Electric Properties Continued….

❖ Concepts of Polarization

❖ Types of polarization

1. Electronic polarization (P_e)
2. Ionic polarization (P_i)
3. Oriental polarization (P_o)
4. Interfacial / space charge polarization (P_s)

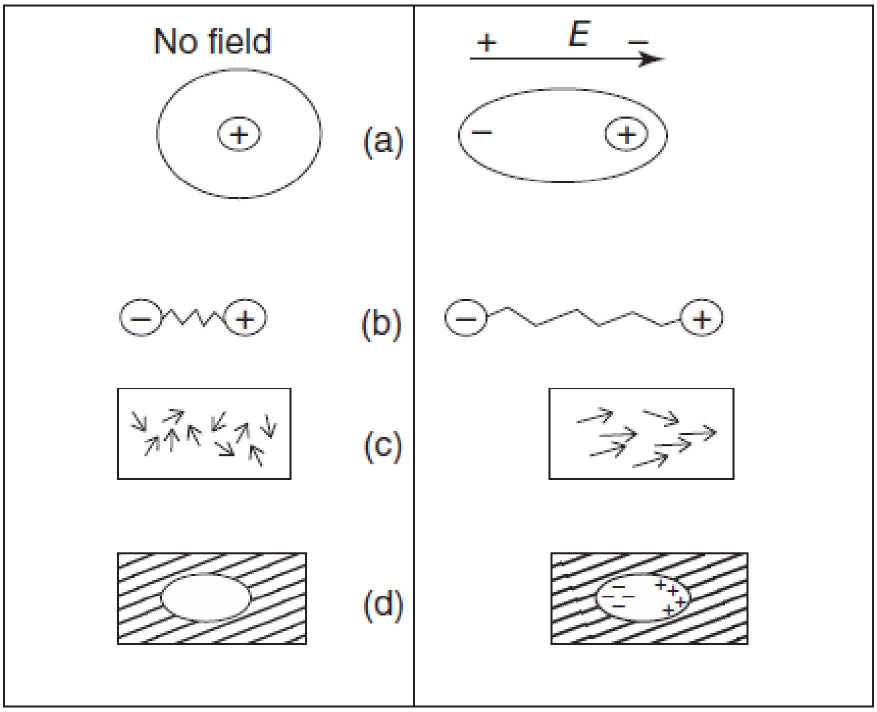

Figure 1: Polarization processes (a) electronic polarization (b) ionic polarization, (c) oriental polarization, and (d) space charge polarization.

1. Electronic polarization (P_e)

- The polarization which occurs due to the relative shifting between centroids of nucleus and electron cloud, in the presence of electric field is known as electronic polarization.
- Also known as atomic polarization.
- Materials which consists of only single type of atoms are having only electronic polarization
- Examples: diamond, sulphur, inert gases

- **Electronic Polarizability (α_e)**
  - The measure of relative shifting between centroids of nucleus and electron cloud is known as electronic polarizability.
  - It is given by: $\alpha_e = 4\pi\varepsilon_o R^3$, where R is the atomic radius.
  - It is independent of temperature.
- **Induced polarization**

$$P = N\,p$$
$$\Rightarrow P = N\,\alpha_e\,E$$

We know, $P = \varepsilon_o\,\chi_e\,E$

$$\Rightarrow \varepsilon_o\,\chi_e\,E = N\,\alpha_e\,E$$
$$\Rightarrow \varepsilon_o\chi_e = N\,\alpha_e$$

We know, $\chi_e = \varepsilon_r - 1$ and $\alpha_e = 4\pi\varepsilon_o R^3$

$$\Rightarrow \varepsilon_o\,(\varepsilon_r - 1) = N\,(4\pi\varepsilon_o R^3)$$
$$\Rightarrow \varepsilon_r - 1 = N\,(4\pi R^3)$$
$$\Rightarrow \boxed{\varepsilon_r = 1 + 4\pi N R^3}$$

2. **Ionic polarization (P_i)**
   - This type of polarization occurs in ionic material for example alkali halides etc. like NaCl, KCl etc.
   - The polarization which occurs due to the relative shifting between positive and negative ions, in the presence of electric field is known as ionic polarization.
   - It is also known as molecular polarization.
   - Total polarization: It is the sum of electronic and ionic polarization.

$$\text{i.e., } P_T = P_e + P_i$$
$$\Rightarrow P_T = N\,\alpha_e\,E + N\,\alpha_i\,E$$
$$\Rightarrow P_T = N\,E\,(\alpha_e + \alpha_i)$$

Where, α_i is the ionic polarizability of material. For dielectrics, ionic polarizability is less than electronic polarizability i.e., $\alpha_i \approx \alpha_e/10$

   - It is also independent of temperature.

3. **Oriental polarization (P_o)**
   - This polarization occurs in those materials in which permanent dipoles are present.
   - Material should have partial ionic bond (covalent bond between dissimilar element)

- Examples: H_2O, H_2S, Ch_3Cl, NO_2 etc.
- **Permanent dipole moment:**

  Dipole moment due to the orientation of molecule is known as permanent dipole moment.

  In the absence of electric field, dipoles are randomly oriented and oriental polarization in the material is zero. With application of electric field, all the dipoles rotate and align parallel to the field. The resultant polarization in this case is non-zero. Thus, the polarization which occurs due to the rotation of permanent dipole is known as oriental polarization (P_o) and is given by:

$$P_o = \frac{NPp^2}{3kT}E \text{ ------------------------- [1]}$$

Where, k is the Boltzmann constant and P_p is the permanent dipole moment.

- Polarization can also be calculated by:

$$P_o = N\alpha_o E \text{ ----------------------- [2]}$$

Where, α_o is the oriental polarizability

From equation [1] and [2] we get:

$$\alpha_o = \frac{Pp^2}{3kT}$$

- Oriental polarization (P_o) is inversely proportional to temperature and directly proportional to the square of permanent dipole moment. As the temperature increases, thermal agitation of dipoles increases. The result of this will be disturbance in dipole arrangement and decrease in polarization.
- **Total polarization**: Total polarization is the sum of electronic, ionic and oriental polarization i.e.,

$$P = P_e + P_i + P_o$$

$$\Rightarrow P = N\,\alpha_e E + N\,\alpha_i E + N\,\alpha_o E$$

$$\Rightarrow P = N\,E\,(\alpha_e + \alpha_i + \alpha_o)$$

$$\Rightarrow P = N\,E\,\{\alpha_e + \alpha_i + (P_p^2/3kT)\}$$

$$\Rightarrow \varepsilon_o\chi_e E = N\,E\,\{\alpha_e + \alpha_i + (P_p^2/3kT)\}$$

$$\Rightarrow \varepsilon_o\chi_e = N\{\alpha_e + \alpha_i + (P_p^2/3kT)\}$$

$$\Rightarrow \varepsilon_o (\varepsilon_r - 1) = N \{\alpha_e + \alpha_i + (P_p^2/3kT)\}$$

$$\Rightarrow (\varepsilon_r - 1) = (N/\varepsilon_o) \{\alpha_e + \alpha_i + (P_p^2/3kT)\}$$

4. Interfacial/space charge polarization (P_i)

- This type of polarization occurs in those materials in which vacancy or impurities are present.
- In dielectrics, some free charge carriers or free electrons are also present which can migrate from one end to the other end of dielectric in the presence of electric field. These free electrons may be trapped by vacancies or impurities present in the material. The result of this will be local accumulation of negative charge which will induce its image charge (opposite in parity) towards negative terminal of the battery. The effect of this will be formation of dipoles and contribution of a different mechanism of polarization known as interfacial/space charge polarization (P_i).
- **Internal field (E_i)**

➢ In case of gaseous state, internal field = external field (as per as molecular density is low).

➢ In solids and liquids, force experienced by atoms or molecules under the influence of electric field depends on two factors:

(i) Applied external field

(ii) Polarization induced inside the material

➢ It is given by:

$$Ei = E + \frac{\gamma}{\varepsilon_o} P$$

Where, E = external electric field

P = Polarization

γ = internal field constant

γ is a unit less quantity and its value depends on structure of material

➢ For cubical structure, γ = 1/3. Thus,

$$\boxed{Ei = E + \frac{P}{3\varepsilon_o}}$$

⇩

Lorentz internal field