Quadrant II- Notes

Programme: Bachelor of Science

Subject: Chemistry

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Paper Title: Properties and Processes of Molecular Chemistry

Unit: 01

Module Name: Ferroelectricity: ferroelectric, antiferroelectric and ferrielectric effect, pyroelectricity, piezoelectricity and their applications.

Module No.: 03

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Polarisation:

- It is a process of separation of positive and negative charge within the molecule when placed between electric field.

Ferroelectricity

- It is property of materials which show polarisation even in absence of electric field. (P>0, E=0)
- Ferroelectric materials have spontaneous polarisation that can be reversed by the application of an external electric field.
- Even in the absence of electric field, there is separation of negative charge and positive charge.
- The term is used as analogy to ferromagnetism in which a material exhibits a permanent magnetic moment.

Ferroelectric materials:

- They exhibit spontaneous electric dipole moment, even in absence of an applied electric field. The centre of positive charge does not coincide with the centre of negative charge.

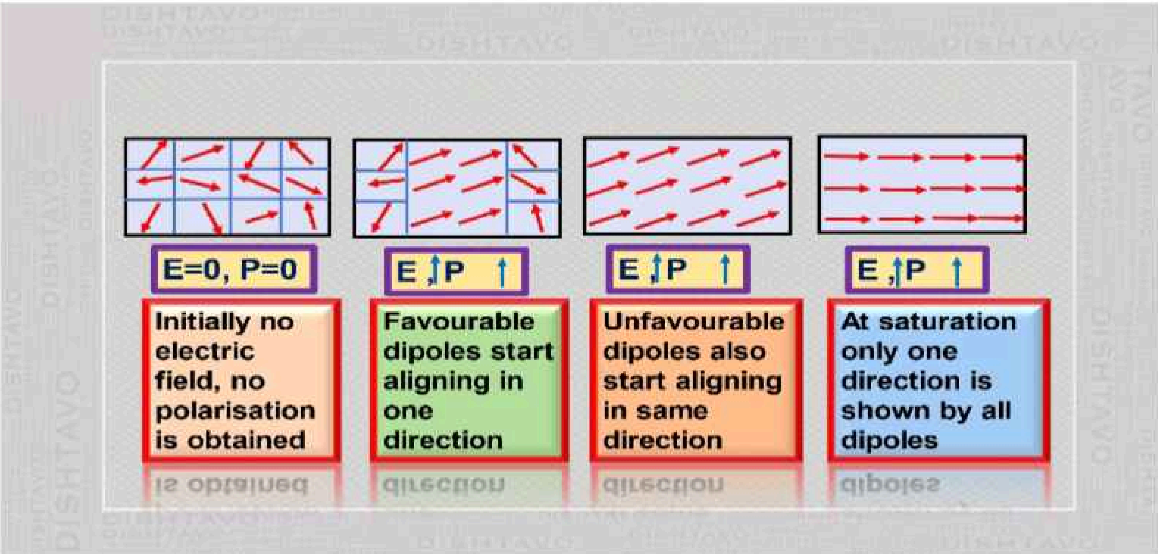
- Examples of ferroelectric materials are; Barium titanate (BaTiO3), Sodium nitrate (NaNO2), Lead titanate (PbTiNO3), Rochelle salt, Dihydrogen Phosphate (KH2PO4)

- When initially electric field is absence (E=0) there will be no polarisation (P=0) and all the dipoles are oriented in any random directions.

- On applying electric field, polarisation starts to occur such that favourable dipoles start aligning in one direction.

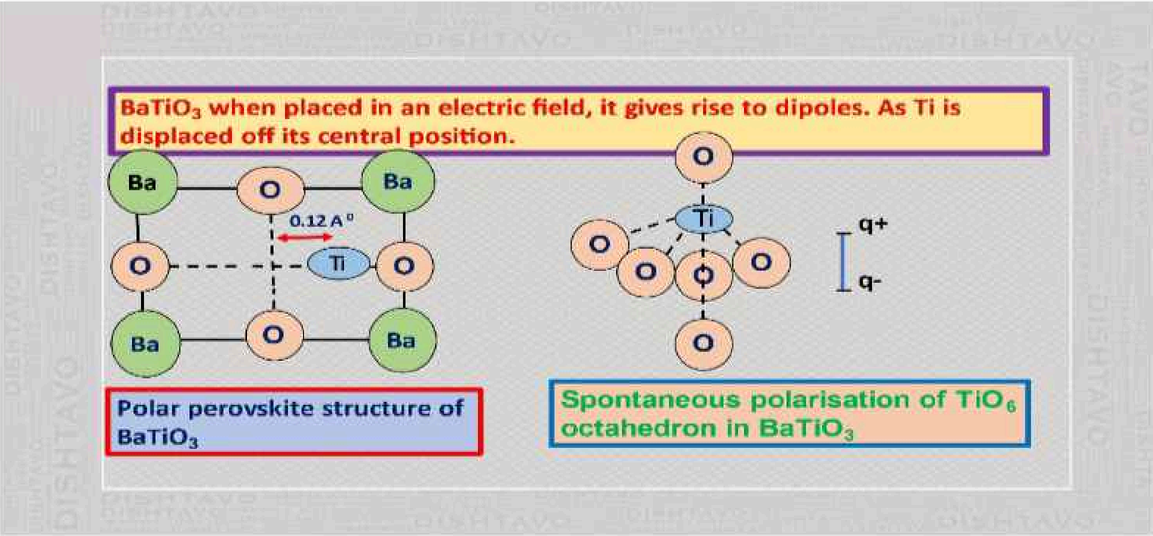
- On further increase of electric field unfavourable dipoles also start aligning in same direction.

- As electric field is increased more there occurs a saturation polarisation where all dipoles show only one direction.



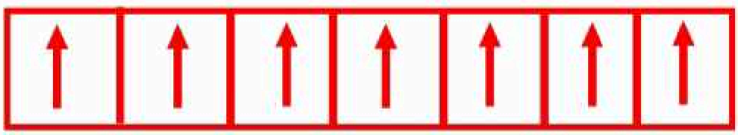
- Consider a ferroelectric material $BaTiO_3$. Ti^{4+} in $BaTiO_3$, can undergo significant displacement of about 0.12 A^0 relative to its anionic neighbour. These charge displacement gives rise to dipoles. Titanium is displaced off its central position which gives rise to spontaneous polarisation.

- In ferroelectric $BaTiO_3$, the individual TiO_6 octahedra are polarised all of the time. The effect of applying electric field is to persuade the individual dipoles to align themselves with the field.
- When complete alignment occurs the condition of saturation polarisation is reached.
- Ferroelectric materials show saturation polarisation at high electric field strength.



Ferroelectric effect

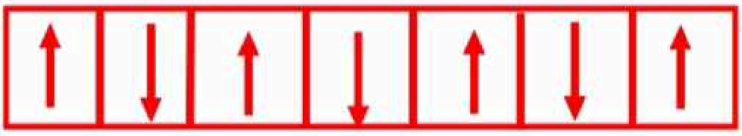
- Electric field make the **individual dipoles align themselves** with the field.
- Such materials have **permanent dipole moment.**
- Such effect of ferroelectric materials is known as **ferroelectric effect.**



Dipole orientation in ferroelectric materials

Antiferroelectric effect

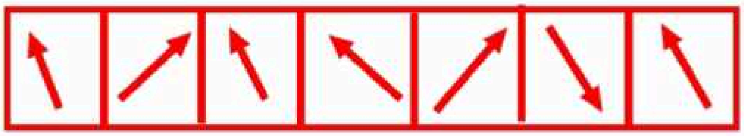
- Consist of an **adjacent dipole oriented in opposite directions.**
- Thus, an adjacent dipole moment cancels each other out

- Have **zero spontaneous polarisation.**
- Examples: **$PbZrO_3$, $NaNbO_3$, NH_4H_2PO.**
- Such effect of antiferroelectric materials is known as **antiferroelectric effect.**
- 

Dipole orientation in antiferroelectric materials

Ferrielectric effect

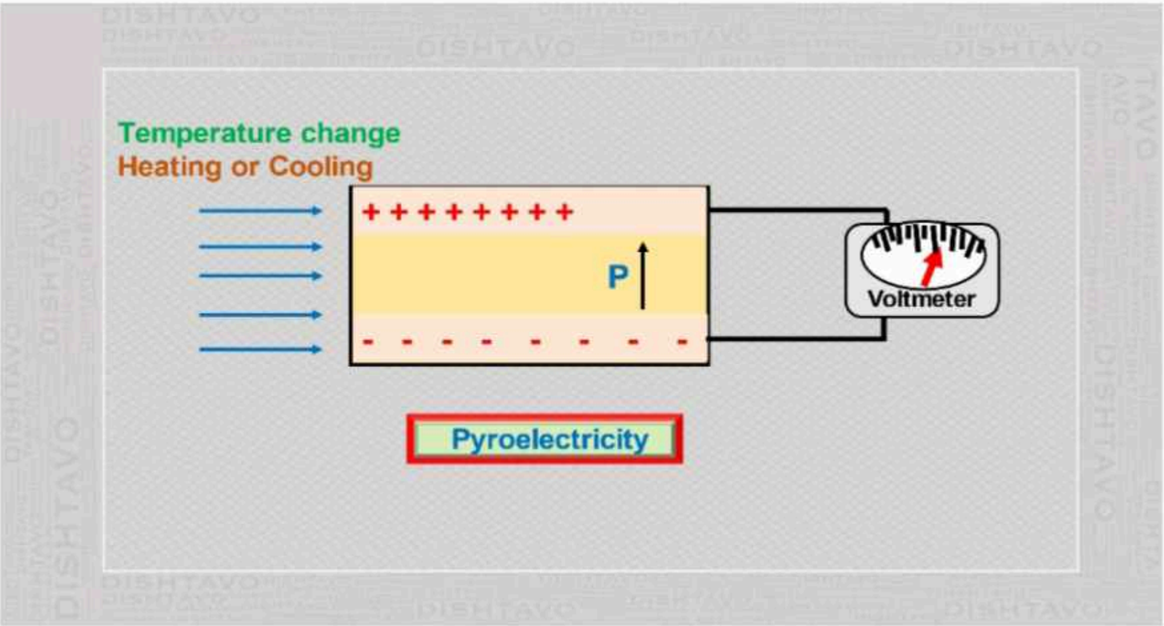
- Ferrielectric materials have some net spontaneous polarisation as the **dipoles are oriented randomly in any direction.**
- Examples: $Bi_4Ti_3O_{12}$, lithium ammonium tartrate monohydrate.
- Such effect of ferrielectric materials is known as **ferrielectric effect.**



Dipole orientation in ferrielectric materials

Pyroelectricity

- Pyroelectricity comes from Greek words **pyr** means fire and **electricity.**
- Pyroelectricity is ability of certain materials to generate a temporary voltage when they are heated or cooled.
- The change in temperature modifies the size of the dipoles within the crystals, such that the polarisation of the material changes.
- This polarisation change gives to a voltage across the crystal.

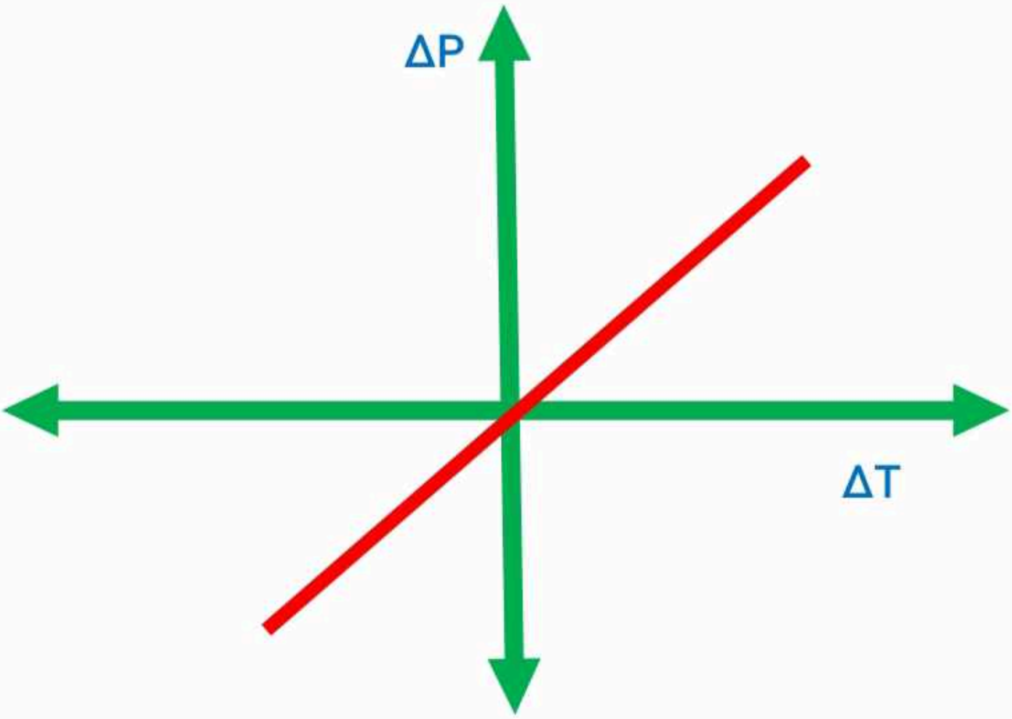


- **Pyroelectricity** is measured as the change in net polarisation proportional to a change in temperature.

$$\Delta P_S = \pi \Delta T$$

where **π** is the pyroelectric coefficient

Change of polarisation with changing temperature



- This arises because the thermal expansion that occurs on heating changes the sizes (i.e., lengths) of the dipoles.
- A good example of pyroelectric crystals is ZnO, which has Wurtzite structure.

Applications of Pyroelectricity

1.Used in Passive Infrared Sensor (PIR sensor):

- PIR sensors are a common type of **motion detector sensors which can detect the movement of human beings, animals or any objects that radiates thermal IR radiations.**

- A PIR sensors are made with pyroelectric materials which generate electrical energy with response to the absorbed thermal energy. The thermal energy radiated in the form of IR waves are invisible to human eyes.

- So, the PIR sensors can work as hidden device.

- Because of this ability, they are widely used for security and automation applications.

2. Used in Infrared thermometers:

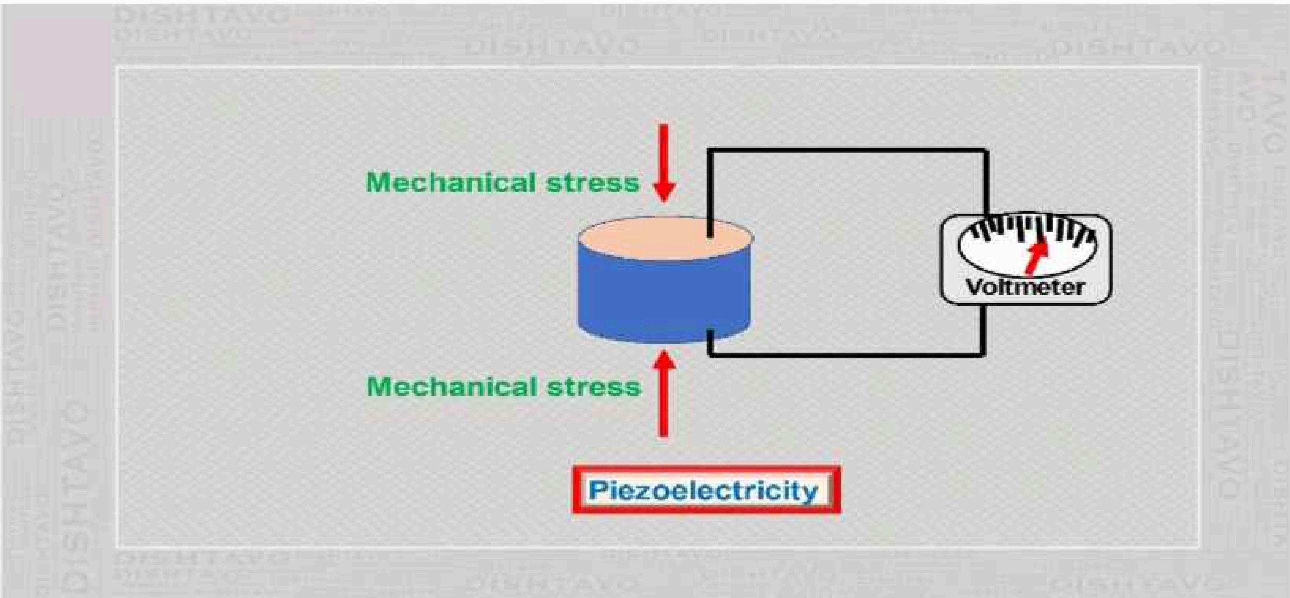
- The Infrared thermometers or pyrometers are used for **temperature measurements** in areas where physical contact is not possible.
- Such as moving objects, extremely heated substances.

3. Used in Fire alarms:

- **Suitable pyroelectric materials** are used during fire emergencies.

Piezoelectricity

- In 1880, Pierre Curie and Jacques Curie discovered piezoelectricity.
- Greek word Piezein, means to squeeze or press.
- On application of **mechanical stress,** an electrical potential is developed which is directly proportional to the **amount of stress applied.**
- Under an action of an applied mechanical stress, piezoelectric crystals polarise and develop electrical charges.
- **Examples:** Many crystals that contain tetrahedral groups like **ZnO and ZnS are** piezoelectric since on application of stress it distorts the tetrahedra, one of the most important piezoelectric is **PZT (Lead Zirconate Titanate)**

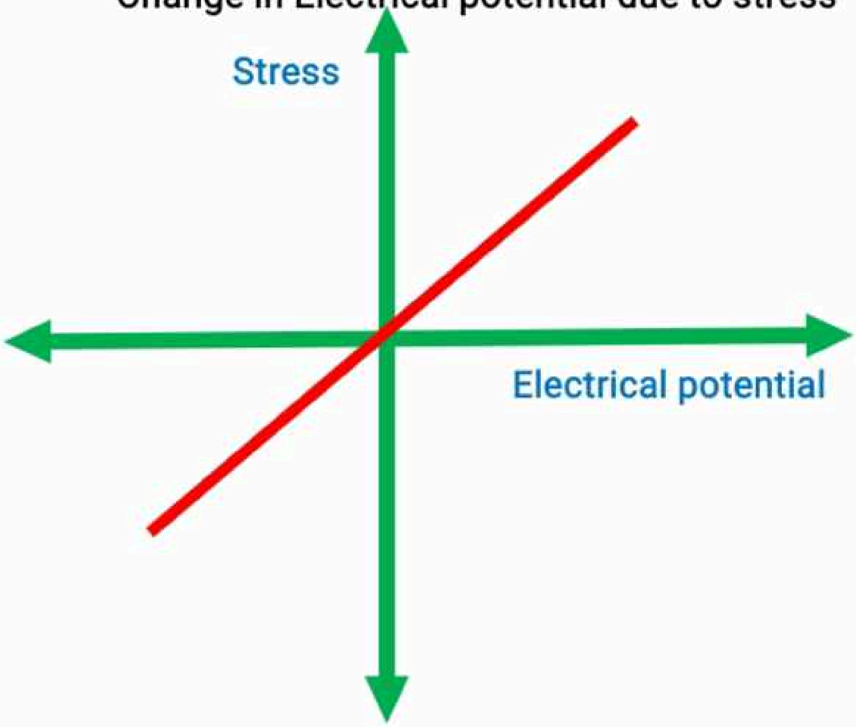


- The polarisation, P and stress, σ are related to the piezoelectric coefficient, d by

$$P = d\,\sigma$$

where d is the piezoelectric coefficient

Change in Electrical potential due to stress



Applications of Piezoelectricity

1. Used in SONAR, Ultrasonic waves detectors:

 - Piezoelectric materials can be used in **SONAR, Ultrasonic submarine detector. This was the first application of piezoelectricity.**

2. Used in LPG stove lighters

 - **PZT (Lead Zirconate Titanate)** is used in stove lighters.
 - When the bottom of the lighter is pressed, the hammer inside the lighter hits the piezoelectric crystal and a high voltage is generated across the crystal (approximately 800 V)
 - Due to high voltage, air break down occurs and a spark is produced that lights up the gas coming outside from the gas cylinder.

3. Used in Quartz clocks

- **Piezoelectric quartz called silicon dioxide (SiO_2)** is used in clocks.

4. Used in Microphones/earphones:

- Some microphones use piezoelectric materials to convert **sound vibrations to an electrical output.**