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PART - A

2 Marks Questions

Q.1

- Sol. • The generation of an electromotive force (emf) in a circuit of two different metals with temperature difference.

Q.2

- Sol. Copper: higher conductivity, more expensive; Aluminium: lighter, less conductive, cheaper.

Q.3

- Sol. Material that generates voltage under mechanical stress;
example: quartz.

Q.4

- Sol. The average velocity of electrons in a conductor due to applied electric field.

Q.5

- Sol. Maximum electric field a dielectric can withstand without breakdown.

Q.6

- Sol. Magnetic susceptibility (χ) measures the degree of magnetization (M) of a material in response to an applied magnetic field intensity (H). It is defined as $\chi = M/H$. It indicates whether a material is diamagnetic, paramagnetic, or ferromagnetic based on its value.

Q.7

- Sol. Addition of 0.3 to 4.5% silicon to iron increases the electrical resistivity of iron and reduces eddy current losses. Silicon steel possesses low hysteresis loss, high permeability, and small eddy current loss, making it ideal for transformer cores, reactors, and electrical machines requiring efficient electromagnetic performance.

Q.8

- Sol. Diamagnetic materials are substances that produce an induced magnetic field in the opposite direction to an externally applied magnetic field. They are weakly repelled by a magnetic field.
Characteristics include no permanent magnetic moment, negative magnetic susceptibility, and independence from temperature.
Examples: copper, bismuth, gold.

Q.9

- Sol. Paramagnetic materials have unpaired electrons and get weakly attracted to magnetic fields. They exhibit positive magnetic susceptibility which decreases with temperature.
Examples: aluminum, manganese, platinum.

Q.10

- Sol. Ferromagnetism is a phenomenon where materials get strongly magnetized in the direction of an applied magnetic field due to aligned magnetic moments of domains. Ferromagnetic materials have high retentivity and coercivity, making them suitable for permanent magnets.
Examples: iron, cobalt, nickel.

Q.11

- Sol. Retentivity is the ability of a material to retain magnetization after the external field is removed. Coercivity is the ability of a material to resist demagnetization by an opposing magnetic field. Materials with high retentivity and coercivity make good permanent magnets.



PART - B

5 Marks Questions

Q.12

Sol. Doping is the process of adding specific impurities to intrinsic semiconductors to improve their electrical properties and control carrier concentration. When a semiconductor is doped with a P-type impurity, each impurity atom introduces a hole (positive charge carrier) into the lattice by accepting electrons from the crystal structure. This enhances the conductivity of the material and enables its use in P-type devices for various electronic applications.

Q.13

Sol. Dielectric polarization is the process by which a dielectric material develops electric dipoles under the influence of an external electric field. The applied field causes a separation of positive and negative charges within the atoms or molecules, resulting in dipoles throughout the material. Types of polarization include electronic polarization (displacement of electron cloud relative to the nucleus), ionic polarization (relative displacement of positive and negative ions), and orientation polarization (alignment of permanent dipole moments, typical of polar dielectrics).

Each type affects the total polarizability and dielectric constant of the material.

Q.14

Sol. Dielectric strength is defined as the maximum electric field a dielectric material can withstand before electrical breakdown occurs, often measured in volts per meter (V/m). Mica has a high dielectric strength, typically around 118 V/m, making it suitable for high-voltage insulation. Fused silica is even higher, in the range of 470-670 V/m. Porcelain has a lower dielectric strength compared to mica and fused silica. The order, from highest to lowest dielectric strength among these materials, is fused silica > mica > porcelain.

Q.15

Sol. Polar dielectric materials possess permanent electric dipole moments due to asymmetrical charge distribution in their molecules, which align under an external electric field (examples: water, quartz, certain polymers). These materials exhibit higher dielectric constants and strong temperature dependence due to thermal agitation affecting dipole alignment. Non-polar dielectrics lack permanent dipoles; their dipoles are induced only in the presence of an electric field (examples: nitrogen, benzene, most simple gases). Non-polar dielectrics generally have lower dielectric constants and are less affected by temperature changes.

Q.16

Sol. Good dielectric materials should possess high electrical resistivity to minimize leakage current, high dielectric strength to withstand elevated voltages without breakdown, low dielectric loss to ensure low power dissipation, sufficient mechanical strength to resist physical stress, and chemical stability for consistent performance over time.

Examples include ceramic, mica, and certain plastics that meet these requirements and are widely used in electrical insulation and capacitors.

Q.17

Sol. Dielectric loss is the loss of energy in dielectric materials due to the lag in polarization response relative to the applied alternating electric field, resulting in heat generation. The loss tangent is defined as the ratio of the imaginary part to the real part of the dielectric constant and is a measure of the energy dissipated as heat. Low dielectric loss and loss tangent are crucial in AC applications to minimize inefficiency and overheating, ensuring that insulators and capacitors operate reliably and efficiently under alternating currents.



Q.18

Sol. Polarizability

The application of an electric field to a dielectric material causes a displacement of electric charges giving rise to the creation or re-orientation of the dipoles in the material. The average dipole moment P of an elementary particle may assumed to be proportional to electric field strength E , that acts on the particle so that

$$P = \alpha_e E$$

- The proportionality factor α_e is called Polarizability.

Q.19

Sol. Magnetic Permeability

Magnetic Permeability may be defined as the ratio of magnetic field density to magnetic field intensity of a magnetic material when placed in a magnetic field.

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

Henry/meter or kg-m/c²

Magnetic permeability of free space.

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

The ratio of the permeability of the solid material (μ) to the permeability of free space (μ_0) is known as relative permeability (μ_r)

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

and magnetic susceptibility

$$\chi_m = \mu - 1$$

may be defined as magnetization per unit magnetic field intensity.

Q.20

Sol. Magnetization

- The magnitude of dipole moment per unit volume, is called the magnetization, when a magnetic induction (flux density) is the sum of the effect. on vacuum and that on the material, so that,

$$\vec{B} = \mu_0 \vec{H} + \mu_0 \vec{M}$$

where M is the magnetization of the medium, A/m;

$$\therefore \vec{B} = \mu_0 \mu_r \vec{H}$$

$\therefore$ Equation (3.6) becomes,

$$\mu_0 \mu_r \vec{H} = \mu_0 \vec{H} + \mu_0 \vec{M}$$

then

$$\vec{M} = (\mu_r - 1) \vec{H}$$

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

where χ_m is the magnetic susceptibility, a dimensionless quantity.

The magnetization $\vec{M}$ of a material expressed in terms of its elementary magnetic dipole moments, P_m by

$$\vec{M} = N \vec{P}_m$$

where N is the number of magnetic dipoles per unit volume.

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Q.21

Sol. **Soft Magnetic Materials**

- Soft magnetic materials are easy to magnetize and easy to demagnetize. This enables them to reverse magnetize rapidly in response to alternating electric fields where they are required to concentrate magnetic flux in transformers and inductances.
- Soft magnetic materials form the magnetic circuit in an electrical machine, like transformers, motors, 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**

Q.22

Sol. **Super Conductor**

- A state of material in which it has zero resistivity, is called super conductivity. At the state of super conductivity material has zero resistivity as well as di-magnetism.
- Mercury was first discovered super conductor material and observed that the resistivity of mercury vanished completely below 4.2 K, the transition from normal to super conductivity occurring over a very narrow range of temperature of the order of 0.05 K.
- The temperature at which superconductivity appears is called the critical temperature or transition temperature.

Q.23

Sol. **Applications**

- Superconducting materials are of interest because they promise low Joule heating losses in electric power generation and transmission system.
- Superconducting magnets find applications in the following areas.
 - Magnets for nuclear fusion.
 - Generator and motors.
 - Magnetically Levitated Transportation.
 - Magnets for high energy physics.
 - Superconducting magnets for energy storage
 - Magnetic resonance imaging and other application (in medicine).

PART - C

20 Marks Questions

Q.24

Sol. **MECHANISM OF POLARIZATION**

- In dielectric materials, all electrons are bound, the only motion possible in the presence of an electric field is a minute displacement of positive and negative charges in opposite directions. The displacement is usually small compared to atomic dimensions. A dielectric in which this charge displacement takes place is said to be polarized, and its molecules are said to possess induced dipole moments. These dipoles produces their own field, which adds to the external field. In addition to displacing the positive and negative charges, an applied electric field can also polarize a dielectric by orienting molecule that possess a permanent dipole moment. Such molecules experience a torque which tends to align them with the field but collisions arising from the thermal agitation of the molecules tend to destroy the alignment. An equilibrium polarization is thus established in which there is, on the average a net alignment torque.

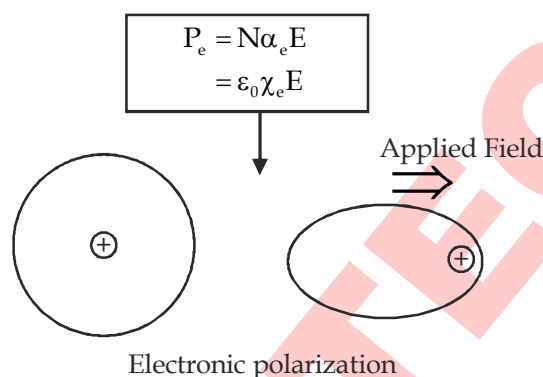


Polarization Mechanism

- Electric or induced polarization
- Ionic polarization
- Orientational polarization
- Interfacial or space charge polarization

Electronic Polarization

- This type of polarization has been explained with the help of rare gaseous atoms, in which it is assumed that interaction among the atoms is negligible, This is because the distance between the molecules is large enough so that mono- atomic gases and any neighbour-neighbour reactions can be eliminated.
- Monoatomic gas exhibits only this kind of polarization, so electronic polarization is given as



- The contribution of P_e to the dielectric constant may be obtained as follows:

$$\epsilon_r = 1 + \epsilon_e = 1 + \frac{P_e}{\epsilon_0 E} = 1 + \frac{N\alpha_e E}{\epsilon_0 E}$$

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

- This above expression indicates the dielectric constant due to electronic polarization alone and thus gives the dielectric constant of a non-polar gaseous dielectric.
- It shows that dielectric constant of a non-polar gas depends on the polarizability of a molecule and the number of molecules in a unit volume of the dielectric. In case of a monoatomic gas it is found that the electronic polarization is given by:

$$\alpha_e = 4\pi\epsilon_0 R^3$$

put this value of α_e in equation and we get

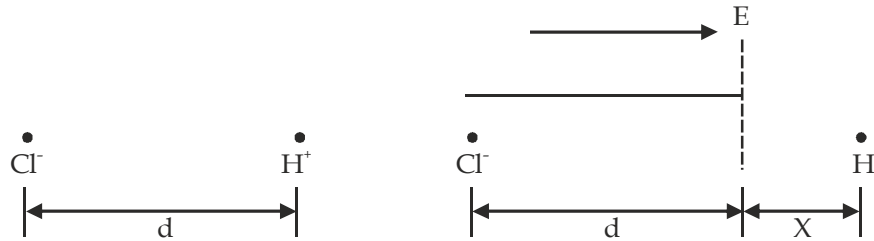
$$\therefore \epsilon_e = 1 + 4\pi N R^3$$

where R represents the radius of the atom.

- The above expression shows that electronic polarizability is a function of atomic radius only.

Ionic Polarization

- In an ionic bond, when two different atoms join together, there is a transfer of electrons from one atom to another. In NaCl bond there is a transfer of an electron from Na^+ atom to Cl-atom.
- Ionic polarization exists only for those types of materials which have a net positive charge and negative charge. Even in the absence of an applied field, HCL molecules has a permanent dipole moment $e.d$, where d is the distance of separation of ions. In an dipoles parallel to field at absolute zero of temperature, as indicated in figure.



Ionic separation of ions when subjected to an Electric Field

- The field produces force on the two charges, as well as a torque on the dipole. The distance between ions increases from d to $d + x$. The field has induced an additional dipole moment, $P_{\text{ind}} = e \cdot x$ in the molecule.
- The induced dipole moment is proportional to the applied electric field, and the proportionality constant is the ionic polarizability. we have,

$$P_{\text{ind}} = \alpha_i E$$

where α_i is the ionic polarizability.

The simultaneous occurrence of electronic and ionic polarization (P_e and P_i , respectively) result in a volume polarization P , which is the sum of the individual effects (for non-polar gases), such that

$$P = P_e + P_i = N(\alpha_e + \alpha_i)E$$

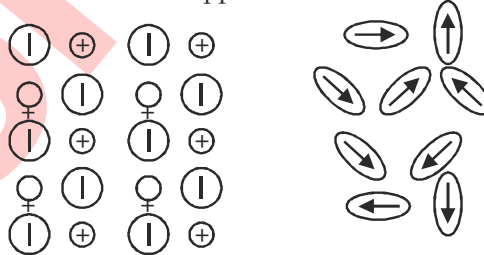
Note:

- Ionic polarization is also called molecular polarization in which the bonds between the atoms are stretched by applied electric field when the lattice ions are charged.
- Electronic and ionic polarizabilities are independent of temperature because distribution of electrons in both atoms and molecules is almost independent of temperature.

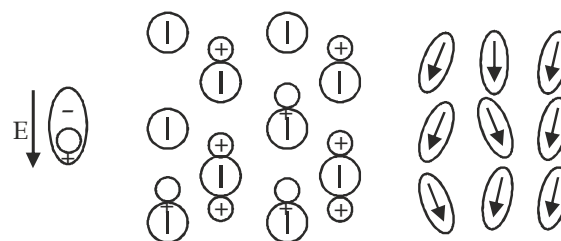
Orientation Polarization

- This type of polarization is found only in substances that possess permanent dipole moment e.g. CH_3Cl . When an electric field is applied on such a molecule, then the dipoles tend to align themselves in the direction of applied field. This polarization is dependent on temperature. Polarization decreases with increasing temperature.

No Applied Field



With Applied Field



Electronic

Ionic

Orientation

Type of polarization that exist in a dielectric material

- The orientation polarizability α_0 is calculated to be

$$\alpha_0 = \frac{p_p^2}{3K_B T}$$

where, K_B is the Boltzmann's constant and p_p the permanent dipole moment and orientation polarization is given by Debye's law.

$$P_0 = N\alpha_0$$

$$E = \frac{Np_p^2}{3K_B T}$$

which states that the orientation polarization is inversely proportional to the temperature and proportional to the square of the permanent dipole moment.

Q.25

Sol. **Conductivity**

Current density

$$J = eE(n\mu_n + p\mu_p) = \sigma E$$

$$\sigma = \text{conductivity}$$

$$= e(n\mu + p\mu_p)$$

For intrinsic semiconductor $n = p = n_i$

Intrinsic Concentration

Variation of n_i with temp. T is given as

$$n_i^2 = A_0 T^3 e^{-E_{G0}/kT}$$

where, E_{G0} is the energy gap at 0°K in electron volts, k -Boltzman const. in $\text{eV}/^\circ\text{K}$ and A_0 is constant independent of T .

Recombination centres which contribute electronic states in the energy gap of the semiconductor. Gold is extensively used as recombination agent by manufactures. Device designers obtain desired carrier lifetimes by introducing gold into silicon under controlled conditions. These lifetimes range from ns to ms.

Diffusion

- The concentration of holes (p) varies with distance x in the semiconductor and there exists a concentration gradient dp/dx in the density of carriers. The diffusion hole-current density J_p (amperes per square metre) is proportional to concentration gradient dp/dx and is given by

$$J_p = -qD_p \frac{dp}{dx}$$

and

$$J_n = +qD_n \frac{dn}{dx}$$

where D_p, D_n = diffusion constant for holes and electrons in square meters per second.

Einstein Relationship

$$\begin{aligned} \frac{D_p}{\mu_p} &= \frac{D_n}{\mu_n} = V_T \\ &= \frac{kT}{q} = \frac{T}{11600} \end{aligned}$$

where k is Boltzman constant in joules per degree kelvin at room temperature $V_T = 0.026$, $V = 26$ mV.

Total Current

- In presence of both potential and concentration gradient total hole current and electron current are given by following equations respectively.

$$J_p = q\mu_p pE - qD_p \frac{dp}{dx},$$

$$J_n = q\mu_n nE + qD_n \frac{dn}{dx}$$

Electrical Properties of Semiconductor

- The resistivity of a semiconducting materials is less than an insulating materials but more than a (conducting material).
- Semiconducting materials have negative temperature coefficient of resistance. It means, the resistance decreases with the rise in temperature and vice-versa. According to this property, the semiconductors behaves like an insulator at very low temperatures but act as a conductor at high temperatures.
- When a suitable metallic impurity (like arsenic, gallium etc.) is added to a semiconductor material, it changes the current conducting properties of the semiconductor appreciably.

Q.26

Sol.

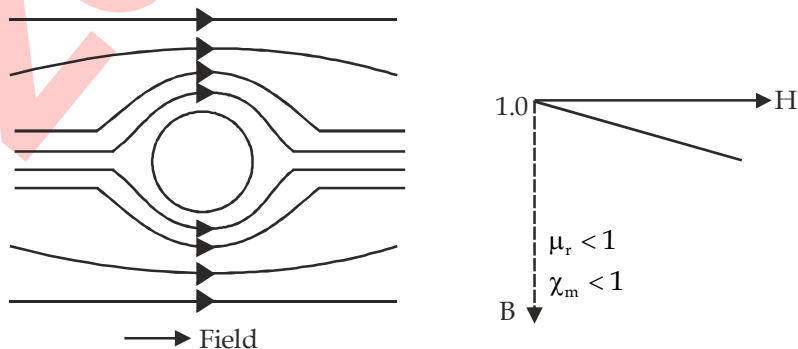
CLASSIFICATION OF MAGNETIC MATERIALS

- On the basis of magnetic behaviour, material may be classified as:
 1. Diamagnetic
 2. Paramagnetic
 3. Ferromagnetic
 4. Anti-ferromagnetic
 5. Ferrimagnetic
- The magnetic behaviour may be attributed to
 - Electron orbital motion
 - Electron spin and
 - Nuclear spin
- All the three of these causes are representable by equivalent atomic currents flowing in circular loops. The equivalent atomic current loops are characterized by their magnetic dipole moments.

Diamagnetic Materials

- The materials when placed in a magnetic field acquire weak magnetization in a direction opposite to that of the applied field are called diamagnetic materials.
- On the other words, a diamagnetic is a substance which exhibits so to speak negative magnetism.

For diamagnetic ($\chi_m < 0$) χ_m is negative magnetic field.



- Diamagnetism has no ordinary practical use. Some of the materials which only exhibit diamagnetic behaviour are Cu, Au, Ge, Si, diamond, Al_2O_3 , NaCl. etc. when an external field is applied to a diamagnetic substances, it expels the magnetic lines as shown in figure gives B-H curve for a diamagnetic substance

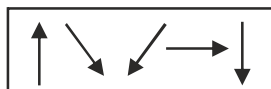


Note:

- The induced dipole moment occurs in all the materials in the sense that all materials are diamagnetic.
- However, when permanent dipole moments are present in numbers comparable to the total number of atoms, the properties of permanent dipoles usually over shadow the diamagnetic effect.

Paramagnetic Materials

- The materials when placed in a magnetic field acquire a weak magnetization in the same direction as the applied field are called paramagnetic materials. The permanent magnetic moments of the atoms or ions are acted upon individually, with no-mutual interaction among them (randomly distributed), this effect is called Paramagnetism.



- However in the presence of the field, the magnetic moments have a tendency to turn towards the direction of the field. But thermal agitation of the atoms opposes this tendency and tends to keep the atomic dipole moments at random. The result is only a partial alignment in the field direction, therefore, a weak magnetization and a small positive susceptibility.
- The effect of an increase in temperature is to increase the randomizing effect of thermal agitation and therefore, decreases the susceptibility.
- Some of the paramagnetic materials are: Fe_2O_3 , MnSO_4 , FeSO_4 , FeCl_2 , NiSO_4 etc.

Note:

- Many paramagnetic material do not obey the curie law,

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

- They obey a modified law, called curie weiss law,

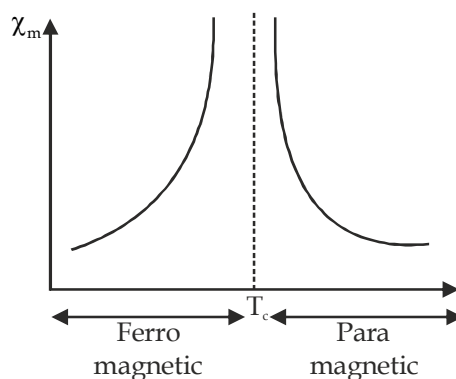
$$\chi_m = \frac{C}{T - \theta}$$

where θ is a constant with the dimensions of temperature for any one substance and equals zero for those substances which obey curie law.

- The properties of paramagnetics are not much of practical importance, but it helps to understand the theory of ferro and ferrimagnetism.

Ferromagnetic Materials

- Ferromagnetic materials are spontaneously magnetized even in the absence of external magnetic field. All ferromagnetic material becomes paramagnetic above a temperature called curie temperature T_c .



- Magnetic susceptibility χ_m of ferromagnetic material ($T < T_c$) increases with increase in temperature, where as it reduces with increase in temperature ($T > T_c$) in case of paramagnetic materials which is shown in figure.
- The most important ferromagnetic materials are iron (Fe), cobalt (CO), nickel (Ni) and gadolinium (Gd).
- The ferromagnetic properties of the transition elements Fe, CO and Ni are due to the spins of the inner unpaired electrons. In Fe, CO, and Ni the unpaired inner 3d electrons are responsible for the ferromagnetism.
- Ferromagnetic material is characterized by parallel alignment of dipole moment even in the absence of external field.



Q.27

Sol. DIELECTRICS PARAMETERS

- Dielectric constant
- Dipole moment
- Polarization
- Polarizability

Dielectric Constant

- The electric flux density and the electric field intensity are proportional to each other

$$D \propto E$$

$$D = \epsilon E$$

where ϵ is the proportional constant, ϵ is the dielectric constant of the medium, farad/meter (also called permittivity).

D is the electric flux density and E is the electric field intensity.

- If the medium to which the electric field is applied in free space (vacuum). The proportionality constant of vacuum, ϵ_0 of value 8.854×10^{-12} farad meter⁻¹ be expressed by ϵ_r , relative to that of vacuum by

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

$\therefore \epsilon = \epsilon_r \epsilon_0$ Put in equation

$$D = \epsilon_r \epsilon_0 E$$

The relative permittivity ϵ_r for free space (vacuum) is 1.

The relative dielectric constant ϵ_r is a dimensionless quantity.

Note:

- If ϵ is dependent upon the direction of measurement, then D and E may not be parallel and ϵ is a tensor
- D is also called electric displacement.

We can also understand the dielectric constant by considering a parallel plate capacitor (rectangular plates), with the area of the plates as 'a' meter² each, a distance d-meter apart in vacuum.

The capacitance of this capacitor is

$$C_0 = \frac{\epsilon_0 a}{d}$$

ϵ_0 is dielectric constant or permittivity of vacuum, 8.854×10^{-12} farad meter⁻¹.

- If the space between the plates is filled with a dielectric material, the capacitance of the capacitor increases and is given by

$$C = \frac{\epsilon_0 \epsilon_r a}{d}$$

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

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

$$\epsilon_r = \frac{C}{C_0}$$

Different materials have different values of ϵ_r .

Its value being unity for vacuum, 1.0006 for air, 1.0000684 for helium (S.T.P.), 11.7 for silicon and 16 for germanium.

- The study of the dielectric properties of the materials is the study of ϵ_r in details and includes:
- The study as to why some materials have a high and the others a low dielectric constant? The study of the effect of temperature on ϵ_r for different materials.

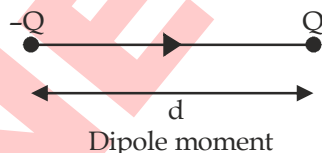
Dielectric materials are mostly used as electrical insulation materials. A large range of widely differing materials is used for this very important engineering application.

Dipole Moment

- Two charges of equal magnitude but of opposite polarity, 'd' distance apart constitute a dipole moment, given as

$$P = Qd$$

P is the dipole moment in coulomb-meter. Dipole moment is a vector, pointing from the negative charge to the positive charge as indicated by figure and its unit is also debye ($1 \text{ debye} = 3.33 \times 10^{-30} \text{ coulomb-meter}$).



- The dipole moment can also be defined with respect to a neutral system of point charges $Q_1, Q_2, \dots, Q_i, \dots, Q_n$ as

$$P = \sum_i Q_i r_i$$

where r_i represents vector drawn from the origin of a coordinate system to the position of the charge Q_i may be either positive, or negative,

but $\sum Q_i = 0$, as the system of the charges is neutral. When the net charge of the system is zero, this definition is independent of the choice of origin. If the origin is displaced by an amount Δr , the new value for the dipole moment is

$$\begin{aligned} P + \Delta P &= \sum_i Q_i (r_i + \Delta r) \\ &= \sum_i Q_i r_i + \Delta r \sum_i Q_i = P \end{aligned}$$

- The dielectric properties basically involves the creation of displacements in dielectric materials by an applied static electric field.

Polarization

- In atoms, because of their spherical symmetry, the centre of mass of the electrons coincides with the nucleus. Therefore atoms do not have permanent electric dipole moments. However, when atoms are placed in an electric field. They acquire an induced electric dipole moment in the direction of the field. This process is called the electrical polarization.