18.5.2015 Mat. Sci

$R \propto \frac{l}{a}$

$R = \rho \frac{l}{a}$

$\rho = \frac{Ra}{l}$

Dielectric Materials

Characteristics

1. High electrical resistivity
2. Insulators and capacitors are uses
3. Piezoelectricity
4. Electrostriction
5. Ferroelectricity

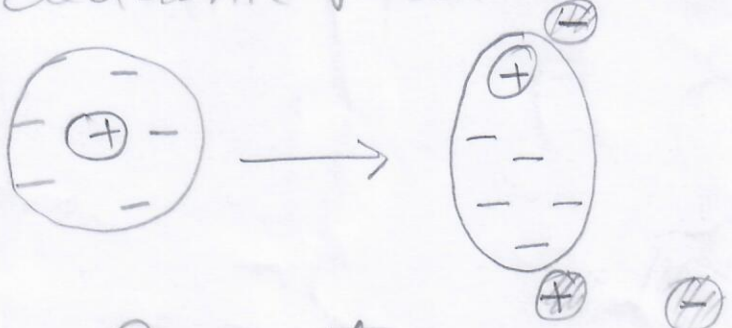
Na = 11 atomic no. ⊖

Cl = 17 atomic no

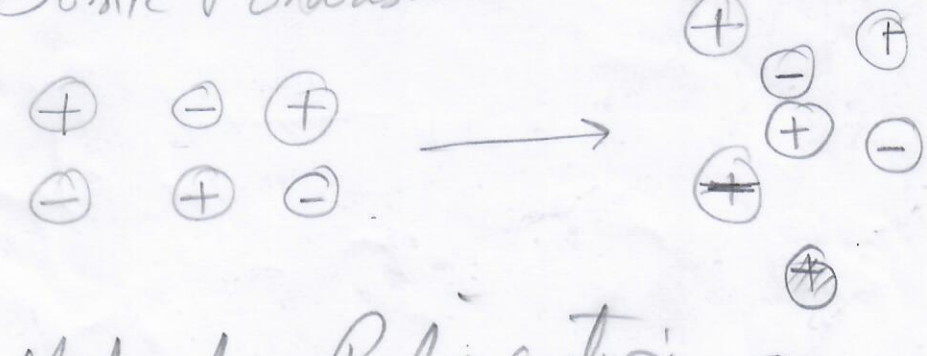
6.

Dipoles and Polarisation

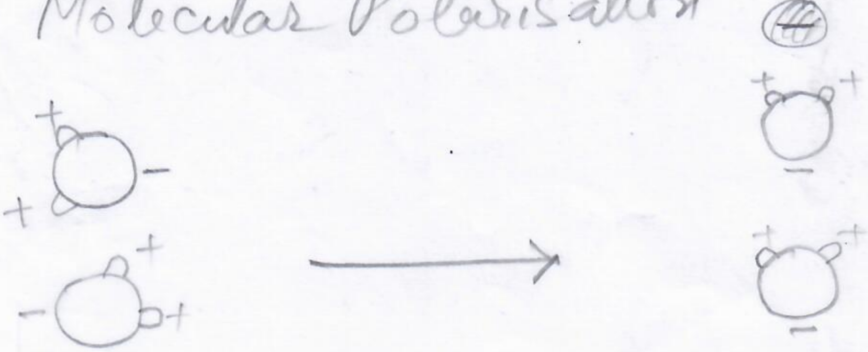
(a) → Electronic Polarisation



(b) Ionic Polarisation

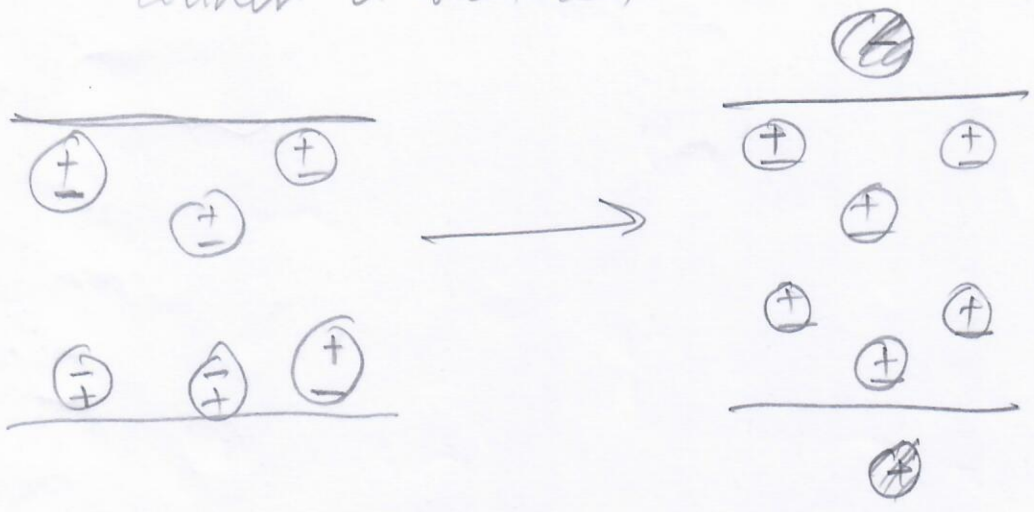


(c) Molecular Polarisation



(d) Space Charges

(charges between interfaces of different phases within a material.



Electronic Polarisation

Dipoles

P ⇒ polarisation (C/m^2)

$= \underset{\sim}{Q} \times d \quad c/m^3 \times d = c/m^2$

$= Z_i q d$ charge/electron

where Z_i is the no. of charge centers $/m^3$

when an electric field is applied to an atom, the electronic arrangement is distorted, with electrons induced

EXAMPLE

Suppose that the average displacement of the electrons relative to the nucleus in a copper atom is 1×10^{-18} A° when an electric field is imposed on a copper plate. Calculate the polarisation.

N (atomic no. of copper) = 29

No. of electrons in copper atom = 29

$a_0)_{copper} = 3.6151$ A°

Z = no. of ~~atoms~~ electrons in one cubic meter

$$= \frac{(4\ \text{atom/cell})(29\ \text{electrons/atom})}{(3.6151 \times 10^{-10}\ \text{m})^3}$$

$$= 2.46 \times 10^{30}\ \text{electrons}/\text{m}^3$$

$$P\ (\text{C}/\text{m}^2) = Zqd$$

$$= \left(2.46 \times 10^{30}\ \frac{\text{electron}}{\text{m}^3}\right) \times \left(1.6 \times 10^{-19}\ \frac{\text{C}}{\text{electron}}\right) \times 10^{-18}\ \text{m}$$

$$= 3.94 \times 10^{-7}\ \text{C}/\text{m}^2$$

Ionic Polarisation

when an ionically bonded material is placed in an electric field, the bonds between the ions are elastically deformed. Consequently charge is redistributed within the material. Depending on the direction the cations and anions move either closer together or further apart. These temporarily induced dipoles provide polarisation and may also change the overall dimensions of the material.

EXAMPLE

The ionic polarisation observed in NaCl crystal is $4.3 \times 10^{-8} C/m^2$. Calculate the displacement between Na^+ and Cl^- ions.

In this example There is one electric charge on each Na^+ ion. In the NaCl unit cell, (lattice parameter = 5.5 A°). There are 4, sodium Na^+ ions.

Sol In this example, there is one electric charge on each Na^+ ion. In the

$$Z = \left(4\, Na^{+} \text{ ions}/\text{cell}\right)\left(1 \text{ charge}/Na^{+} \text{ ion}\right) \Big/ a_0^3$$

$$= \underbrace{2.4\times10^{28} \text{ charges}/m^3}$$

$$\frac{4}{(5.5\times10^{-10})^3} = 2.9\times10^{28}$$

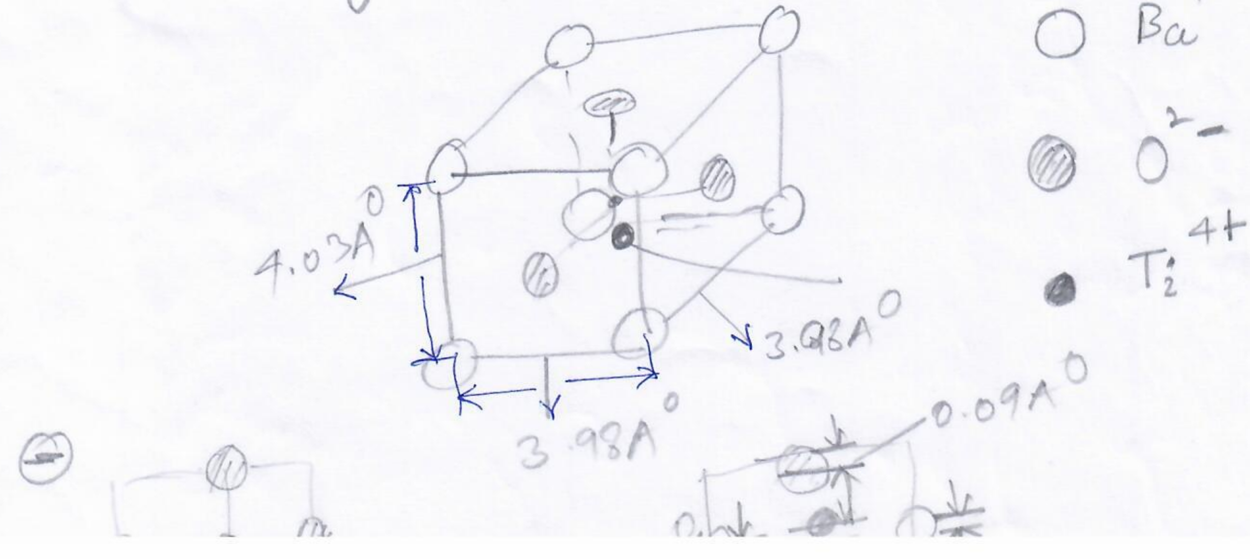
$$d = \frac{P}{Zq} = \frac{4.3\times10^{-8}}{(2.4\times10^{28})(1.6\times10^{-19})}$$

$$= 11.2\times10^{-18}\,m = 11.2\times10^{-8}\,A^{\circ}$$

Molecular Polarisation:

Some materials contain natural dipoles. when a field is applied, the dipoles rotate to line up with the imposed field. Water molecules show molecular polarisation.

Barium titanate, $BaTiO_3$ a crystalline ceramic has an asymmetrical structure at room temp.



The titanium ion is displaced slightly from the centre of the unit cell and the oxygen ions are displaced slightly in the opposite directions from their face centered positions, causing the crystal to be tetragonal and permanently polarised

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~~EXAMPLE~~

~~Compare the tendencies~~

Space Charges

A charge may develop at interfaces between phases within a material, normally as a result of the presence of impurities. The charge moves on the surface when the material is placed in an electric field.

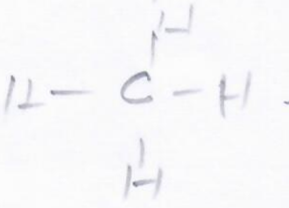
Molecular Polarisation Example

Compare the tendencies of the following organic molecules to act as dipoles and produce molecular polarisation.

Solution

The structure of each molecule is shown. The chlorine atoms are strong centers of -ve charge and hydrogen atoms are weak centers of +ve charge

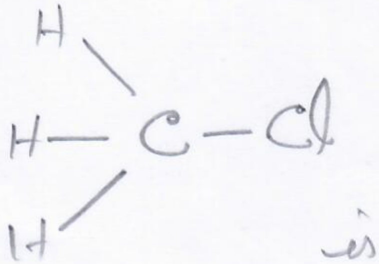
CH, CH_4



$H-\overset{H}{\underset{H}{C}}-H$

— Since the molecule is symmetric so no molecular polarization is ~~ex~~ possible.

CH_3Cl



A large dipole effect is created, since the +ve hydrogen atoms are displaced from the chlorine atom.

EXAMPLE

Calculate the maximum polarisation per cubic centimeter and the maximum charge that can be stored per square centimeter for barium titanate.

Solution

The strength of the dipoles is given by the product of the charge and the distance between the charges. In $BaTiO_3$, the separations are the distances that the Ti^{4+} and O^{2-} ions are displaced from the normal lattice points (Fig already shown). The charge on each ion is the product of q and the number of excess or missing electrons. Thus the dipole moments are

Ti^{4+}: (1.6×10^{-19}) (4 electrons/ion) $(0.06\times10^{-10}\ m)$

$= 3.84\times10^{-30}$ C.m/ion

$O^{2-}_{top} = (1.6\times10^{-19})$ (2 electrons/ion) $(0.09\times10^{-10}\ m)$

$= 2.88\times10^{-30}$ C.m/ion

O^{2-}_{side}: (1.6×10^{-19}) (2 electrons/ion) $(0.06\times10^{-10}\ m)$

Each oxygen ion is shared with another unit

Diple moment $= (1\ Ti^{4+}/\text{cell})(3.84\times10^{-30})$

$+ (1 O^{2-} \text{ at top}/\text{cell})(2.88\times10^{-30})$

$+ (2 O^{2-} \text{ at sides}/\text{cell})(1.92\times10^{-30})$

$= 1.056\times10^{-29}\ C.m/\text{cell}$

The polarisation is

$$P = \frac{1.056\times10^{-29} C\cdot m/\text{cell}}{(3.98\times10^{-10} m)^2(4.03\times10^{-10} m)}$$

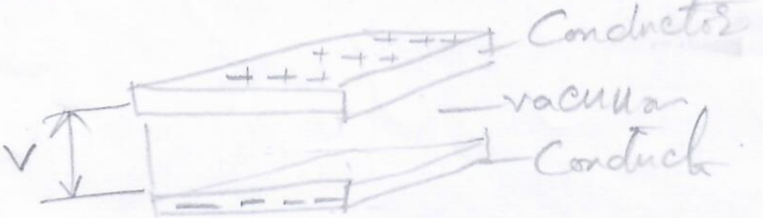
$= 0.165\ C.m^{-2} = 1.65\times10^{-5}\ C.m^{-2}$

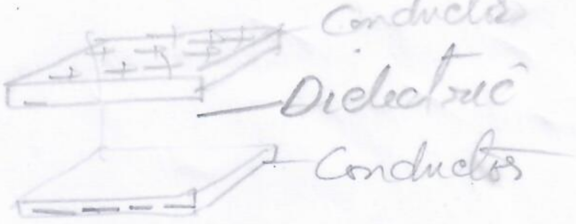
The total charge on a $BaTiO_3$ crystal $1cm \times 1cm$ is

$Q = PA = (1.65\times10^{-5})(1)^2$

$= 1.65\times10^{-5} C$

Dielectric Properties





Capacitors are constructed by separating two or more conductor plates by dielectric material, whose properties determine the effectiveness of the device.

$$Q \propto V \Rightarrow Q = CV$$

$$C = \frac{\text{coulomb}}{\text{volt}} \text{ or farad}$$

$$C \propto \frac{A}{d} \Rightarrow C = \epsilon_0 \frac{A}{d} \quad \text{for vacuum}$$

$$C \propto \frac{A}{d} \Rightarrow C = \epsilon \frac{A}{d} \quad \text{for dielectric medium}$$

$\epsilon_0 \longrightarrow$ permittivity of vacuum

$\epsilon \longrightarrow$ permittivity of dielectric

$K_r = \frac{\epsilon}{\epsilon_0} \Rightarrow$ Dielectric constant — always >1

$$P = (K_r - 1)\epsilon_0 \mathcal{E}$$

where $\mathcal{E} \longrightarrow$ strength of electric field (V/

Suppose sodium chloride has a polarisation of $4.3 \times 10^{-8}\ C/m^2$ in an electric field of $1000\ V/m$. Calculate the dielectric constant for sodium chloride.

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sol.

$$P = (K-1)\epsilon_0 \mathcal{E}$$

$$K - 1 = \frac{P}{\epsilon_0 \mathcal{E}} = \frac{4.3 \times 10^{-8}}{(8.85 \times 10^{-12})1000}$$

$$\boxed{K = 5.9}$$

Properties of selected dielectric material (xerox).

Dielectric Strength

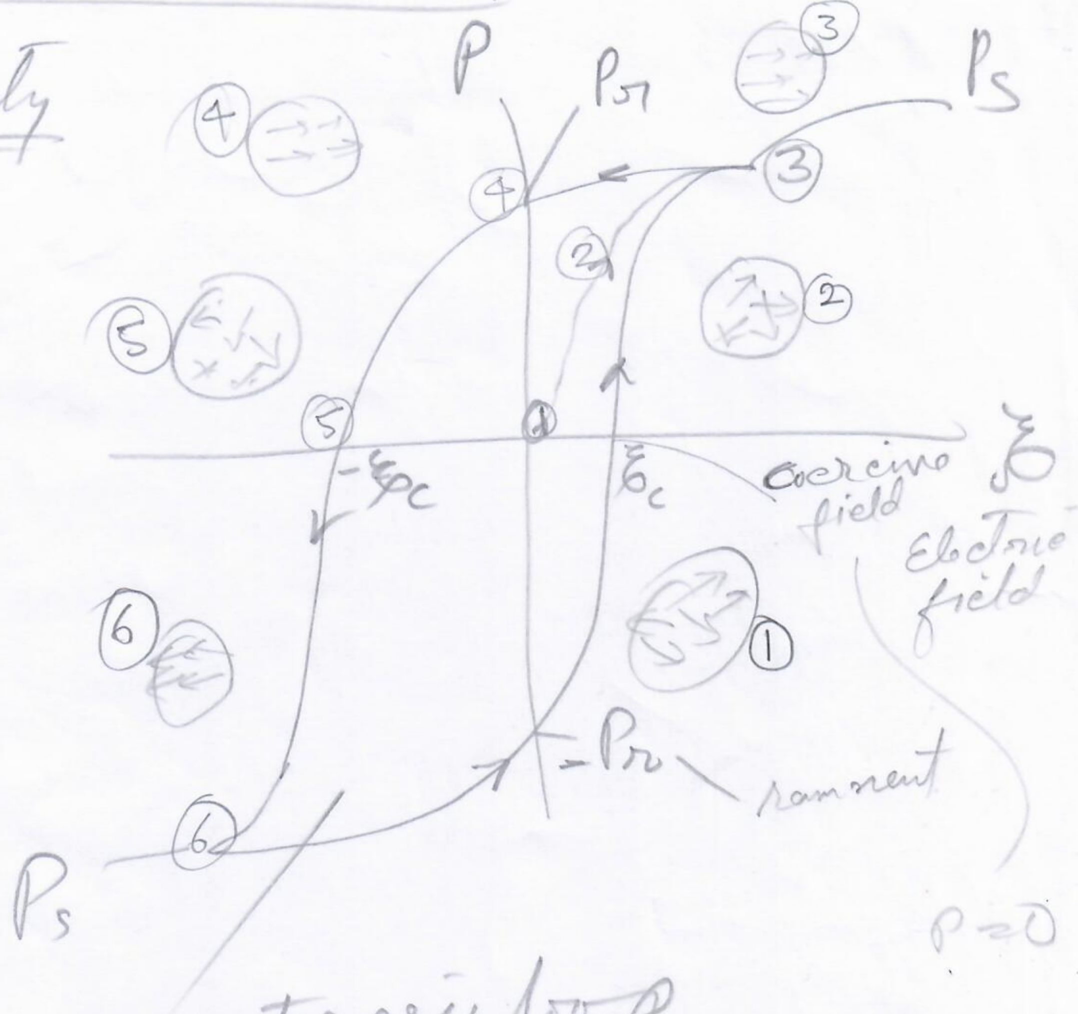
$$\mathcal{E}_{max} = \left(\frac{V}{d}\right)_{max}$$ before break down

Electrical conductivity

They have $10^8\ \Omega$-m electrical resistivity.

Effect of Material Structure

Ferroelectricity



hysteresis loop

Curie temp

xerox copy