

## DIELECTRICS

Matter comes in many varieties - solids, liquids, metals, gases, woods, glasses and these substances do not all respond in the same way to electrostatic fields. Nevertheless, most everyday objects belong to one of two large classes: Conductors and Insulators (or dielectrics).

Conductors contain an unlimited supply of charges that are free to move about through the material, many of the electrons (one or two per atom, in typical metals) are not associated with any particular nucleus, but roam around at will. In dielectrics, by contrast, all charges are attached to specific atoms or molecules - they are on microscopic displacements are not as dramatic as the wholesale rearrangement of charge in a conductor, but their cumulative effects account for the characteristic behaviour of dielectric materials.

There are actually two principal mechanisms by which electric fields can distort the charge distribution of a dielectric atom or molecule; stretching and rotating. In the next two sections.

## INDUCED DIPOLES

The atom as a whole is electrically neutral, there is a positively charged core (the nucleus) and a negatively charged electron cloud surrounding it. These two regions of charge within the atom are influenced by the field: the nucleus is pushed in the direction of the field, and the electrons the opposite way. In principle, if the field is large enough, it can pull the atom apart completely, "ionizing" it (the substance then becomes a conductor). With less extreme fields, however, an equilibrium is soon established, for if the centre of the electron cloud does not coincide with the nucleus, these positive and negative charges attract one another, and that holds the atom together.

The two opposing forces -  $E$  pulling the electrons and nucleus apart, their mutual attraction drawing them back together - reach a balance, leaving the atom polarized, with plus charge shifted slightly one way, and minus the other. The atom now has a tiny dipole moment  $p$ , which points in the same direction as  $E$ . Typically, this induced dipole moment is approximately proportional to the field.

$$p = \alpha E.$$

The constant of proportionality  $\alpha$  is called atomic polarizability. Its value depends on the detailed structure of the atom.

H	He	Li	Be	C	Ne	Na	Ar	K
0.667	0.205	24.3	5.60	1.67	0.396	24.1	1.64	43.4

Table of Atomic Polarizabilities.

## ALIGNMENT OF POLAR MOLECULES

Some molecules have built-in, permanent dipole moments. In the water molecule, for example, the electrons tend to cluster around the oxygen atom, and since the molecule is

bent at  $105^\circ$ , this leaves a negative charge at the vertex and a net positive charge on the opposite side. The dipole moment of water is unusually large:  $6.1 \times 10^{-30} \text{ C}\cdot\text{m}$ ; in fact, this is what accounts for its effectiveness as a solvent.

When such molecules (polar molecules) are placed in electric field, if the field is uniform, the force on the positive end,  $F_+ = qE$ , exactly cancels the force on the negative end,  $F_- = -qE$ , there will be a torque:

$$\begin{aligned} N &= (r_+ \times F_+) + (r_- \times F_-) \\ &= [(d/2) \times (qE)] + [(-d/2) \times (-qE)] \\ &= qd \times E \end{aligned}$$

Thus a dipole  $p = qd$  in a uniform field  $E$  experiences a torque.

$$N = p \times E$$

Notice that  $N$  is in such a direction as to line  $p$  up parallel to  $E$ ; a polar molecule that is free to rotate will swing around until it points in the direction of the applied field.

If the field is non-uniform, so that  $F_z$  does not exactly balance  $F_z$ , there will be a net force on the dipole, in addition to the torque. Of course,  $E$  must change rather abruptly for there to be significant variation in the space of one molecule, so this is not ordinarily a major consideration.

$$F = F_+ + F_- = q(E_+ - E_-) = q \Delta E$$

where  $\Delta E$  represents the difference between the field at the plus end and the field at the minus end. Assuming the dipole is very short, we use approximate small change in  $E_x$ :

$$\Delta E_x \equiv (\nabla E_x) \cdot d,$$

with corresponding formulas for  $E_y$  and  $E_z$

$$\Delta E = (d \cdot \nabla) E,$$

$$\therefore, F = (p \cdot \nabla) E.$$