ANNA UNIVERSITY SOLVED PROBLEMS

Problem 5.1

A parallel plate capacitor consists of two plates each of area 5×10^{-4} m^2. They are separated by a distance 1.5×10^{-3} m and filled with a dielectric of relative permittivity 6. Calculate the charge on the capacitor if it is connected to a 100 volt DC supply.

(A.U. Dec 2012)

Given data

Area of the capacitor plate $A = 5 \times 10^{-4}$ m^2

Distance between the plates $d = 1.5 \times 10^{-3}$ m

Relative permittivity of the dielectric $\varepsilon_r = 6$

Applied voltage $V = 100$ V

Permittivity in free space, $\varepsilon_o = 8.85 \times 10^{-12}$ F m^{-1}

Solution:

We know that $Q = CV$

Also, we have the relation

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

$$Q = \frac{\varepsilon_o \varepsilon_r AV}{d}$$

Substituting the given values, we have

$$Q = \frac{8.85 \times 10^{-12} \times 6 \times 5 \times 10^{-4} \times 100}{1.5 \times 10^{-3}}$$

$$Q = 1.77 \times 10^{-9} C$$

$$\boxed{\text{Charge on the capacitor} = 1.77 \times 10^{-9} \text{ coulomb.}}$$

Problem 5.2

If a NaCl crystal is subjected to an electrical field of 1000 V/m and the resulting polarisation is 4.3×10^{-8} C/m^2, calculate the relative permittivity of NaCl.

(A.U. April 2012)

Given data

Applied electrical field $E = 1000$ V m^{-1}

Polarisation $P = 4.3 \times 10^{-8}$ C m^{-2}

Permittivity in free space $\varepsilon_o = 8.85 \times 10^{-12}$ F m^{-1}

Solution:

We know that $P = \varepsilon_o (\varepsilon_r - 1) E$

$$(\varepsilon_r - 1) = \frac{P}{\varepsilon_o E}$$

$$\varepsilon_r = 1 + \frac{P}{\varepsilon_o E}$$

Substituting the given values we have

$$\varepsilon_r = 1 + \frac{4.3 \times 10^{-8}}{8.85 \times 10^{-12} \times 1000}$$

$$= 1 + 4.86$$

$$\boxed{\varepsilon_r = 5.86}$$

Problem 5.3

Calculate the electronic polarisability of argon atom given $\varepsilon_r = 1.0024$ at NTP and $N = 2.7 \times 10^{25}$ atoms/m^3.

(A.U. Nov 2011)

Given data

Relative permittivity $\varepsilon_r = 1.0024$

Number of atoms per unit volume $N = 2.7 \times 10^{25}$ atoms m^{-3}

Permittivity in free space $\varepsilon_0 = 8.85 \times 10^{-12}$ F m^{-1}

Solution:

We know that $P = \varepsilon_0 (\varepsilon_r - 1) E$

Also, $P = N \alpha_e E$

$$N \alpha_e E = \varepsilon_0 (\varepsilon_r - 1) E$$

i.e.,
$$\alpha_e = \frac{\varepsilon_0 (\varepsilon_r - 1)}{N}$$

Substituting the given values, we have

$$\alpha_e = \frac{(8.85 \times 10^{-12})(1.0024 - 1)}{2.7 \times 10^{25}}$$

$$\boxed{\alpha_e = 7.9 \times 10^{-40} \text{ Fm}^2}$$

Problem 5.4

The dielectric constant of He gas at NTP is 1.0000684. Calculate the electronic polarisability of He atoms if the gas contains 2.7×10^{25} atoms per m^3

(A.U. Nov 2011)

Given data

Dielectric constant of the gas at NTP $\varepsilon_r = 1.0000684$

Number of He atoms per unit volume $N = 2.7 \times 10^{25}$ m^{-3}.

Solution

Electronic polarisability is given by

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

Substituting the given values, we have

$$\alpha_e = \frac{8.85 \times 10^{-12} (1.0000684 - 1)}{2.7 \times 10^{25}}$$

$$\boxed{= 2.242 \times 10^{-41} \text{ Fm}^2}$$

Problem 5.5

A parallel plate condenser has a capacitance of 2 μ F. The dielectric has permittivity $\varepsilon_r = 100$. For an applied voltage of 1000 V, find the energy stored in the condenser as well as the energy stored in polarising the dielectric.

(A.U. Dec 2011)

Given data

$C = 2 \times 10^{-6} F$

$$V = 1000\text{ V} = 10^3\text{ V}$$

$$\varepsilon_r = 100$$

Solution:

Total energy stored in the capacitor $E = \frac{1}{2}CV^2$

$$E = \frac{1}{2} \times 2 \times 10^{-6} \times (10^3)^2 = 1\text{ J}$$

To calculate the energy stored in the dielectric material which is in between the parallel plates of the condenser, capacitance has to be calculated by removing the dielectric material.

$$C_o = \frac{C}{\varepsilon_r} = \frac{2 \times 10^{-6}}{100} = 0.02\ \mu F$$

Energy stored without the dielectric,

$$E = \frac{1}{2} C_o V^2 = \frac{1}{2} \times 0.02 \times 10^{-6} \times (10^3)^2$$

$$= 0.01\text{ J}$$

Hence, energy stored in the dielectric

$$E' = E - E_o = 1 - 0.01$$

$$\boxed{E' = 0.99\text{ J}}$$

Part - A '2' Marks Q & A

ANNA UNIVERSITY Q&A

1. Define dielectric constant. *(A.U. Jan 2013)*

It is the ratio between absolute permittivity of the medium (ε) and permittivity of free space (ε_0)

$$\text{Dielectric constant } \varepsilon_r = \frac{\text{Absolute permittivity } (\varepsilon)}{\text{permittivity of free space } (\varepsilon_0)}$$

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

2. Define polarisation of a dielectric material. *(A.U. June 2012)*

The process of producing electrical dipoles inside the dielectric by the application an external electrical field is called polarisation in dielectrics.

Induced dipole moment $(\mu) = \alpha E$

$E \rightarrow$ Applied electrical field

$\alpha \rightarrow$ Polarizability

3. Name the four polarisation mechanisms. *(A.U. May 2012)*

(i) Electronic polarisation

(ii) Ionic polarisation

(iii) Orientational polarisation

(iv) Space - charge polarisation.

4. What is electronic polarisation? *(A.U. May 2011)*

The induced dipole moment produced in an atom by the application electric field is known as electronic polarization. It is due to shifting of negatively changed electron and positively charged nucleus charges of atom in the material by the applied electric field.

5. What is ionic polarisation? *(A.U. May 2012)*

Ionic polarisation is due to the displacement of cations (negative ions) and anions (positive ions) in opposite direction due to the application of an electrical field. This occurs in an ionic solid.

6. What is orientational polarisation? *(A.U. May 2010)*

When an electrical field is applied on the dielectric medium with polar molecules, the dipoles align themselves in the field direction and thereby increases electric dipole moment.

Such a type of contribution to polarisation due to the orientation of permanent dipoles by the applied field is called orientational polarisation.

7. What is space - charge polarisation? *(A.U. May 2009)*

In some materials containing two or more phases, the application of an electrical field causes the accumulation of charges at the interfaces between the phases or at the electrodes.

As result of this, polarisation is produced. This type of polarisation is known as **space charge polarisation.**

8. What is meant by local field in a dielectric?

(A.U. Jan 2010)

When a dielectric is kept in an external electric field (E), two fields are exerted due to (i) external field and (ii) dipole moment created

These long range coulomb forces which are created due to the dipoles are called **local field in dielectric**.

It is given by $\boxed{E_{int} = E + \frac{P}{3\varepsilon_0}}$

where $P \rightarrow$ polarisation

$\varepsilon_0 \rightarrow$ permitivity in free space.

9. Define dielectric loss and loss tangent.

(A.U. Jan 2012, June 2013)

When a dielectric material is subjected to an A.C voltage, the electrical energy is absorbed by the material and is dissipated in the form of heat. This dissipation of energy is called dielectric loss.

In a perfect insulator, polarisation is complete during each cycle and there is no consumption of energy and the charging current leads the applied voltage by 90°.

But for commercial dielectric, this phase angle is less than 90° by an angle δ and is called dielectric loss angle. Tan δ is taken as measure of dielectric loss and is known as **loss tangent.**

10. Define dielectric breakdown and dielectric strength.

(A.U. Jan 2013)

Whenever the electrical field strength applied to a dielectric exceeds a critical value, very large current flows through it. The dielectric loses its insulating property and becomes conducting. This phenomenon is known as **dielectric breakdown.**

The electrical field strength at which dielectric breakdown occurs is known as **dielectric strength.**

15. What is discharge breakdown?

Discharge breakdown occurs when a dielectric contains occluded gas bubbles. When this type of dielectric is subjected to electrical field, the gases present in the material will easily ionise and thus produce large ionisation current.

The gaseous ions bombard the solid dielectric. This causes electrical deterioration and leads to dielectric breakdown.

16. What is defect breakdown?

The surface of the dielectric material may have defects such as cracks, porosity and blow holes. Impurities like dust or moisture may collect at these discontinuities (defects). This will lead to a breakdown in a dielectric material.

17. Mention any two active and passive dielectrics with their applications (or) Compare active and passive dielectrics.

(A.U. April 2008)

S.No.	Active dielectrics	Passive dielectrics
1.	Dielectrics which can easily adapt itself to store the electrical energy in it is called active dielectrics.	Dielectrics which restricts the flow of electrical energy in it are called passive dielectrics
2.	Examples: Piezo electrics, Ferro electrics, Pyro electrics	**Examples:** glass, mica, plastic
3.	It is used in the production of ultrasonics.	It is used in the production of sheets, pipes etc.

18. How does the dielectric polarization in polar and non-polar substances vary with temperature (or) What are the differences between polar and non-polar molecules.

(A.U May 2008)

S.No.	Polar molecule	Non-polar molecules
1.	These molecules have permanent dipole moments even in the absence of an applied field.	These molecules do not have permanent dipole moments.
2.	The polarization of polar molecules is highly temperature dependent.	The polarization of this kind of molecules is independent of temperature.
3.	These molecules do not have symmetrical structure and they do not have centre of symmetry.	These molecules have symmetrical structure and they have centre of symmetry.
4.	For this kind of molecules, there is absorption or emission, in the infrared range	For these molecules, there is no absorption or emission in the range of infrared.
5.	**Examples:** $CHCl_3$, H_2O, HCl	**Examples:** CCl_4, CO_2, H_2

19. What are requirements of good insulating materials?

(A.U. May 2012)

The good insulating materials should have

- high electrical resistivity to reduce leakage current
- high dielectrical strength to withstand higher voltage
- smaller dielectric loss
- sufficient mechanical strength

Additional Questions

1. Derive the expressions for electronic and ionic polarisabilities.
2. Briefly explain the effects of frequency and temperature on polarisation of dielectrics.
3. Briefly explain the applications of dielectrics.
4. What are ferroelectric material? Mention few example and explain any four applications of ferroelectric materials.

ASSIGNMENT PROBLEMS

1. A parallel plate capacitor of area $650\ mm^2$ and a plate separation of 4 mm has a charge of 2×10^{-10} C on it. What is the resultant voltage across the capacitor when a material of dielectric constant 3.5 is introduced between the plates.

   [Ans: 39.73 V]

2. The atomic weight and density of sulphur are 32 and $2.08\ gm/cm^3$ respectively. The electronic polarisability of the atom is $3.28 \times 10^{-40}\ Fm^2$. If sulphur solid has cubical symmetry, what will be its relative dielectric constant.

   [Ans: $\varepsilon_r = 2.45$]

3. The number of atoms in volume of one cubic metre of hydrogen gas is 9.8×10^{26}. The radius of the hydrogen atom is 0.53 Å. Calculate the polarisability and relative permittivity.

   [Ans: $\varepsilon_r = 1.0018$, $\alpha_e = 1.655 \times 10^{-41}\ Fm^2$]