B.Tech-IV Semester(EX)

Electrical Engineering Material

Solution (SET-A)

Q1.

The Clausius Mosotti relation

This eqn is applicable only for materials having cubical structure (having Lorentz field.)

As we know

$$P = N\alpha_e E_i \quad \text{—(1)}$$

If the internal field is taken as the Lorentz field.

$$E_i = E + \frac{P}{3\varepsilon_0} \quad \text{—(2)} \quad = E + \frac{\varepsilon_0(\varepsilon_r - 1)E}{3\varepsilon_0}$$

$$P = N\alpha_e \left[E + \frac{P}{3\varepsilon_0} \right]$$

$$P = N\alpha_e \left[E + \frac{\varepsilon_0(\varepsilon_r - 1)E}{3\varepsilon_0} \right]$$

$$P = N\alpha_e \left[E + \frac{\varepsilon_r E}{3} - \frac{E}{3} \right]$$

$$P = N\alpha_e \left[1 + \frac{\varepsilon_r}{3} - \frac{1}{3} \right] E$$

$$P = N\alpha_e \left[\frac{\varepsilon_r + 2}{3} \right] E$$

$$\varepsilon_0(\varepsilon_r - 1)E = N\alpha_e \left[\frac{(\varepsilon_r + 2)}{3} \right] E$$

$$\frac{3\varepsilon_0}{N\alpha_e} = \frac{\varepsilon_r + 2}{\varepsilon_r - 1}$$

$$\boxed{\frac{N\alpha_e}{3\varepsilon_0} = \frac{\varepsilon_r - 1}{\varepsilon_r + 2}} \quad \text{—(3)}$$

This eq is well known as Clausius mosotti eqn.

Debye's generalization of CM eqn.
It is applicable for gaseous dielectrics.

For gaseous dielectric

$$N = \frac{N_A}{M} \rho$$

where N_A = Avagrado no.
$= 6.023 \times 10^{23}$
M = Molecular weight of material
ρ = density in kg/m^3

C-M Eqn

$$\frac{\epsilon_r - 1}{\epsilon_r + 2} = \frac{N \alpha_e}{3\epsilon_0}$$

$$\frac{\epsilon_r - 1}{\epsilon_r + 2} = \left(\frac{N_A \rho}{M}\right) \frac{\alpha_e}{3\epsilon_0}$$

$$\boxed{\frac{N_A \alpha_e}{3\epsilon_0} = \left(\frac{\epsilon_r - 1}{\epsilon_r + 2}\right) \cdot \left(\frac{M}{\rho}\right)}$$

Maxwell equation
Relation b/w refractive index and relative permittivity of dielectric medium.

$$\eta = \frac{c}{v}$$

$$\eta = \frac{1}{\sqrt{\mu_0 \epsilon_0}} \times \frac{1}{\frac{1}{\sqrt{\mu_r \epsilon_r}}}$$

$$= \frac{1}{\sqrt{\mu_0 \epsilon_0}} \times \sqrt{\mu_0 \mu_r \epsilon_0 \epsilon_r}$$

$$\eta = \sqrt{\epsilon_r \mu_r}$$

For dielectric
$\mu_r = 1$

$$\boxed{\epsilon_r = \eta^2}$$

Q1.Solution

Piezoelectricity, also called the piezoelectric effect, is the ability of certain materials to generate an AC (alternating current) voltage when subjected to mechanical stress or vibration, or to vibrate when subjected to an AC voltage, or both. The most common piezoelectric material is quartz. Certain ceramics, Rochelle salts, and various other solids also exhibit this effect.

Application of piezoelectric Materials

1. Microphones,
2. Earphones,
3. Beepers, and buzzers
4. Crystals and ceramics as oscillators that generate predictable and stable signals at RF (radio frequencies)

Q2.

Polarizability

$$\boldsymbol{\alpha = \frac{\varepsilon_0(\varepsilon_r - 1)}{N}}$$

Given

$\varepsilon_r = 12$

$N = 5 \times 10^{28} atoms/m^3$

$\varepsilon_0 = 8.854 \times 10^{12} \mathrm{F/m}$

$$\boldsymbol{\alpha = 19.47 \times 10^{-40} F - m^2}$$

\

Q2.Solution

Dielectric loss

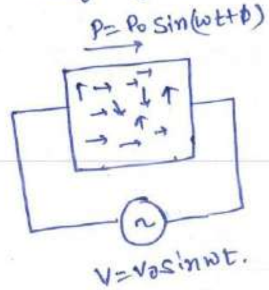
The absorption of electrical energy by a dielectric material that is subjected to an alternating electric field is termed dielectric loss.

The dielectric constant ε_r is a complex number given by

$$\varepsilon_r = \varepsilon_r' - j\varepsilon_r'' \quad \text{—— (1)}$$

ε_r' ↓ Real part, ε_r'' ↓ imaginary part.

- Consider a parallel plate Capacitor with lossy dielectric



$$C = \frac{\varepsilon_0 \varepsilon_r A}{d}$$

Impedance

$$Z = \frac{1}{jwC} = \frac{d}{jw\varepsilon_0\varepsilon_r A}$$

Admittance $\left(Y = \frac{1}{Z}\right)$

$$Y = \frac{1}{Z} = \frac{jw\varepsilon_0\varepsilon_r A}{d}$$

$$Y = \frac{jw\varepsilon_0(\varepsilon_r' - j\varepsilon_r'')A}{d}$$

$$Y = \frac{jw\varepsilon_0\varepsilon_r' A}{d} + \frac{w\varepsilon_0\varepsilon_r'' A}{d}$$

The admittance can be written in the form.

$$Y = jwC' + G_p$$

$$C' = \frac{\varepsilon_0 \varepsilon_r' A}{d}$$

$$G_p = \frac{\omega\varepsilon_0\varepsilon_r'' A}{d}$$

The admittance of the dielectric medium is Equivalent to a parallel combination of an ideal lossless Capacitor C with a relative permittivity ε_r and a resistance of $1/G_P$ or conductance G_P.

- Real part ε_r' represents the relative permittivity.
- imaginary part ε_r'' " the energy loss in dielectric medium.

Loss tangent defined as.

$$\tan\delta = \frac{\varepsilon_r'}{\varepsilon_r''}$$

Q3

Magnetic materials for electrical devices:

→ Soft magnetic material

→ Hard magnetic material.

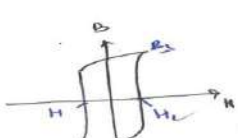
Soft magnetic material:

Soft magnetic materials are easy to magnetize and easy to demagnetize. This enables them to reverse magnetization rapidly in response to alternating electric fields where they are required to concentrate magnetic flux in transformer and inductances.

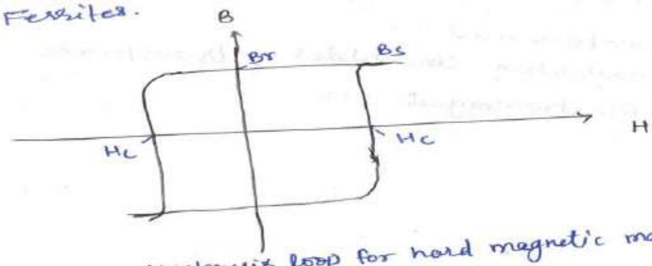
- Soft magnetic materials form the magnetic circuit in an electrical machine like transformer, motor etc.

The different types of materials used as soft magnetic materials divided into three groups

1. Alloys based on iron
2. Nickel iron alloys
3. Ferrites.



Hysteresis loop for soft magnetic



Hysteresis loop for hard magnetic materials.

Hard magnetic matarials :

- Hard magnetic matarials are hard to magnetize and hard to demagnetize.
- High value of residual flux density B and Coercive force H_c characterize these matarials and make them excellent permanent magnets. Matarials with large BHmax are called hard magnetic matarials.
- B_s is highest value of flux density called saturation flux density.
- The residual flux density B_r on the saturation loop is called retentivity.

Application : Hard magnet.

- Electronic device such as printers, magnetic bearing, loudspeakers, microwaves devices etc.
- They are used for making permanent magnet.

Application for soft magnetic matarials :

- Electrics machine
- construction core plates of transformer
- Electromagnets etc

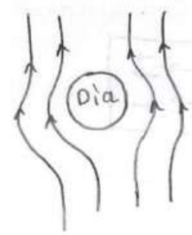
Q3

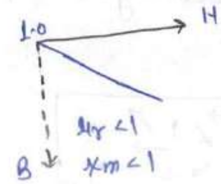
Classification of magnetic matarial

1) Diamagnetic
2) Paramagnetic
3) ferro-megnetic.
4) Anti-ferromagnetic
5) ferrimagnetic.

Diamagnetic matarial

- These matarials do not have permanent dipole.
- these matarial are having small & -ve value of magnetic susceptibity
- these matarial repelled away from applied magnetic field.





For dia-magnetic matarials.

$B = 0$

$B = \mu_0 (H+M)$

$0 = \mu_0 (H+M)$

$H+M = 0$

$M = -H$

we know

$M = \chi_m H$

$\chi_m H = -H$

$\boxed{\chi_m = -1}$

$\chi_m = \mu_r - 1$

$-1 = \mu_r - 1$

$\boxed{\mu_r = 0}$

perfect dia-magnetism.

$\mu_r = 0$ or perfect diamagnetism is one of the neccessary condition for a matarial to be a super conductor.

Ex :- Cu, Au(gold), Ge, Si, Diamond, NaCl, Al_2O_3 etc.

Paramagnetic matarials

- Paramagnetism occurs in matarials where the atoms or molecules have magnetic moment due to partially filled orbits in this case there is positive ~~susceptibility~~ susceptibility.

→ The matarials when placed in a magnatic field acquire a weak magnetization in the same direction as the applied field are called paramagnetic matarials.

H=0 H≠0

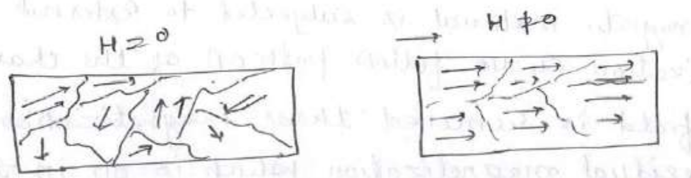
Some paramagnetic materials are

Fe_2O_3, MeSo4 (Aluminium), Platinum ($NiSO_4$), Tungsten ($FeCl_2$)

$FeSO_4$. etc.

Ferromagnetic materials :-

- Strong permanent dipole moment exist in ferromagnetic materials.
- Adjacent dipole will be aligned in a particular direction due to strong alignment forces even in the absence of external field. The neigbouring dipoles are aligned as aligment forces is very strong, so there are groups of large number of dipoles aligned in particular direction (also parallel to each other) resulting in domains.
- The magnetic susceptibity of ferromagnetic matarial is positive and very large these matarial get strongly magnetized in the direction of applied field.

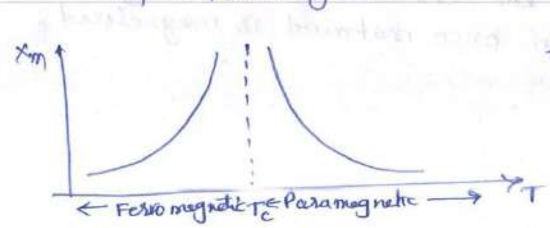


Ferromagnetic matarial follow Curie-weiss law

$$\chi_m = \frac{C}{T-\theta} \quad \text{for } T > \theta$$

where θ = paramagnetic curie temp

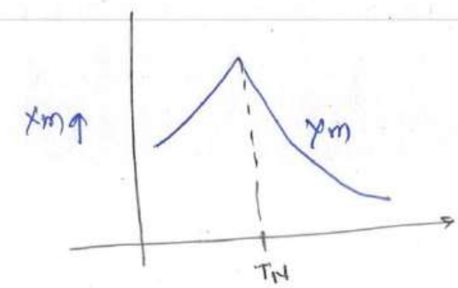
θ_f = ferromagnetic curie temperature ($\theta_f \leq \theta$)



Antiferromagnetic matarial :

- In an antiferromagnetic matarials the magnetic moments of adjacent atoms align in opposite direction so that the net magnetic moment of a specimen is nill even in the presence of an external applied field.
- The magnetic susceptivitity is positive and the order is 10^{-3} to 10^{-5}. The susceptivility χ increases with increasing temperature and reaches at maximum at a certain temperature called Neel temperature T_N above T_N the matarial becomes paramagnetic.

↑↓ ↑↓ ↑↓ ↑↓



$$\chi_m = \frac{C}{T+\theta_N}$$

Ex :- MnO, MnS, Cr_2O_3, NiCr, MnF_2 etc.

Ferrimagnetic matarials

These materials are also having dipoles with antiparallel arrangement but they are not equal.

↓↑ ↓↑ ↓↑ ↓↑

Q4i)

Magnetization (M)

It is defined as magnetic dipole moment per unit volume

i.e

$$M = \frac{p_B}{\text{Volume}} \quad \text{--- (1)}$$

$$M = N p_B$$

where N = No. of dipole / unit volume.

the total flux density inside magnetic material is because of 2 factors,

1) Applied external field intensity

2) Induced magnetization.

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

- B → flux density inside magnetic material
- $\mu_0 H$ → flux density due to external field
- $\mu_0 M$ → flux density due to magnetization.

$$B = \mu_0 (H + M) \quad \text{--- (1)}$$

Also

$$B = \mu_0 \mu_r H$$

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

$$\mu_r H - H = M$$

$$M = (\mu_r - 1) H$$

$$M = \chi_m H \quad \text{--- (2)}$$

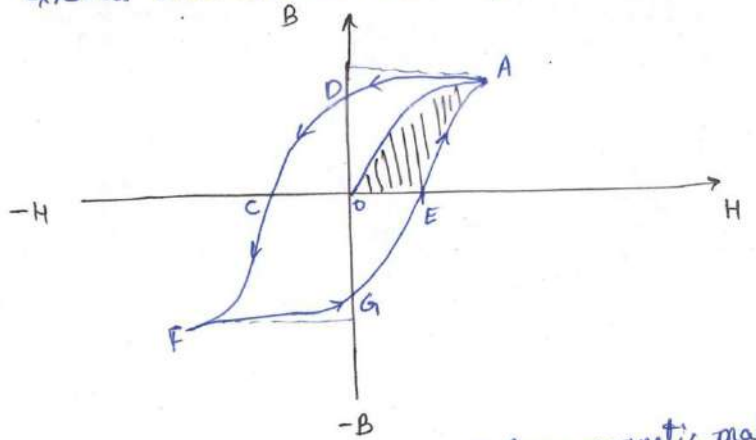
$$\chi_m = \mu_r - 1$$

χ_m = magnetic susceptibility.

Q4ii)

Hysteresis curve in ferromagnet.

→ Ferromagnetic materials below the curie temperature exhibits characteristics called hysteresis loop.



· Magnetization curve of ferromagnetic material.

- when a ferromagnetic material is subjected to external field magnetization curve follow path OA of the charg. If external field is removed these magnetization is called residual magnetization which is OD in the characteristics.
- To reduce the residual magnetization to zero. the external field is required to be applied in the reverse direction This field is called coercive force represented by OC of this characteristics
- we can see from the characteristics the magnetization never returns to origin once material is magnetized.

Q4

<u>Ques</u>. Find the magnetictude of the magnetic flux density in a material for which

1) The magnetization is 2.8 A/m & susceptibility is 0.0025
2) The magnetic field intensity is 1300 A/m & relative permeability $\mu_r = 1.006$
3) There are 8.2×10^{28} atoms/m³ each having a dipole moment of 3×10^{-30} A-m² in the same direction & $\chi_m = 2 \times 10^{-4}$

<u>Sol</u>

$M = 2.8$ A/m, $\chi_m = 0.0025$

$H = 1300$ A/m, $\mu_r = 1.006$

$N = 8.2 \times 10^{28}$, $p_B = 3 \times 10^{-30}$ A-m², $\chi_m = 2 \times 10^{-4}$.

1)

$$M = \chi_m H$$

$$2.8 = 0.0025 \times H$$

$$H = \frac{2.8 \times 100 \times 100}{0.0025 \times 10} = 28 \times 40 = 1120 \text{ A/m}$$

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

$$B = 4\pi \times 10^{-7} (2.8 + 28 \times 40)$$

$$\boxed{B = 1.41 \text{ wb/m}^2}$$

(2)

$$B = \mu_0 \mu_r H$$

$$= 4\pi \times 10^{-7} \times 1.006 \times 1300$$

$$B = 1.61 \text{ wb/m}^2.$$

(3)

$$M = \chi_m H$$

$$N p_B = \chi_m \cdot H \Rightarrow H = \frac{N p_B}{\chi_m} = \frac{8.2 \times 10^{28} \times 3 \times 10^{-30}}{2 \times 10^{-4}}$$

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

$$B = 1.545 \text{ wb/m}^2.$$

B.Tech-IV Semester(EX)

Electrical Engineering Material

Solution (SET-B)

Q1.Solution

polarization:- In the dielectric malarial most of the electrons are bound to the nucleas. when an External electric fied is applied then the bound electron of an atom are displaced such that the controid of the electronic cloud is seperated from the controid of the nucleus. Hence an electric dipole is created and the atom is said to be polarized. this phenomenon is known as polarization.

on a microscopic scale in field theory we define $\vec{P}$ called polarization as an electric dipoles moment per unit volume. thus N- denotes the Number of molecules per unit volume of a material, then there are $N\Delta V$ molecules in a volume ΔV and

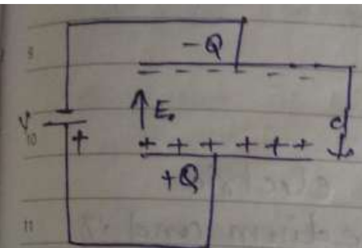
$$\vec{P} = \frac{1}{\Delta V} \sum_{J=1}^{N\Delta V} \vec{P_J} = N\vec{P} \quad (1)$$

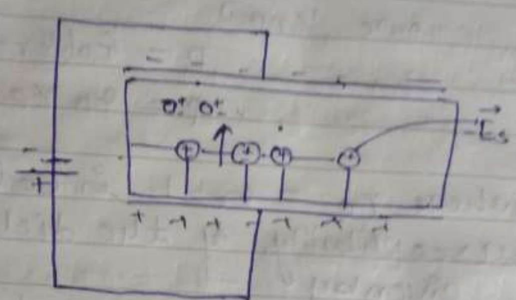
where P is the average dipole moment. the unit of $\vec{P}$ is Coulomb per square meter.

when a dielectric malarial is placed in a electric field the induced dipoles produced a secondry electric field such that the resultant field.

$$\boxed{\vec{P} = \varepsilon_0 \chi_e \vec{E}} \quad (2)$$

where χ_e is a dimensionless parameter, know as the electric susceptibility. It is a measure of the ability of the material to become polarized and differ from one to another.





$$\vec{E}_s = -\frac{\vec{P}}{\varepsilon_0} \quad -(3)$$ [opposite to the electric field]

The total field in the dielectric is

$$\vec{E} = \vec{E}_0 + \vec{E}_s = \vec{E}_0 - \frac{\vec{P}}{\varepsilon_0}$$

$$\vec{E} + \frac{\vec{P}}{\varepsilon_0} = \vec{E}_0 \Rightarrow \varepsilon_0\vec{E} + P = \varepsilon_0\vec{E}_0 \quad -(4)$$

$$\varepsilon_0 \vec{E} + \varepsilon_0 \chi_e \vec{E} = \varepsilon_0 \varepsilon_r \vec{E}$$

$$\boxed{\varepsilon_r = 1 + \chi_e}$$

$$\boxed{\chi_e = \varepsilon_r - 1}$$

We know $\varepsilon_r \geq 1$

$\chi_e \geq 0$.

Actually electrical susceptibility represents the susceptance toward applied electric field.

We know

$$P = \varepsilon_0(\varepsilon_r - 1)\vec{E}$$

$$P = \varepsilon_0 \chi_e \vec{E}$$

where $\chi_e = \varepsilon_r - 1$ is called the electric susceptibility of the dielectric medium and is given by

$$\frac{\text{Bound storage density}}{\text{Free charge density}}.$$

Q1.Solution

Dielectric :- A dielectric is a non-conducting material which can be polarized by an electric field. If the main function of non-conducting material is to provide insulation material is called insulator. If the main function of non-conducting material is to provide storage of charge material is called Dielectric.

Dielectric parameter

There are four types of Di-electric parameter.

- Dielectric constant (ε_r)
- Dipole moment (P)
- polarization (P)
- polarizability (α).

Dielectric constant :-

Consider a parallel plate capacitor, with the area of the plates as a meter^2 each a distance d meter apart in vaccum. The capacitance of vaccum is.

$$\boxed{C_0 = \frac{\varepsilon_0 a}{d}} \quad \text{--- (1)}$$

ε_0 is dielectric constant or permittivity of vaccum

$\varepsilon_0 = 8.854 \times 10^{-12}$ F/m.

If the space b/w the plates is filled with a distance dielectric material the capacitance of the capacitor increased and is given by.

$$C = \frac{\varepsilon_0 \varepsilon_r . a}{d} \quad — (2)$$

ε_r is the relative dielectric constant of the dielectric material and is the property of the material as compared to vaccum

The value of ε_r of a material can be determined by measuring the capacitance of a capacitor with vaccum as dielectric and then with material as dielectric ε_r is given

$$\varepsilon_r = \frac{C}{C_0} \quad — (3)$$

Electrical permittivity of medium can be given as.

$$\varepsilon = \varepsilon_r \varepsilon_0$$

dielectric constant

$$\varepsilon_r = \frac{\varepsilon}{\varepsilon_0}$$

Hence, the dielectric constant for a medium is defined as the ratio of electrical permittivity of a medium to the electrical permittivity of free space.

Different material have different value of ε_r, it lower value being unity for Vaccum, for air 1.006, helium 1.0000684 Si, 12, germanium - 16

Dipole moment :- Two opposite type of charges equal in magnitude and separated by a small distance results in an electric dipole. If Q is the magnitude of charge and d is the distance between charges then dipole moment is given by.

$$\boxed{P = Qd}$$

-Q ⟶ +Q

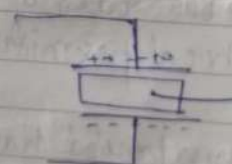
$$\vec{P} = Q\vec{d}$$

P is dipole moment in coulomb-meter. Dipole moment is a vector pointing from the negative charge to the positive charge ~~as indicating by~~ and it unit is debye (1 debye = 3.33×10^{-30} C-m]

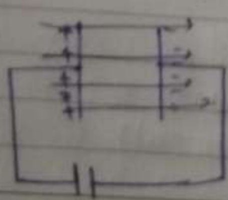
~~polarization~~

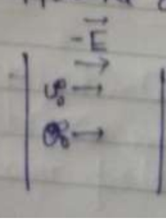
Di-electric are insulator. - Glass, ~~ver~~ pure water, plastic.

Die-electric is maintain capacitor b/w plates.



when dielectric insert b/w plate capacitor and plate not charge then dipole randomly different direction.



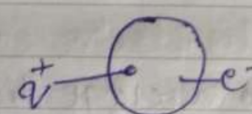


A nonpolar molecules is one in which the centre of gravity of the positive charges (protons) coincide with the centre of gravity of the negative charge electron.
Ex: O_2, H_2, N_2.

→ The non-polar molecules do not have a permanent dipole moment.

If a non polar dielectric is placed in a electric field the centre of charges get displaced.
- The molecules are then said to be polarised and are called induced dipoles.

- A polar molecules is one in which the centre of gravity of the positive charge is separated from the centre of gravity of -ve charge by finite distance.
Ex: N_2O, H_2O, HCL, NH_3.
→ They have a permanent dipole moment.



→ In the absence of a external field, the dipole moment of polar molecules orient themselves in random direction. Hence NO net dipole moment is observed in the dielectric.
- When an electric field is applied, the dipoles orient themselves in the direction of electric field. Hence a net dipole moment is produced.

Q1.Solution

polarization:- In the dielectric malarial most of the electrons are bound to the nucleas. when an External electric field is applied then the bound electron of an atom are displaced such that the centroid of the electronic cloud is seperated from the centroid of the nucleus. Hence an electric dipole is created and the atom is said to be polarized. This phenomenon is known as polarization.

on a microscopic scale in field theory we define $\vec{P}$ called polarization as an electric dipoles moment per unit volume. thus N-denotes the Number of molecules per unit volume of a material. then there are $N\Delta V$ molecules in a volume ΔV and

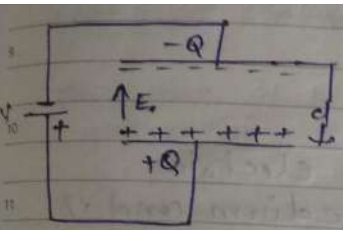
$$\vec{P} = \frac{1}{\Delta V}\sum_{J=1}^{N\Delta V}\vec{P_J} = N\vec{P} \quad (1)$$

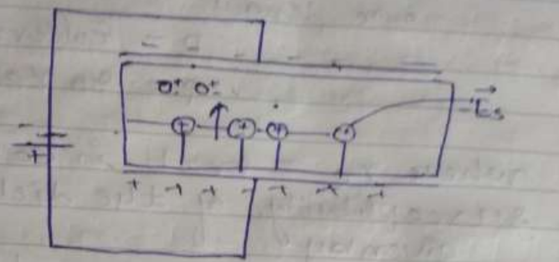
where P is the average dipole moment. the unit of $\vec{P}$ is Coulamb per square meter.

when a dielectric malarial is placed in a electric field the induced dipoles produced a secondry electric field such that the resultant field.

$$\boxed{\vec{P} = \varepsilon_0 \chi_e \vec{E}} \quad (2)$$

where χ_e is a dimensionless parameter, know as the electric susceptibility. It is a measure of the ability of the material to become polarized and differs from one to another





$$\vec{E}_s = -\frac{\vec{P}}{\varepsilon_0} \quad \text{--- (3)}$$ [opposite to the electric field]

The total field in the dielectric is

$$\vec{E} = \vec{E}_0 + \vec{E}_s = \vec{E}_0 - \frac{\vec{P}}{\varepsilon_0}$$

$$\vec{E} + \frac{\vec{P}}{\varepsilon_0} = \vec{E}_0 \Rightarrow \varepsilon_0\vec{E} + P = \varepsilon_0\vec{E}_0 \quad \text{--- (4)}$$

$$\varepsilon_0 \vec{E} + \varepsilon_0 \chi_e \vec{E} = \varepsilon_0 \varepsilon_r \vec{E}$$

$$\boxed{\varepsilon_r = 1 + \chi_e}$$

$$\boxed{\chi_e = \varepsilon_r - 1}$$

we know $\varepsilon_r \geq 1$

$\chi_e \geq 0$.

Actually electrical susceptibility represents the susceptance toward applied electric field.

we know

$$P = \varepsilon_0(\varepsilon_r - 1)\vec{E}$$

$$P = \varepsilon_0 \chi_e \vec{E}$$

where $\chi_e = \varepsilon_r - 1$ is called the electric susceptibility of the dielectric medium and is given by

$$\frac{\text{Bound storage density}}{\text{Free charge density}}.$$

Q2.Solution

APPLICATIONS OF DIELECTRIC MATERIALS
1.Capacitors which use vacuum,air& gases as dielectrics
2.Dielectric losses in these capacitors are very small.Therefore these are used in radio frequency circuits
3.Dielectric capacitors are used in mineral oil(transformer oil,sulphurhexafluoride) sulphurhexafluoride stable upto 100 degree celsius. it is used as an insulating material in high voltage transformers.
4.Some enamels ,paints, varnishes are used to insulating coating on the wide range.

Q2.Solution

(i)Orientation Polarization

The orientation polarization arises due to the presence of polar molecule in the dielectric medium.

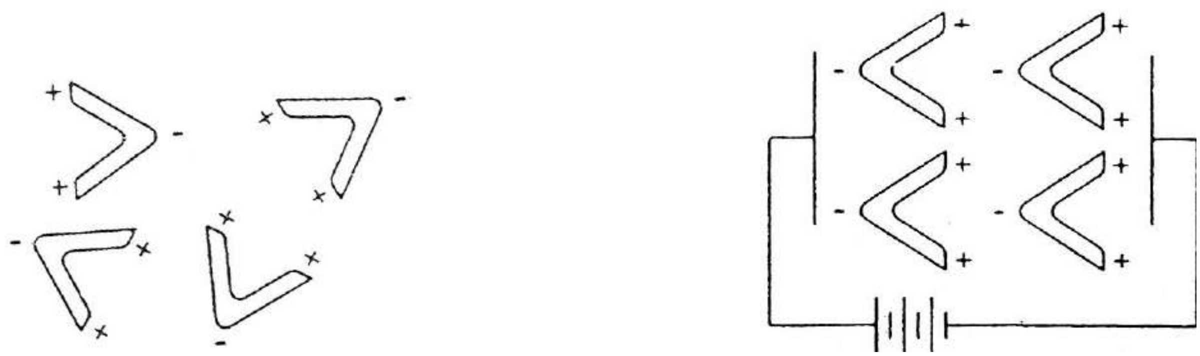


Fig. (a) Without field (b) With field

Explanation:

- In the case of a CH_3Cl molecule, the positive and negative charges do not coincide. The Cl^- has more electro negativity than hydrogen. Therefore, the chlorine atoms pull the bonded electrons towards them more strongly than hydrogen atoms. Therefore, even in the absence of field, there exists a net dipole moment.
- Now, when the field is applied, positive portion align along the direction of field and negative portion align in the opposite direction of the field. This kind of polarization is called as orientation polarization.
- This depends on temperature; when temperature is increased, the thermal energy tends to randomize the alignment

(ii) Space-Charge Polarization

The space-charge polarization occurs due to the diffusion of ions, along the field direction, thereby giving rise to redistribution of charges in the dielectrics

Fig. (a) Without field (b) With field

Explanation

- Without the application of external field, the ions are orderly arranged as shown in the Fig.
- Now, when the field is applied, the ions diffuse with respect to the direction of applied field. Thus the polarization occurs, known as space charge polarization.
- Normally, this type of polarization occurs in ferrites and semiconductors and will be very small.

Q3.Solution

Piezoelectricity, also called the piezoelectric effect, is the ability of certain materials to generate an AC (alternating current) voltage when subjected to mechanical stress or vibration, or to vibrate when subjected to an AC voltage, or both. The most common piezoelectric material is quartz. Certain ceramics, Rochelle salts, and various other solids also exhibit this effect.

Application of piezoelectric Materials

1. Microphones,
2. Earphones,
3. Beepers, and buzzers
4. Crystals and ceramics as oscillators that generate predictable and stable signals at RF (radio frequencies)

Q4.Solution

Que A magnetic material has a magnetization of 3300 A/m & flux density is 0.0044 wb/m². Calculate field intensity & relative permeability of material.

Solve $M = 3300\ A/m$

$B = 0.0044\ wb/m^2$

$B = \mu_0 (M + H)$

$H = \frac{B}{\mu_0} - M$

$= \frac{0.0044}{4 \times \pi \times 10^{-7}} - 3300$

$H = 203\ A/m$

Relative pr (μ_r)

$M = \chi_m H$

$\chi_m = \frac{M}{H}$

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

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

$\mu_r = \frac{3300}{203} + 1$