Dielectrics

9.1 INTRODUCTION

A dielectric is an insulating material in which all the electrons are tightly bound to the nuclei of the atoms and there are no free electrons available for the conduction of current. Therefore, the electrical conductivity of a dielectric is very low. The conductivity of an ideal dielectric is zero. On the basis of band theory, the forbidden gap (E_g) is very large in dielectrics. Materials such as glass, polymers, mica, oil and paper are examples of dielectrics. They prevent flow of current through them. Therefore, they can be used for insulating purposes.

9.2 DIELECTRIC CONSTANT

It is found experimentally that the capacitance of a capacitor is increased if the space between its plates is filled with a dielectric material. To understand this fact, Faraday took two identical capacitors, one was evacuated and the other was filled with dielectric material, as shown in Fig. 9.1.

Then these two capacitors were charged with a battery of same potential difference. He found that the charge on the capacitor filled with dielectric is larger than that of the other filled with air. If C_0 be the capacitance in vacuum and C the capacitance when the space is filled with a dielectric material, then the dielectric constant of the material

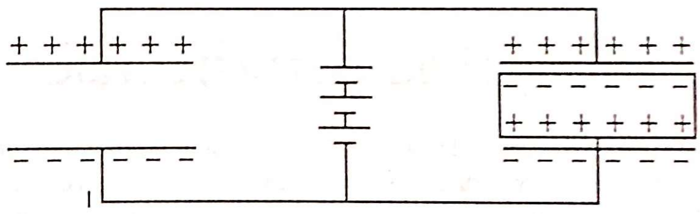

Fig. 9.1

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

Thus, the dielectric constant of a material is the ratio of the capacitance of a given capacitor completely filled with that material to the capacitance of the same capacitor in vacuum. In other words, the ratio of permittivity of medium to that of the vacuum is also known as *dielectric constant*.

i.e.,

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

This is also known as *relative permittivity* (ε_r). It is found to be independent of the shape and dimension of the capacitor.

9.3 TYPES OF DIELECTRICS

A molecule is a neutral system in which the algebraic sum of all the charges is zero. Based on the dipole moment, the molecules of dielectrics are termed as non-polar and polar molecules. Accordingly these dielectrics are referred to as non-polar and polar dielectrics.

9.3.1 Non-polar Dielectrics

A 'non-polar' molecule is the one in which the centre of gravity of the positive (protons) and negative charges (electrons) coincide. So such molecule does not have any permanent dipole moment, as shown in Fig. 9.2a. Few common examples of non-polar molecules are oxygen (O_2), nitrogen (N_2) and hydrogen (H_2). As mentioned earlier, the dielectrics having non-polar molecules are known as non-polar dielectrics.

9.3.2 Polar Dielectrics

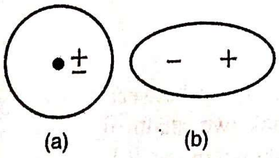

Fig. 9.2

A polar molecule is the one in which the centre of gravity of the positive charges is separated by finite distance from that of the negative charges. Unbalanced electric charges, usually valency electrons, of such molecules result in a dipole moment and orientation. Therefore, these molecules possess permanent electric dipole (Fig. 9.2b). Few examples of polar molecules are N_2O, H_2O and HCl. The dielectrics having polar molecules are known as polar dielectrics.

9.4 POLARISATION OF DIELECTRICS

When an electric field is applied to a dielectric material; it exerts a force on each charged particle and pushes the positive charge in its own direction while the negative charge is displaced in opposite direction, as shown in Fig. 9.3. Consequently, the centres of positive and negative charges of each atom are displaced from their equilibrium positions. Such a molecule (or atom) is then called as *induced electric dipole* and this process is known as *dielectric polarisation.*

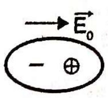

Fig. 9.3

We consider a parallel plate capacitor which has vacuum initially between its plates. When it is charged with a battery, the electric field of strength E_0 is set up between the plates of the capacitor (Fig. 9.4a). If σ and $-\sigma$ are the surface charge densities of the two plates of the capacitor, then the electric field developed between the plates is given by

$$E_0 = \frac{\sigma}{\varepsilon_0} \qquad \text{(i)}$$

If now a slab of dielectric material is placed between the two plates of the capacitor (Fig. 9.4b), then it becomes electrically polarised. Hence, its molecules become electric dipole oriented in the direction of the field. Because of this the centre of positive and negative charges gets displaced from each other. Therefore, in the interior of the dielectric as marked by dotted lines these charges cancel. However, the polarisation charges on the opposite faces of the dielectric slab are not cancelled. These charges produces their own electric field E_p, which opposes the external applied field E_0. Under this situation, the net electric filed in the dielectric is given by

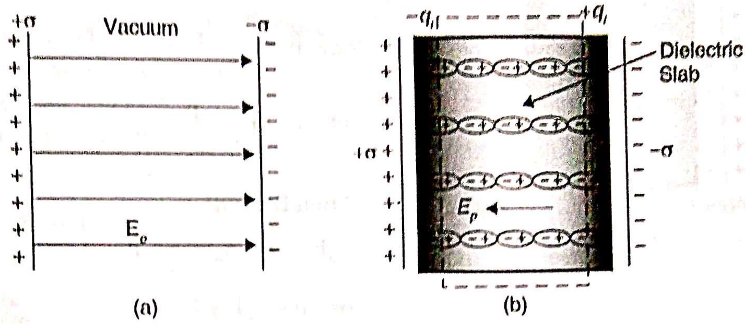

Fig. 9.4

$$\vec{E} = \vec{E}_0 - \vec{E}_p \qquad \text{(ii)}$$