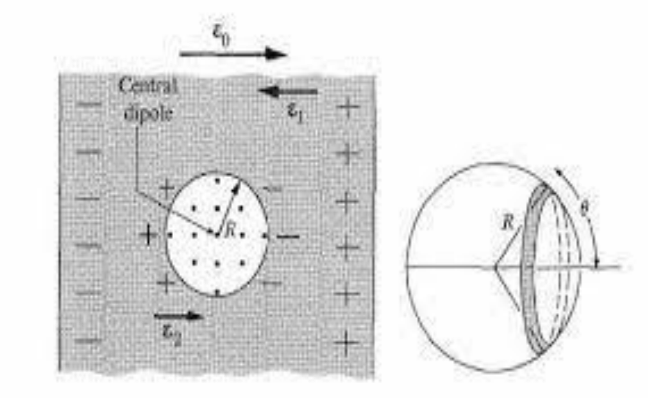
HSST PHYSICS

MODULE 7 SOLID STATE PHYSICS PART 3

Local Electric Field

- The electric field acting at an atom in a dielectric is known as the polarizing field or the local field, E_{loc} and is different from the applied external field $E_{app.}$. In order to evaluate this, it is necessary to calculate the total field acting on a certain typical dipole. This was first of all calculated by Lorentz.
- The local field is a microscopic field which fluctuates rapidly within the medium.
- When a liquid or solid dielectric placed in an external electrical field, its atoms becomes electric dipole which provides field which is different than applied field. The total field at the atomic site is called the internal field or local field. It is represented by $E_{loc} = E_0+E_1+E_2+E_3$



(a) (b)

- Where E_0 is the applied external field(uniform), $=E + \frac{P}{\varepsilon 0}$
- E_1 is the field due to the polarizing charges lying on the external surface of the dielectric medium, also known as depolarization field. $E_1 = -\frac{NP}{\varepsilon 0}$

  N is known as depolarization factor and P is the polarization.

- E_2 is the field due to polarization charges lying on the surface of Lorentz sphere(cavity) also known as Lorentz cavity field. $E_2 = \frac{P}{3\varepsilon 0}$
- E_3 is the field due to other dipoles lying within the sphere. For spherically symmetric case $E_3 = 0$
- E is the macroscopic average field

- $E_{loc} = E_0+E_1+E_2+E_3 = E + \frac{P}{\varepsilon 0} - \frac{P}{\varepsilon 0} + \frac{P}{3\varepsilon 0} = E + \frac{P}{3\varepsilon 0}$

This is known as Lorentz relation.

Ferro electricity

- Ferro electricity was first of all discovered by J Valasek in 1921 in Rochelle salt.
- This phenomenon is analogous to that of ferromagnetism.
- A ferroelectric material like a ferromagnetic one exhibits spontaneous polarization even in the absence of an external electric field. Similarly, the spontaneous polarization gets destroyed and the ferroelectricity disappears above a certain temperature called the transition temperature or the **Curie temperature**, where the materials become paraelectric.
- A phase transition from paraelectric to ferro electric or vice versa is accompanied by a change in crystal structure, such that the ferroelectric phase is well ordered and has lower crystal symmetry than the paraelectric one.

Ferroelectric domain

- Assemblies of spontaneously polarized unit cells form regions known as domains.

- In a particular domain, the atomic dipoles are aligned parallel to one another. Further the direction of alignment of dipoles varies from one domain to another.
- Ferroelectric materials are crystalline materials that exhibit spontaneous electrical polarizations switchable by an external electric field.
- A ferroelectric crystal splits into domains because such splitting lowers the free energy by reducing the electrostatic energy of the spontaneous polarization charges. However, domain splitting cannot be continued without limit because a definite energy is required for the formation of domain walls. The splitting of a crystal into domains stops when the energy gained by reduction of the electrostatic energy becomes equal to the energy lost in the formation of walls. These considerations apply to an open circuited crystal. However, the splitting into domains occurs also in short-circuited crystals if only because the polarization, which arises at different points in a crystal at the Curie temperature, is equally likely to assume any of the various crystallographically equivalent directions. This equiprobable distribution of the polarization directions is responsible for the splitting of antiferroelectric crystals into domains (in the case of antiferroelectric, there is no reduction in the electrostatic energy because antiferroelectric domains are not polar). In some real crystals, the splitting into domains depends strongly on the presence of stressed regions, defects, as well as on external electric and mechanical fields, etc.

Piezo- Pyro and Ferroelectric properties of crystals

- A material can be piezoelectric, pyroelectric or ferroelectric only if its crystalline symmetry is inherently asymmetric, ie. It lacks an inversion centre.
- A basic principle due to Neumann is that any physical property exhibited by a crystal must have atleast the symmetry of the point group of the crystal. Thus the above properties which are inherently asymmetric can only arise in asymmetric crystals.

- Of the thirty two crystal symmetry classes, eleven exhibit centre of symmetry, in another one case, a combination of symmetries effectively provides such a centre, leaving twenty classes which have asymmetric properties.
- All the crystals in these 20 classes are piezoelectric. When such a non-centro-symmetric crystal is subjected to a mechanical stress, the ions are displaced from each other in an asymmetric manner and the crystal becomes electrically polarized. This is called **piezoelectric effect**.
- The piezoelectric effect is often used to convert electrical energy into mechanical energy, and vice versa.
- Quartz is the most familiar piezoelectric substance and the one most frequently used in transducers.
- Crystal in ten of 20 classes have a unique polar axis responsible for the appearance of a spontaneous electric polarization even in the absence of an electric field.
- A change in the temperature of the crystal produces a change in its polarization according to the relation; $\Delta p = \lambda \Delta T$

  Where λ is the pyroelectric coefficient and can be measured. This effect is called the pyroelectric effect and can be produced either by heating or cooling the crystal. Eg: Wurtzite

- In some pyroelectric crystals, the spontaneous polarization can be reversed by an external applied field giving dielectric hysteresis loop. Such crystals are called ferroelectric crystals and the phenomenon of reversing the direction of polarity is called ferroelectric effect.

Applications Best Suited for the Piezoelectric Effect

Due to the intrinsic characteristics of piezoelectric materials, there are numerous applications that benefit from their use:

1. High Voltage and Power Sources

An example of applications in this area is the electric cigarette lighter, where pressing a button causes a spring-loaded hammer to hit a piezoelectric crystal, thereby producing a sufficiently high voltage that electric current flows across a small spark gap, heating and igniting the gas. Most types of gas burners and ranges have a built-in piezo based injection systems.

2. Sensors

The principle of operation of a piezoelectric sensor is that a physical dimension, transformed into a force, acts on two opposing faces of the sensing element. The detection of pressure variations in the form of sound is the most common sensor application, which is seen in piezoelectric microphones and piezoelectric pickups for electrically amplified guitars. Piezoelectric sensors in particular are used with high frequency sound in ultrasonic transducers for medical imaging and industrial nondestructive testing.

3. Piezoelectric Motors

Because very high voltages correspond to only tiny changes in the width of the crystal, this crystal width can be manipulated with better-than-micrometer precision, making piezo crystals an important tool for positioning objects with extreme accuracy, making them perfect for use in motors.

Regarding piezoelectric motors, the piezoelectric element receives an electrical pulse, and then applies directional force to an opposing ceramic plate, causing it to move in the desired direction. Motion is generated when the piezoelectric element moves against a static platform (such as ceramic strips).

Piezoelectricity

Solid in which individual dipoles are formed and the net dipole moment of the solid (crystal) is oriented to exhibit piezoelectricity. When pressure is applied to such a solid, those atoms or ions move to generate electricity. Piezoelectricity is the charge that accumulates in some crystals due to mechanical stress. This means that piezoelectricity is the electricity that results from pressure and latent heat. The word piezoelectric comes from the Greek words piezein, which means "push or push," and elecktron, which means "amber" (ancient source of charge). Piezoelectricity was discovered in 1880 by the French physicists Jack and Pierre Curie. This dielectric property of solids is used in medicine, the automotive industry, information technology, and telecommunications.

Pyroelectricity

The word "pyroelectricity" comes from two Greek words, pyrr, which means "fire" and elecktron, which means "amber" (ancient source of charge) or "electricity". Pyroelectricity is the ability to generate a temporary voltage when a particular crystal is heated or cooled. Some piezoelectric crystals generate electricity when heated, so the generated electricity is called pyroelectricity, and this phenomenon is called the pyroelectric effect. Pyroelectric crystals are generally electrically polarized and therefore contain a large electric field. Changes in temperature change the position of atoms in the crystal structure. Due to the change in crystal structure, the polarization of the crystal changes and the voltage across the crystal rises. If the temperature remains constant at the new value, the pyroelectric voltage will disappear due to the leakage current.

Anti - Ferroelectricity

As the name implies, it is the opposite of ferroelectricity. The relationship between antiferromagnetism and ferroelectricity is similar to the relationship between ferromagnetism and antiferromagnetism. Crystals with the antiferromagnetic properties of dipoles are composed of a regular arrangement of electric dipoles, with adjacent dipoles oriented in opposite (antiparallel) directions. This creates a Net Zero dipole moment. Spontaneous electric polarization is zero because the adjacent dipoles cancel each other out. This property of crystals can appear and disappear depending on temperature, pressure, growth method, external electric field, etc. The temperature at which the antiferroelectricity disappears is called the Néel or Curie point.