University of Jeddah
Faculty of Engineering
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Electromagnetic Fields (ECE 308)

Lecture 8 – Electrostatics - V

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Dielectrics:

The fundamental difference between dielectric is that electrons in the outermost atomic shells of a conductor are only weekly tied to atoms and hence can freely migrate through the material, whereas in a dielectric they are strongly bound to the atom. In the absence of an electric field, the electrons in so called **nonpolar** molecules form a symmetrical cloud around the nucleus, with the center of the cloud coinciding with the nucleus as in **fig. a**.

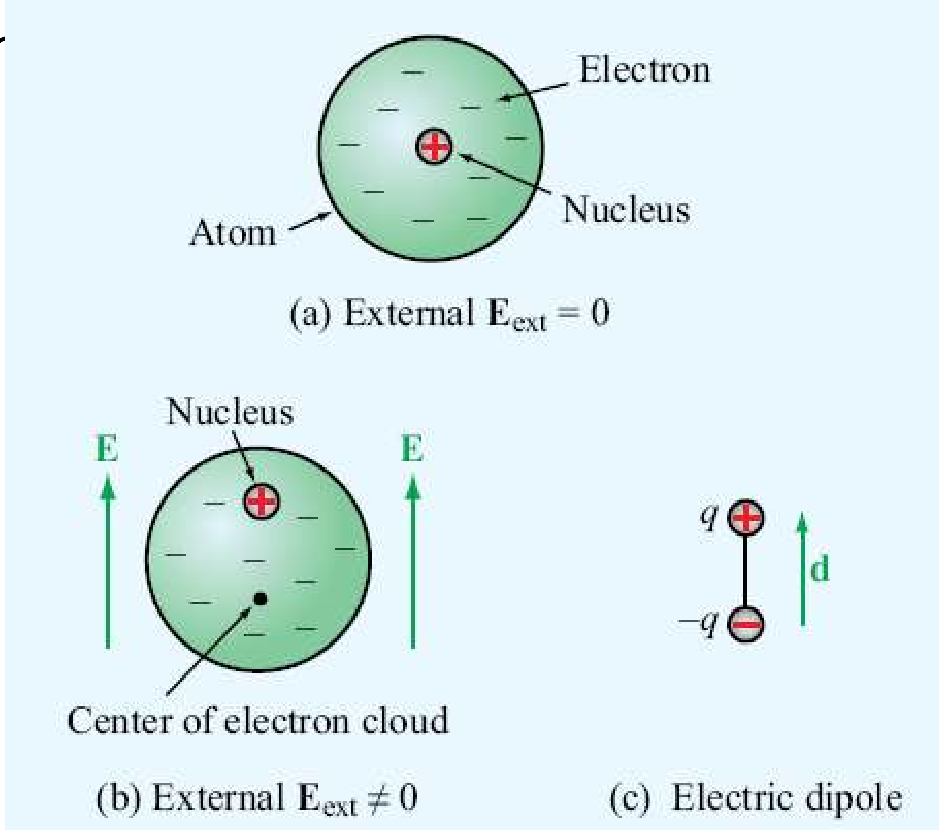

Figure 4-16 In the absence of an external electric field **E**, the center of the electron cloud is co-located with the center of the nucleus, but when a field is applied, the two centers are separated by a distance d.

Dielectrics:

The electric field generated by the positively charged nucleus attracts and holds the electron cloud around it, and the mutual repulsion of the electron clouds of adjacent atoms shapes its form. When a conductor is subjected to an externally applied electric field, the most loosely bound electrons in each atom can jump from one atom to the next, thereby setting up an electric current. In a dielectric, however, an externally applied electric field **E** cannot effect mass migration of charges since none are able to move freely. Instead, **E** will **polarize** the atoms or molecules in the material by moving the center of the electron cloud away from the nucleus, as shown in **fig. b**. The polarized atom or molecule may be represented by an electric dipole consisting of charges +q in the nucleus and -q at the center of the electron cloud as in **fig. c.** Each such dipole sets up a small electric field, pointing from the positively charged nucleus to the center of the equally but negatively charged electron cloud. This induced electric field, called a **Polarization** field, generally is weaker than and opposite in direction of **E**.

Dielectrics:

The net electric field present in the dielectric material is smaller than E. Within a block of dielectric material subject to a uniform external field, the dipoles align themselves linearly as shown in fig. Along the upper and lower edges of the material, the dipole arrangement exhibits positive and negative surface charge densities, respectively.

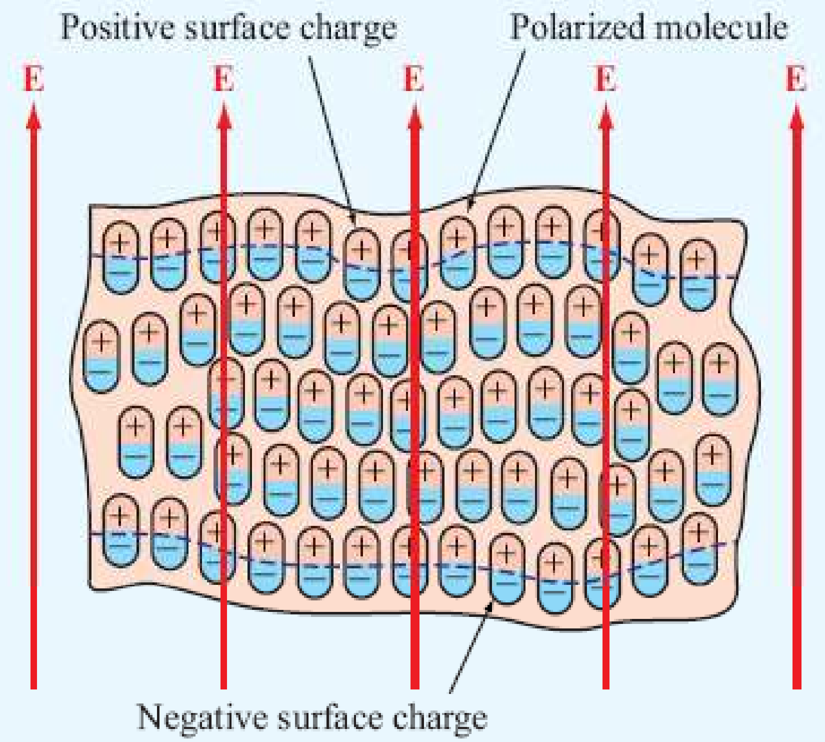

Figure 4-17 A dielectric medium polarized by an external electric field **E**.

It is important to stress that this description applies to only nonpolar molecules, which do not have permanent dipole moments. Nonpolar molecules become polarized only when an external field is applied, and when field removed, the molecules return to their original state.

Dielectrics:

In polar materials, such as water, the molecules possess built-in **permanent dipole moments** that are randomly oriented in the absence of an applied electric field, and owing to their random orientations, the dipoles of polar materials produce no net macroscopic dipole moment (at the macroscopic scale, each point in the material represents a small volume containing thousands of molecules).

Under the influence of an applied field, the permanent dipoles tend to align themselves along the direction of the electric field, in a manner similar to nonpolar materials.

Polarization Field:

Whereas in free space **D** = ε_0**E** , the presence of microscopic dipoles in a dielectric material alerts that relationship to

D = ε_0**E + P,** where **P** called the ***Electrical Polarization Field***, accounts for the polarization properties of the material. The polarization field is produced by the electric field **E** and depends on the material properties. A dielectric medium is said to be **Linear** if the magnitude of the induced polarization field **P** is directly proportional to the magnitude of **E**, and **Isotropic** if **P** and **E** are in the same direction. Some crystals allow more polarization to take place along certain directions, such as the crystal axes, than along others. In such **Anisotropic** dielectrics, **E** and **P** may have different directions. A medium is said to be **Homogeneous** if its constitutive parameters (ε, μ and σ) are constant throughout the medium. Here, $\boxed{\mathbf{P} = \epsilon_0 \chi_e \mathbf{E},}$ where, χ_e is called the **Electric Susceptibility**.

Polarization Field:

Put the value of P in **D** = ε_0**E + P** gives $\mathbf{D} = \epsilon_0 \mathbf{E} + \epsilon_0 \chi_e \mathbf{E} = \epsilon_0 (1 + \chi_e) \mathbf{E} = \epsilon \mathbf{E},$

which defines the permittivity as the material as,

$$\boxed{\epsilon = \epsilon_0 (1 + \chi_e)}$$

It is often convenient to characterize the permittivity of a material relative to that of free space, ε_0; this is accommodated by the relative permittivity ε_r. For most of the conductors the value of ε_r is equals to 1. The dielectric constant of air is approximately 1.0006 at sea level, and decreases toward unity with increasing altitude. Except in some special case, such as when calculating electromagnetic wave refraction (bending) through the atmosphere over long distances, *air can be treated as if it were free space.*

Dielectric Breakdown:

The preceding dielectric-polarization model presumes that the magnitude of **E** does not exceed a certain critical value, known as the **Dielectric Strength** of the material (Example of Transformer oil), beyond which electrons will detach from the molecules and accelerate through the material in the form of a conductor current. When this happens, sparking can occur, and the dielectric material can sustain permanent damage due to electron collisions with the molecular structure. This abrupt change in behavior is called **Dielectric Breakdown.**

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Capacitance:

When separated by an insulating (dielectric) medium, any two conducting bodies, regardless of their shapes and sizes, form a **Capacitor**. If a dc voltage source is connected across them the surfaces of the conductors connected to the positive and negative source terminals accumulate charges +Q and –Q, respectively.

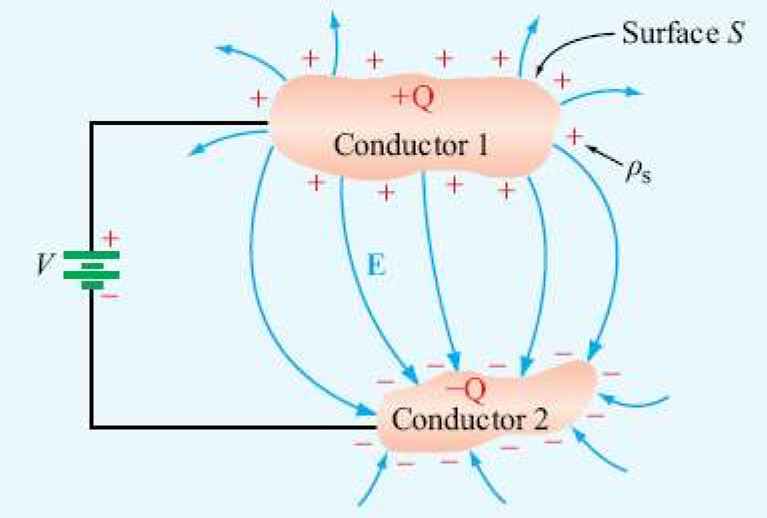

Figure 4-23 A dc voltage source connected to a capacitor composed of two conducting bodies.

-The capacitance of a two conductor configuration is defined as

$$C = Q / V$$

where V is the potential difference between the conductors.

Capacitance:

The presence of free charges on the conductor's surfaces gives rise to an electric field **E** with the field lines originating on the positive charges and terminating on the negative ones. Since the tangential component of **E** always vanishes at a conductor's surface, **E** is always perpendicular to the conducting surfaces. The normal component of **E** at any point on the surface of either conductor is given by

$$E_n = \hat{\mathbf{n}} \cdot \mathbf{E} = \frac{\rho_s}{\epsilon}, \quad \text{(at conductor surface)}$$

where ρs is the surface charge density at that point.

$$C = \frac{Q}{V} = \frac{Q}{Ed} = \frac{\epsilon A}{d}$$

Electrostatic Potential Energy:

A source connected to a capacitor expends energy in charging up the capacitor. If the capacitor plates are made of a good conductor with effectively zero resistance, and if the dielectric separating the two plates has negligible conductivity, then no real current can flow through the dielectric, and no ohmic losses occur anywhere in the capacitor. The energy ends up getting stored in the dielectric medium in the form of **Electrostatic Potential Energy**.

$v = \frac{q}{C}$ From the definition of *v*, the amount of work dW_e required to transfer an additional incremental charge dq from one conductor to the other is $dW_e = v\,dq = \frac{q}{C}\,dq.$ If we transfer a total charge Q between the conductors of an initially uncharged capacitor, then the total amount of work performed is $W_e = \int_0^Q \frac{q}{C}\,dq = \frac{1}{2}\,\frac{Q^2}{C}$ Using C = Q/V, The electrostatic potential energy is,

$$\boxed{W_e = \tfrac{1}{2} C V^2}$$

Thank you !