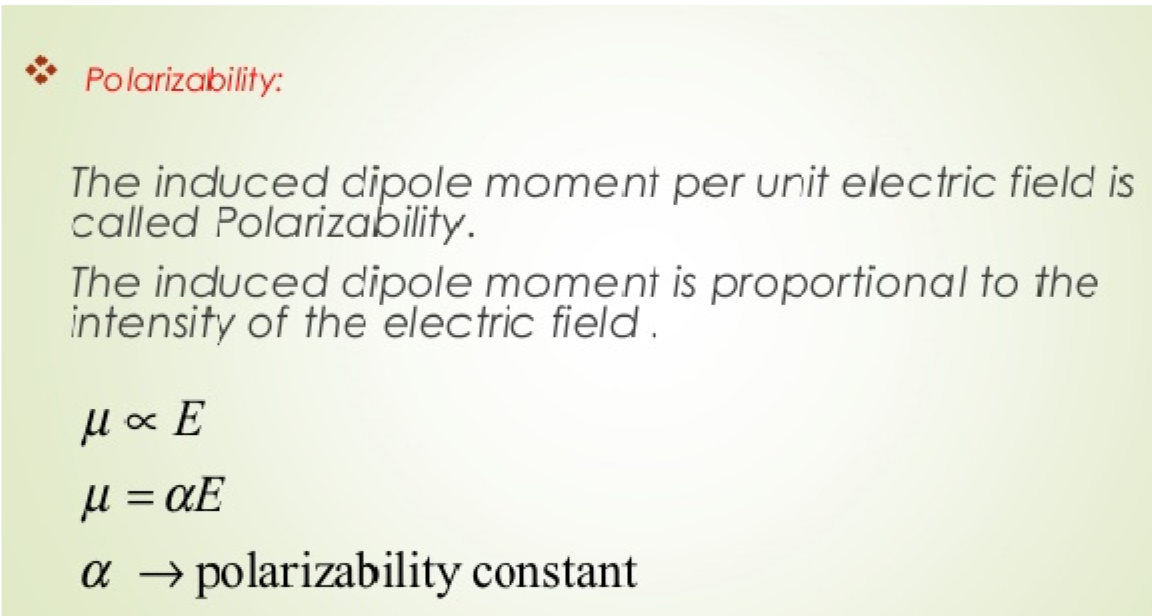
K= Dielectric Constant.

ε = The permittivity of a substance.

ε_0 = The permittivity of free space.

4.) Explain in detail, the terms: (a) Polarizability (b) Polarization vector (c) Electric dipole (d) Electric dipole moment

A.) POLARIZABILITY: When an external electric field is applied to a dielectric material this material becomes polarized, which means that it acquires a dipole moment. This property of dielectrics is known as polarizability. The effect is therefore to pull the opposite charges apart, i.e., to polarize the molecule.



POLARIZATION VECTOR: It is defined as the average dipole moment per unit volume of a dielectric. If 'N' molecules are present per unit volume, Then polarization vector $\vec{P}$=(Nμ)/volume

$\vec{P}$ = N μ coulomb/m. Example, if p denotes the average dipole moment per molecule or atom and n is the total number of molecules or atoms per unit volume, then the polarization vector P = np.

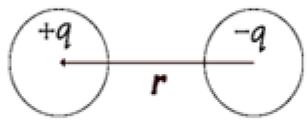
ELECTRIC DIPOLE MOMENT: The product of charge and distance between two charges is called electric dipole moment.

$$\mu = q \times r$$

Units: coulomb - meter or Debye.

$$\text{Debye} = 3.33 \times 10^{-30} \text{ coulomb – meter}$$

ELECTRIC DIPOLE: An electric dipole is defined as a couple of opposite charges q and –q separated by a distance d.The simplest example of an electric dipole is a pair of electric charges of two opposite signs and equal magnitude separated by distance r.



$$\mu = qr$$

Fig. Electric dipole

5.) Discuss about Clausius-Mossotti relation in dielectrics subjected to static fields and also explain its significance?

A.)The Clausius-Mossotti relation connects the relative permittivity ε_r of a dielectric to the polarizability α of the atoms or molecules constituting the dielectric. The relative permittivity is a bulk (macroscopic) property and polarizability is a microscopic property of matter; hence the relation bridges the gap between a directly-observable macroscopic property with a microscopic molecular property.

Clausius – Mosotti relation

This makes the relation between microscopic & macroscopic quantities of Polarization. From Polarization Vector

$\vec{P} = N\mu \quad \rightarrow (1)$

Where N = No. of molecules per unit volume, μ = average dipole moment

$\mu = \alpha E = \alpha E_i \quad \rightarrow (2)$

Where E_i = local (or) internal field $= \frac{P}{3\epsilon o} \quad \rightarrow (3)$

Substituting (2) & (3) in (1)

$$P = N\alpha E_i$$

$$P = N\alpha\left[E + \frac{P}{360}\right]$$

$$P - N\alpha E + \frac{N\alpha P}{3\epsilon o}$$

$$\left[P - \frac{N\alpha P}{3\epsilon o}\right] = N\alpha E$$

$$P\left[1 - \frac{N\alpha}{3\epsilon o}\right] = N\alpha E$$

$$P = \frac{N\alpha E}{\left[1 - \frac{N\alpha}{3\epsilon o}\right]} \quad \text{———} (4)$$

We know that $P = \epsilon_0 E[\epsilon_r - 1] \quad \rightarrow (5)$

Equating (4) & (5)

$$\frac{N\alpha E}{\left(1-\frac{N\alpha}{360}\right)} = \epsilon_0 E[\epsilon_r - 1]$$
$$\frac{N\alpha}{\epsilon_0[\epsilon_r-1]} = \left(1 - \frac{N\alpha}{3\epsilon_0}\right)$$
$$\frac{N\alpha}{\epsilon_0[\epsilon_r-1]} = 1 - \frac{N\alpha}{3\epsilon_0}$$
$$\frac{N\alpha}{\epsilon_0[\epsilon_r-1]} + \frac{N\alpha}{3\epsilon_0} = 1$$
$$1 = \frac{N\alpha}{3\epsilon_0}\left[\frac{3}{\epsilon_{r-1}} + 1\right]$$
$$1 = \frac{N\alpha}{3\epsilon_0}\left[\frac{3+\epsilon_r-1}{\epsilon_r-1}\right]$$
$$1 = \frac{N\alpha}{3\epsilon_0}\left[\frac{\epsilon_r+2}{\epsilon_r-1}\right]$$
$$\frac{\epsilon_r-1}{\epsilon_r+2} = \frac{N\alpha}{3\epsilon_0}$$
$$\text{If} \left\{\begin{matrix} \alpha_m = molar\ polarization \\ N_A = Avagadro\ number \\ \rho = density \\ M = molecular\ weight \end{matrix}\right\}$$
$$\Rightarrow \mathrm{N} = \frac{\rho N_A}{M}$$
$\Rightarrow$ From Clausius Mosotti relation
$$\left[\frac{\epsilon_r-1}{\epsilon_r+2}\right] = \frac{N_A}{3\epsilon_0}$$
$$\left[\frac{\epsilon_r-1}{\epsilon_r+2}\right] = \frac{\rho N_A}{3\epsilon_0}\left[\frac{\alpha_m}{3\epsilon_0}\right]$$

SIGNIFICANCE OF CLAUSIUS AND MOSSOTTI EQUATION IS:
The Clausius-Mossotti equation relates the dielectric constant of a material to the polarizability of its atoms. It finds natural explanation in terms of the (often omitted) delta function in the electric field of an ideal dipole. This avoids the subtleties of the rather tricky conventional derivation.

6.) On application of external electric fields, various polarization processes take place in dielectric material. Explain briefly all these polarization processes?

A.) Polarization occurs when an electric field distorts the negative cloud of electrons around positive atomic nuclei in a direction opposite the field. This polarization process of slight separation of charge makes one side of the atom somewhat positive and the opposite side somewhat negative. In some materials whose molecules are permanently polarized by chemical forces, such as water molecules, some of the polarization is caused by molecules rotating into the same alignment under the influence of the electric field. One of the measures of polarization is electric dipole moment, which equals the distance between the slightly shifted centers of positive and negative charge multiplied by the amount of one of the charges. Polarization P in its quantitative meaning is the amount of dipole moment p per unit volume V of a polarized material, P = p/V.

7.) Obtain an expression for the internal field experienced by an atom inside a dielectric material subjected to an external field by using the Lorentz method.?

A.Local field or internal field in a dielectric is the space and time average of the electric field intensity acting on a particular molecule in the dielectric material.

Evaluation of internal field

Consider a dielectric be placed between the plates of a parallel plate capacitor and let there be an imaginary spherical cavity around the atom A inside the dielectric.The internal field at the atom site 'A' can be made up of four components E_1 ,E_2, E_3 & E_4

Field E_1:

E_1 is the field intensity at A due to the charge density on the plates

$$E_1 = \frac{D}{\varepsilon_0}$$

$$D = \varepsilon_0 E + P$$

$$E_1 = \frac{\varepsilon_0 E + P}{\varepsilon_0}$$

$$E_1 = E + \frac{P}{\varepsilon_0} \text{..........(1)}$$

Field E_2:

E_2 is the field intensity at A due to the charge density induced on the two sides of the dielectric

$$E_2 = \frac{-P}{\varepsilon_0} \text{..........(2)}$$

Field E_3:

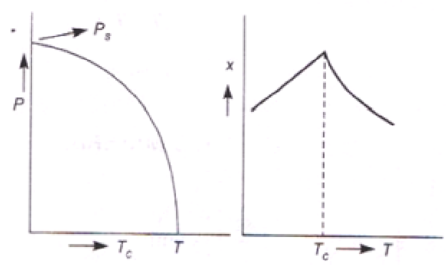
E_3 is the field intensity at A due to the atoms contained in the cavity, we are assuming a cubic structure, so $E_3 = 0$.

8.) Write notes on dielectric theory of ferroelectricity. What are the important characteristics of ferroelectric material?

A.) Ferroelectricity, property of certain non conducting crystals, or dielectrics, that exhibit spontaneous electric polarization (separation of the center of positive and negative electric charge, making one side of the crystal positive and the opposite side negative) that can be reversed in direction by the application of appropriate electric field. Some materials (below a certain temperature) possess spontaneous polarization even when the electric field is not applied. These materials have acquired an electric dipole moment even when no field is applied. These materials are known as Ferroelectrics. And this phenomenon is known as Ferro electricity.

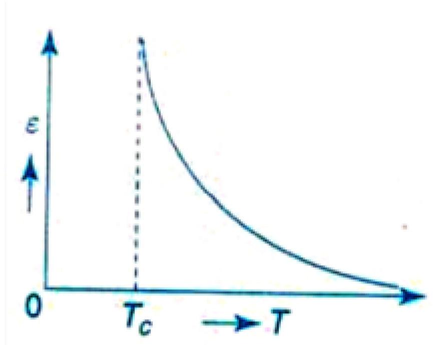
CHARACTERISTICS OF FERROELECTRIC MATERIAL

The Ferroelectric materials possess spontaneous polarization below a certain temperature. As temperature increases the spontaneous polarization decreases and at a particular temp, the spontaneous polarization vanishes. This temperature is called Curie temperature. It is defined as the temperature at which Ferroelectric material converts into a Para electric material.



Spontaneous polarization with respect to temperature (b) Variation of ϵ_r or χ with respect to temperature

Below Tc - curie temperature; the dielectric material possesses Ferroelectric property. As temperature increases the dielectric constant reduces after 'Tc '. It is shown in the figure below:



Variation of dielectric constant with temperature

Variation of dielectric constant with temperature

From curie-Weiss law

$\epsilon_r = c / T - T_c$, ϵ_r= Dielectric constant, C=curie constant,

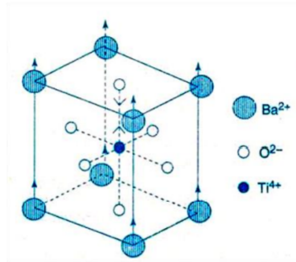
T= absolute temperature, T_c=curie temperature

Ferro electrics exhibit the property called Piezo–electricity & Pyroelectricity. "Piezo electricity" means when mechanical stress is applied to Ferroelectric materials then the opposite charges are formed on the surface of crystal generating electricity.[In Greek _piezo' means pressure] "Pyro electricity" means the change of Spontaneous Polarization of Ferroelectric materials by the application of temperature.[In Greek —Pyro means Heat] Ferroelectric materials also exhibit the property called "Di-electric Hysteresis" Dielectric Hysteresis: It is defined as the lagging of polarization behind the electric field app

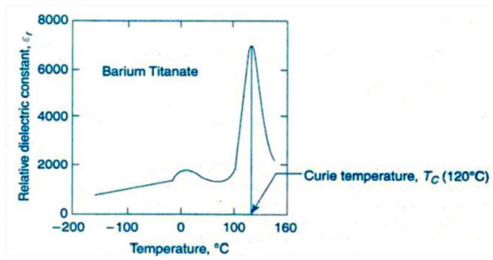
9.) Explain the phenomenon of ferroelectricity with particular reference to Barium titanate.

A.) Some materials (below a certain temperature) possess spontaneous polarization even when the electric field is not applied. These materials have acquired an electric dipole moment even when no field is applied. These materials are known as Ferroelectrics. And this phenomenon is known as Ferro electricity.

Structure of BaTiO_3- A Ferro electric material



Structure of BaTiO_3above T_C



Variation of dielectric constant with temperature

We know that BaTiO3 is a ferroelectric material.

The cubic unit cell of BaTiO3crystal structure consists of 71 barium cations at the corners & oxygen anions at the face centers. Titanium ion is in the octahedral void at the body center.

Above 120°C, BaTiO3 is a cubic crystal. In this state, the centers of positive and negative charges coincide. Hence there is no spontaneous dipole moment & polarization is zero. If the crystal is cooled below 120°C, the titanium ions shift to one side of the body centre and neighboring oxygen ions also get shifted. The centers of positive charge due to titanium cat ions and centers of negative charges due to oxygen anions get shifted (o) displaced. Hence dipoles are created to give dipole moments.

10.) Define dielectric breakdown. What are the different mechanisms involved in dielectric breakdown?

A.) Electrical breakdown or dielectric breakdown is a process that occurs when an electrical insulating material, subjected to a high enough voltage, suddenly becomes an electrical conductor and electric current flows through it. All insulating materials undergo breakdown when the electric field caused by an applied voltage exceeds the material's dielectric strength. The voltage at which a given insulating object becomes conductive is called its breakdown voltage and depends on its size and shape. Under sufficient electrical potential, electrical breakdown can occur within solids, liquids, gases or vacuum.

11.) Explain the terms magnetic dipole, magnetic dipole moment, magnetic field intensity and magnetic induction?

A.) Magnetic dipole: Each tiny dimension of a magnetic material (or) atoms in magnetic materials is called magnetic dipole. This magnetic dipole produces a magnetic moment depending on the alignment with respect to the applied magnetic field.

Magnetic dipole moment: A vector quantity associated with the magnetic properties of electric current loops or, more generally, magnets. It is equal to the amount of current flowing through the loop multiplied by the area encompassed by the loop, and its direction is established by the right-hand rule for rotations. It is the product of the pole strength of one of the poles of a magnet and the distance between the poles. It's S.I. unit is Am^2.

Magnetic field intensity: Magnetic field strength, also called magnetic intensity or magnetic field intensity, the part of the magnetic field in a material that arises from an external current and is not intrinsic to the material itself. It is expressed as the vector H and is measured in units of amperes per metre.

Magnetic induction: Magnetic induction at a point is defined as the force experienced by a unit North Pole placed at that point.

It is denoted by 'B '

$$\text{i.e., } B = \Phi/A \text{ weber / m}^2$$

12.) Discuss in detail about the magnetic permeability, relative permeability, Intensity of magnetization and magnetic susceptibility?

A.) Magnetic permeability: It indicates, with which the material allows magnetic lines of force to pass through it.

Or

It is the ability of the medium to pass magnetic lines of forces through it. There are three Permeabilities i.e., $\mu 1$, $\mu 0$, μr

$\mu = \mu 0\ \mu r$

Where μ = Absolute permeability of the medium

$\mu 0$ = Permeability of free space i.e., air or vacuum

μr = Relative permeability of the medium

Relative permeability: Relative permeability of the medium is derived from magnetic permeability as the ratio of permeability of any medium to that of air or free space. It is denoted by μ. $\mu r=\mu/\mu 0$.

Here, $\mu 0$= absolute permeability of air or free space =$4\pi\times10-7$ tesla x m/amp.

Intensity of magnetization: When a material is magnetized, it develops a net magnetic moment. The magnetic moment per unit volume is called

Intensity of magnetization Magnetization (M) =
Magnetic moment /Volume Units: Amp/m

Magnetic susceptibility: If H is the applied magnetizing field intensity and M is the amount of magnetization of the material,

Then $\chi = M/H$

χ = 0 in vacuum

χ = +Ve for paramagnetic and Ferromagnetic materials

χ = −Ve for diamagnetic materials

Units: It has no units.

13.) Obtain a relation between magnetic susceptibility, magnetization and magnetic field intensity.

A.) We know that

$$B = \mu H \rightarrow (1)$$

But $\mu = \mu_0 \mu_r$

$$B = \mu_0 \mu_r H \rightarrow (2)$$

Adding & subtracting with $\mu_0 H$ on right hand side of equation (2)

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

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

$$= \mu_0 H [\mu_r - 1] + \mu_0 H$$

But $M = H [\mu_r - 1] \rightarrow (3)$

Now eq (3) becomes $B = \mu_0 M + \mu_0 H$

$$B = \mu_0 [H+M] \rightarrow (4)$$

Consider equation (3), $M = H [\mu_r - 1]$

$$M/H = \mu_r - 1 \rightarrow (5)$$

But magnetic susceptibility $\chi = M/H$ from equations (5) and (6)

$$\chi = M/H = \mu_r - 1$$

$$\mu_r = 1 + \chi$$

14.) Describe the origin of magnetic moment and find the magnetic dipole moments due to orbital and spin motions of an electron.?

A.) Origin of magnetic moment (Or) Sources of magnetic moment:

In atoms, the permanent magnetic moment arises due to

a) Orbital motion of electrons and its magnetic moment is called orbit magnetic moment of electrons (μl).

b) The spin of electrons and its magnetic moment is called spin magnetic moment of electrons (μs).

c) The spin of the nucleus (due to protons) and its magnetic moment is called spin magnetic moment of the nucleus (μn or μp).

Explanation: a) Magnetic moment due to orbital motion of the electrons ($\boldsymbol{\mu l}$). Let us consider an electron of charge e revolving around a nucleus in time period T in a circular orbit of radius r. Then a magnitude of circular current I is given by

$$I = \text{Charge/time} = e/\ T \rightarrow (1)$$

$$\text{But } T = 2\pi/\ \omega$$

Where ω = angular velocity of electron

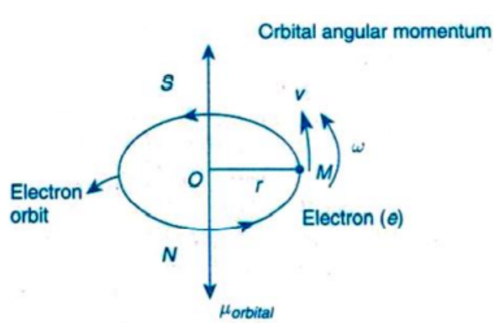
$$I = e\omega/\ 2\pi$$

But magnetic moment of electron is

$$\mu l = I \times A\ \ \mu l = \text{current area of circulating orbit}$$

$$\mu l = e\omega\ 2\pi\ (\pi r\text{^}\ 2)$$

$$\mu l = e\omega\ r\text{^}\ 2\ /2$$



Orbital magnetic moment of electrons

We know that angular momentum of any particle,

$$L = m\omega r^2$$

Substituting eq.(4) in eq.(3) we get

Orbital magnetic moment, $\mu l = (-e/2m).L \rightarrow (5)$

[-ve sign indicates μl and are in opposite directions]

$$\mu l = (-e/2m)\ L$$

But from Bohr's atomic model

$$mvr = nh/2\pi$$

$$L = lh/2\pi$$

Where l = orbital quantum number, L = orbital angular momentum.

The values of l = 0, 1, 2---------- (n-1)

Hence $\mu l = (-e/2m)(lh/2\pi)$

$$\mu l = -(eh/4\pi m)\ l \rightarrow (6)$$

Where $eh/4\pi m = \mu B$ is a constant called Bohr magneton and its value is 9.27×10-24amp-m 2

Hence eq(6) becomes $\mu l = l\mu B \rightarrow (7)$

Bohr magneton is the fundamental unit of magnetic moment.

It is clear from eq (7) that electron can take only certain specified values of magnetic moment depending on the value of 'l '.

Bohr suggested that both magnitude and direction of I are quantified. It is known as — Spatial quantization.

b) Magnetic moment of electrons due to spin of electrons (μs)

According to quantum theory, electrons should have intrinsic angular momentum due to spin. Spin is also quantized both in magnitude and direction spin can take only one value i.e ½ or – ½. The magnetic moment produced due to spin of electrons is called spin magnetic moment (μs).

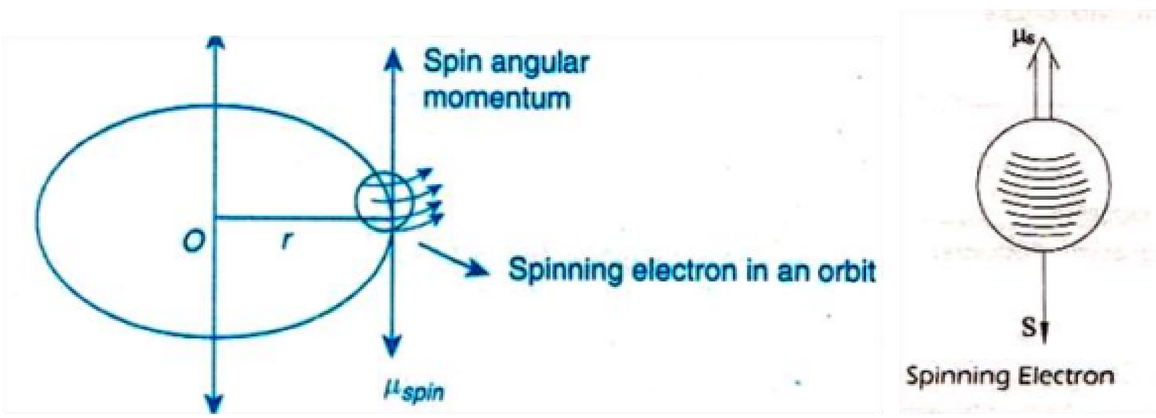
It is given by

Spin magnetic moment $\mu s = -2(e/2m)\, S \rightarrow (9)$

where S=spin angular momentum, e = charge of electron,

m = mass of electron, $S = sh/2\pi$

where S = spin quantum number, h = Planck 's constant



Spin magnetic moment of electrons

From equation (9),

$\mu s = -2(e/2m)\, S$

Since $S = sh/2\pi$

$\mu s = -2(e/2m)(sh/2\pi)$

$s = \pm 1/2$, $\mu s = \pm eh/4\pi m$

$\mu s = eh/4\pi m,\ -eh/4\pi m$

$\mu s = +\mu B,\ -\mu B$

Hence the spin magnetic moment of an electron is equal to μ_B. That is one Bohr magneton.

Hence there are two possible orientations of electrons.

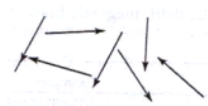
Conclusion: Para magnetism, Ferro magnetism is due to spin magnetic moment. Diamagnetism is due to orbital magnetic moments.

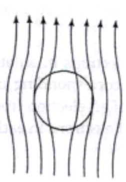
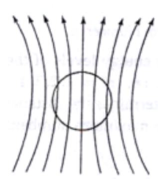
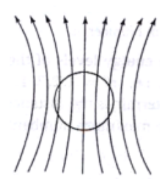
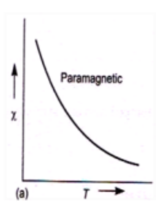
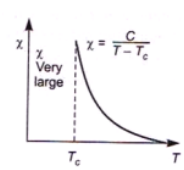
15.) What is a Bohr magneton? How it is related to the magnetic moment of an electron.

A.) The Bohr magneton μ_B is a physical constant and the natural unit for expressing the magnetic moment of an electron caused by either its orbital or spin angular momentum.
$\mu_B = e\hbar/2m$
where e is the elementary charge, $\hbar$ is the reduced Planck's constant, m is the electron rest mass.
The value of Bohr magneton in SI units is 9.27400968(20)×10-24JT-1

Magnetic moment of electrons is the Bohr magneton (equivalent to 9.27×10^{-24} ampere–square meter). A similar unit for magnetic moments of nuclei, protons, and neutrons is the nuclear magneton (equivalent to 5.051×10^{-27} ampere–square meter).

16.) Distinguish between diamagnetic, paramagnetic and ferromagnetic materials. Explain their behavior with the help of examples.?.)

Diamagnetic materials	Paramagnetic materials	Ferromagnetic materials
1.Diamagnetism: It is the property of the material which has repulsive nature (or) opposing magnetization.	*1.Paramagnetism:* It is the property of the material which has weak attractive force.	*1.Ferromagnetism* It is property of the material which has strong attractive force.
2. The property is due to orbital motion of electrons.	2. The property is due to spin of electrons.	2. The property is due to spin of electrons.
3.There is no spin	3.Spin is random 	3.Spin is parallel 
4. These materials are lack of magnetic dipoles.	4. These materials have permanent dipoles.	4. They have permanent magnetic dipoles.
5. They do not possess permanent dipole magnetic moment (it is zero). Hence spontaneous magnetization is zero.	5. They possess permanent magnetic dipole moment. But there is no spontaneous magnetization in the absence of external field, due to random spin.	5. They possess permanent magnetic dipole moment. Also in the absence of field they have spontaneous magnetization even in the absence of external field due to parallel spin.

6.  $B_{in} < B_{out}$	6.  $B_{in} > B_{out}$	6.  $B_{in} > B_{out}$
7. The relative permeability $\mu_r<1$.	7. The relative permeability $\mu_r>1$.	7. The relative permeability $\mu_r>>1$.
8.Susceptibility χ is small and negative	8. Susceptibility is small but positive	8. Susceptibility is large and positive
9. χ does not depend on temperature. No particular is graph is drawn.	9. χ depends on temperature 	9. χ depends on temperature 
10. χ does not depend on temperature.	10. $\chi = c/T$ (curie law) C=curie constant T = absolute temperature	10. $\chi = c/T-\theta$ curie-Weiss law θ = curie temperature
11.Examples Cu, Au, Zn, H_2O, Bi etc. organic materials.	11.Examples: Al, Pt, Mn,CuCl2 etc. Alkali & transition metals.	11.Examples: Fe, Ni, Co, MnO, Fe_2O_3, Zn ferrite, Ni ferrite, Mn ferrite

17.) Illustrate the phenomenon of magnetization. Show that $B = \mu_o(H + M)$.

A.) Magnetism, a phenomenon associated with magnetic fields, which arise from the motion of electric charges. This motion can take many forms. It can be an electric current in a conductor or charged particles moving through space, or it can be the motion of an electron in an atomic orbital. Magnetism is also associated with elementary particles, such as the electron, that have a property called spin.

We know that

$$B = \mu H \rightarrow (1)$$

But $\mu = \mu_O \mu_r$

$$B = \mu_O \mu_r H \rightarrow (2)$$

Adding & subtracting with $\mu_O H$ on right hand side of equation (2)

$$B = [\mu_O \mu_r H] + \mu_O H - \mu_O H$$

$$= [\mu_O \mu_r H - \mu_O H] + \mu_O H$$

$$= \mu_O H [\mu_r - 1] + \mu_O H$$

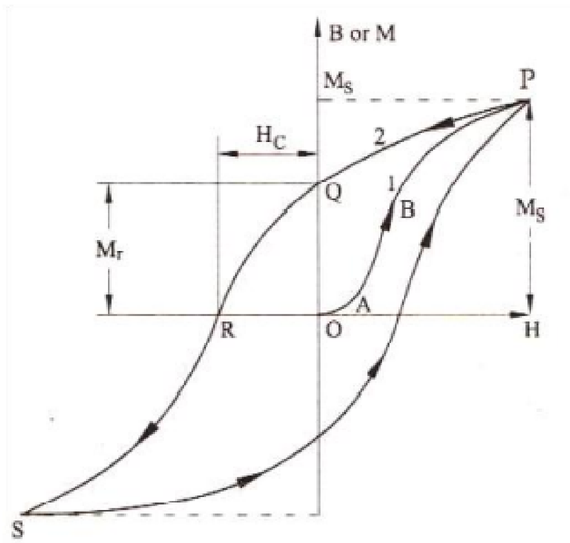
But $M = H [\mu_r - 1] \rightarrow (3)$

Now eq(3) becomes $B = \mu_O M + \mu_O H$

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

18.) Draw the B-H curve for a ferromagnetic material and identify the retentivity and the coercive field on the curve

A.) This phenomenon of magnetic Hysteresis is an Irreversible characteristic of ferromagnetic material. The loop (or) area refers to the hysteresis loop. Hysteresis loss occurs in ferromagnetic materials below Curie temperature.



Magnetic Hysteresis curve (or) B – H curves of a Ferro magnetic material

When the magnetic field is applied on a ferromagnetic material the magnetization increases slowly and reaches a constant Ms called saturation magnetization.

In fig from point O to A, the displacement of domain walls takes place. When the field is suddenly off, the domains again go for the original position.

From point A to B, as the field is further increased, the magnetization also increases. Here when the field is made off the domain displacement does not return back to its original condition.

For higher fields the magnetization reaches maximum i.e. saturation magnetization Ms due to rotation of domain walls. In this case at the region B to P, if the field is suddenly made off, the domain does not return back to the original direction.

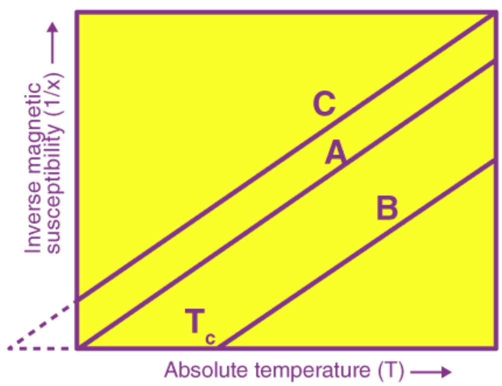
But there is some magnetic field remaining inside the specimen. The point Ms is called saturation of magnetization. When the field is off, the curve does not go back to 'O'[as shown in fig] but creates a new path to a point Mr called retentivity (or) residual (or) remanence Magnetization.

19.) What are the sources of permanent dipole moment in magnetic materials?

A.) Paramagnetic substances have a permanent magnetic dipole moment due to incompletely filled inner electron shells, such as those found in Fe^{2+}, Fe^{3+}, Ni^{2+}, Mn^{2+}, and so on, which results in unpaired electrons. These dipoles interact only weakly with each other and are randomly oriented in the absence of an external magnetic field. When the substance is placed in an external magnetic field, its atomic dipoles tend to line up with the field

20.) Discuss Curie-Weiss law of ferromagnetic materials. Explain the effect of temperature on ferromagnetic properties of a material.

A.) The Curie-Weiss law is one of the important laws in electromagnetism that says that the magnetic susceptibility is above the Curie temperature point of a ferromagnet in the paramagnetic region. The magnetic moment is a quantity of a magnet that determines its torque in an external magnetic field. Example: a bar magnet, electric current loop, a molecule and an electron all have a magnetic moment.



The magnetic polarization or magnetization of a magnetic material expresses the density of induced or permanent magnetic moments in the vector field. The magnetic moment can develop from the microscopic electric current that is generated by the spin of the electrons or motion of electrons in an atom or the spin of the nuclei.

$$X=CT–Tc$$

Here, C = Material specific Curie, T = Absolute temperature

Tc = Curie temperature

Effect of temperature on ferromagnetic properties of a material:

As the temperature of the ferromagnetic material is raised, the thermal energy of the atoms increases. At very high temperatures, the thermal energy is sufficient to break the domains and ferromagnetic materials become paramagnetic.

AP MODULE – IV
ENGINEERED ELECTRIC AND MAGNETIC MATERIALS
NUMERICAL PROBLEMS

Dr. Rizwana
Professor of Physics

1. Find the electric susceptibility of a dielectric gas having dielectric constant of 1.000041.

Solution:

$$\text{Electric susceptibility, } \chi_e = \varepsilon_r - 1$$

$$= 0.000041$$

$$= 0.041 \times 10^{-3}$$

2. A parallel capacitor has an area of 100cm^2, a plate separation of 1 cm and is charged to a potential of 100 Volts. Calculate the capacitance of the capacitor and the change on the plates.

Solution:

$$C = \frac{\varepsilon_o A}{d}$$

We know, $\varepsilon_o = 8.85 \text{ x } 10^{-12} \text{ Fm}^{-1}$

Given : $A = 100 \text{ cm}^2 = 100 \text{ x } 10^{-4} \text{ m}^2$

$d = 1 \text{ cm} = 10^{-2} \text{m}$

Hence $C = \dfrac{8.85 \text{ x } 10^{-12} \text{ x } 100 \text{ x } 10^{-4}}{10^{-2}} = 8.85 \text{ x } 10^{-12} \text{ F}$

$$C = \frac{Q}{V} \Rightarrow Q = CV = 8.85 \text{ x } 10^{-12} \text{x} 100 = 8.85 \text{ x } 10^{-10} \text{ coulomb}$$

3. The dielectric constant of He gas is 1.0000684. Find the electronic polarizability of He atoms if the gas contains 2.7 x 10^{25} atoms per m^3.

Solution:

Formula $\alpha_e = \dfrac{\varepsilon_o(\varepsilon_r - 1)}{N}$

Given $\varepsilon_o = 8.854 \times 10^{-12}\ Fm^{-1}$

$\varepsilon_r = 1.0000684$

$N = 2.7 \times 10^{25}$ atoms per m^3

Hence

$$\alpha_e = \frac{8.854 \times 10^{-12}(1.0000684 - 1)}{2.7 \times 10^{25}} = 2.243 \times 10^{-41}\ Fm^2$$

4. A solid dielectric with density 3 x 10^{28} atoms / m^3 shows an electronic polarizability of 10^{-40} farad -m^{-2}. Assuming the internal electric field to be a Lorentz field, calculate the dielectric constant of the material.

Solution:

Formula $\alpha_e = \dfrac{\varepsilon_o(\varepsilon_r - 1)}{N}$

$$(\varepsilon_r - 1) = \frac{N\alpha_e}{\varepsilon_o} \Rightarrow \varepsilon_r = 1 + \frac{N\alpha_e}{\varepsilon_o}$$

Given $\varepsilon_o = 8.854 \times 10^{-12}\ \text{Fm}^{-1}$

$\alpha_e = 10^{-40}$ Farad m^2

$N = 3 \times 10^{28}$ atoms per m^3

Hence

$$\varepsilon_r = 1 + \frac{3 \times 10^{28} \times 10^{-40}}{8.854 \times 10^{-12}} = 1.339$$

5. A parallel capacitor of area 650 mm^2 and a plate separation of 4 mm has a charge of 2x10^{-10} C on it. When a material of dielectric constant 3.5 is introduced between the plates, what is the resultant voltage across the capacitors?

Solution:

$$C = \frac{\varepsilon_o \varepsilon_r A}{d} = \frac{Q}{V} \Rightarrow \quad V = \frac{Qd}{\varepsilon_o \varepsilon_r A}$$

We know, $\varepsilon_o = 8.85 \times 10^{-12}\ \text{Fm}^{-1}$

Given : $Q = 2 \times 10^{-10}\ \text{C}$

$A = 650\ \text{mm}^2 = 650 \times 10^{-6}\ \text{m}^2$

$\varepsilon_r = 3.5$

$d = 4\ \text{mm} = 4 \times 10^{-3}\ \text{m}$

Hence $$V = \frac{2 \times 10^{-10} \times 4 \times 10^{-3}}{8.85 \times 10^{-12} \times 3.5 \times 650 \times 10^{-6}} = 3.973 \times 10^{-4} \times 10^{5} = 39.73\ \text{Volts}$$

6. Calculate magnetization and magnetic flux density if magnetic field intensity 250amp/m and relative permeability is 15.

Solution:

$$\text{Given}: \quad H = 250 \text{ amp/m and } \mu_r = 15$$

$$\chi = \mu_r - 1 = 15 - 1 = 14$$

$$\chi = \frac{M}{H} \text{ and } B = \mu_o (M + H)$$

$$\text{Hence, } M = \chi H = 14 \text{ x } 250 = 3500 \text{ Am}^{-1}$$

$$\text{Flux density, } B = \mu_o (M + H) = 4\pi \text{ x } 10^{-7} (3500 + 250) = 47100 \text{ x } 10^{-7} = 0.00471 \text{ wb/m}^2$$

7. Find relative permeability, if H=220 amp/m and M=3300 amp/m.

Solution:

Given :

$$M = 3300 \text{ amp/metre}$$

$$H = 220 \text{ amp/metre}$$

$$\mu_r = \frac{M}{H} + 1 = \frac{3300}{220} + 1 = 16$$

8. The magnetic susceptibility of aluminium is 2.3 x 10^{-5}. Find its permeability and relative permeability.

Solution:

Given : Magnetic Susceptibility, $\chi = 2.3 \times 10^{-5}$

Therefore, Relative permeability, $\mu_r = \chi + 1 = (2.3 \times 10^{-5}) + 1 \cong 1.000023$

Permeability, $\mu = \mu_0 \mu_r = 4\pi \times 10^{-7} \times 1.000023 = 12.56 \times 10^{-7}$ Henry/m

9. If a magnetic field of strength 300 amp/meter produces a magnetization of 4200 A/m in a ferromagnetic material, find the relative permeability of the material.
Solution:

Given : Magnetic field strength, $H = 300$ amp/metre

Magnetization, $M = 4200$ amp/metre

Hence, Magnetic Susceptibility, $\chi = \frac{M}{H} = \frac{4200}{300} = 14$

Therefore, Relative permeability, $\mu_r = \chi + 1 = 14 + 1 = 15$

10. A paramagnetic material has a magnetic field intensity of 10^4 A/m. If the susceptibility of the material at room temperature is 3.7×10^{-3}, calculate the magnetization and magnetic flux density in the material.

Solution:

$$\chi = \frac{M}{H} \text{ and } B = \mu_0 (M + H)$$

$$\text{Hence, } M = \chi H = 3.7 \times 10^{-3} \times 10^4 = 3.7 \times 10 = 37 \text{ Am}^{-1}$$

$$\text{Hence magnetization, } M = 37 \text{ Am}^{-1}$$

$$\text{Flux density, } B = \mu_0 (M + H) = 4\pi \times 10^{-7} (37 + 10^4) = 126179.43 \times 10^{-7} = 0.0126 \text{ wb/m}^2$$