ENGINEERING PHYSICS

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Dielectrics

- ***Polarization mechanisms in dielectrics***
- ***Non Linear dielectrics - BaTiO$_3$ structure and origin of non-centro symmetry of charges, phase changes***
- ***Peizo electric materials - Pyro electric materials properties and applications***
- ***Ferro electric hysteresis and application as memory materials***

Polarization mechanism in dielectric materials

Class #53

- *Introduction to dielectrics*
- *Polarization*
- *Local electric field in a dielectric material*
- *Clausius- Mossotti relation*
- *Different polarization mechanisms*

Polarization mechanisms in dielectrics

- ***Suggested Reading***

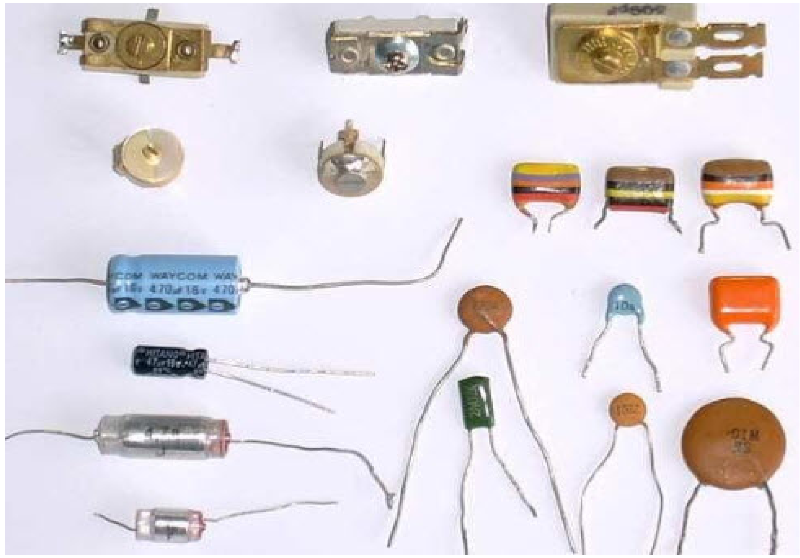
1. The Science and Engineering of Materials, Sixth Edition, Chapter 19, Donald R. Askeland, Pradeep P. Fulay and Wendelin J. Wright, 2010, Cengage Learning, Inc.

2. Learning material prepared by the Department of Physics

ENGINEERING PHYSICS

Dielectrics

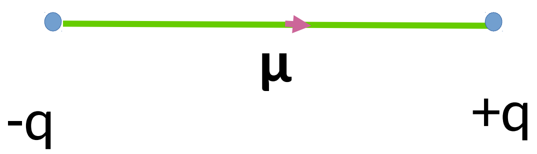
- ***Conductors and semi conductors at appropriate temperatures conducts electricity***
- ***Insulators do not conduct electricity***
- ***Dielectrics: Insulators that have very few or no conduction electrons***



https://www.elprocus.com/ceramic-capacitor-working-construction-applications/

Dielectrics

- *Very high electrical resistivities (~$10^{14}\Omega$.cm)*
- *Electric field (E) creates electric dipoles leading to polarization*
- *Net dipole moment created per unit volume is polarization P*
- *At very high E, due to ionization free electrons start conducting current (~few kV/mm)*



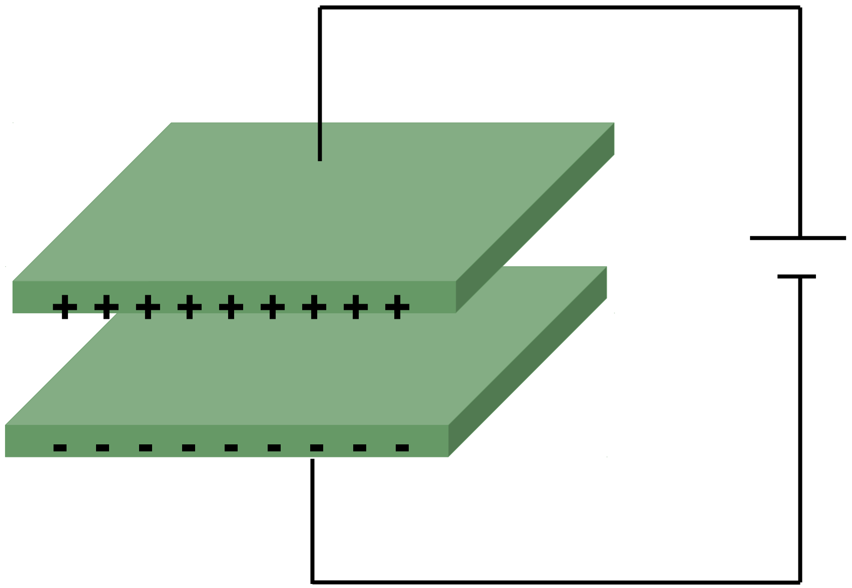
$\mu = \alpha E$

Electric dipole

Natural capacitor (Ref: Olympus website)

Polarization

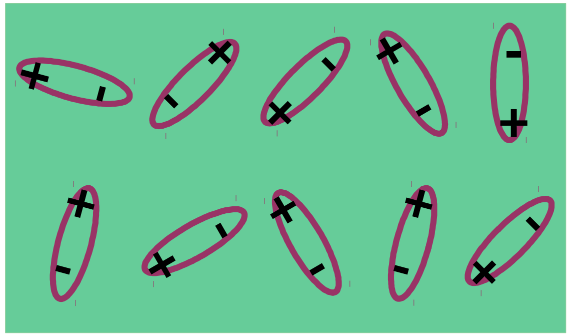
- *Polarization of dielectrics finds useful application in capacitors*
- *In a parallel plate capacitor, electric field* $E_0 = \dfrac{q}{A\epsilon_0}$
- *where* $\varepsilon_o = 8.854 \times 10^{-12}$ *F/m, permittivity of free space*



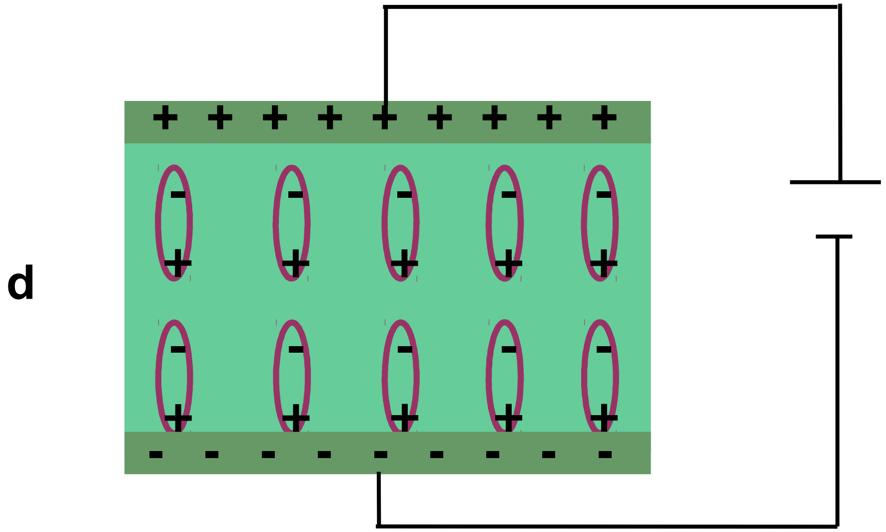
Parallel plate capacitor: Electric field

Polarization

- *If E=0, then there will be no net electric dipole moment*
- *Dielectric placed between the capacitor plates will induce surface charge (q')* $\mathbf{E} = \frac{\mathbf{q} - \mathbf{q}'}{\mathbf{A}\epsilon_o} = \frac{q}{\mathbf{A}\epsilon_o\epsilon_r}$
- *Capacitance increases* $\mathbf{C} = \frac{q}{V} = \frac{\mathbf{A}\epsilon_o\epsilon_r}{d}$ $\mathbf{with}\,\epsilon_r = \frac{C}{C_o}$



Dielectric material in the absence of E



Dielectric constant

- *ε_r is the relative permittivity or dielectric constant*
- *It is a measure of how susceptible the material is to the applied electric field.*
- *Depends on the composition, micro structure, applied field frequency and temperature*
- *At room temperature and frequency ~ 10^6Hz*

Material	Dielectric Constant	Material	Dielectric Constant
Air	1.00059	Paraffin	2.5
Water	78	$BaTiO_3$	2000

Electric susceptibility

- *Equation for capacitance and net electric field can be recombined to get* $\frac{q}{A}=\frac{q}{\epsilon_r A}+\frac{q'}{A} \Rightarrow \vec{D}=\epsilon_o \vec{E}+\vec{P}$
- *D is electric displacement field vector* $\vec{D}=\epsilon \vec{E}$
- *where* $\varepsilon = \varepsilon_r \varepsilon_o$ *is the permittivity of the material*
- *It describes the displacement effects of an electric field on the charges*
- *In an isotropic material, D, P and E will lie in the same direction*
- *Polarization can be written as* $\vec{P}=\epsilon_o(\epsilon_r-1)\vec{E}=\chi \epsilon_o \vec{E}$

Electric susceptibility

- *$\chi = (\varepsilon_r - 1)$ is electric susceptibility of the material*
- *If N is the number of atoms per unit volume,*
- *then* $\vec{P} = \chi \epsilon_o \vec{E} = N \alpha \vec{E}$
- *Note that **α** is polarizability of individual dipoles*

$$\chi = \frac{N\alpha}{\epsilon_o} = \epsilon_r - 1$$

- *This relates macroscopic dielectric susceptibility with microscopic polarizability*

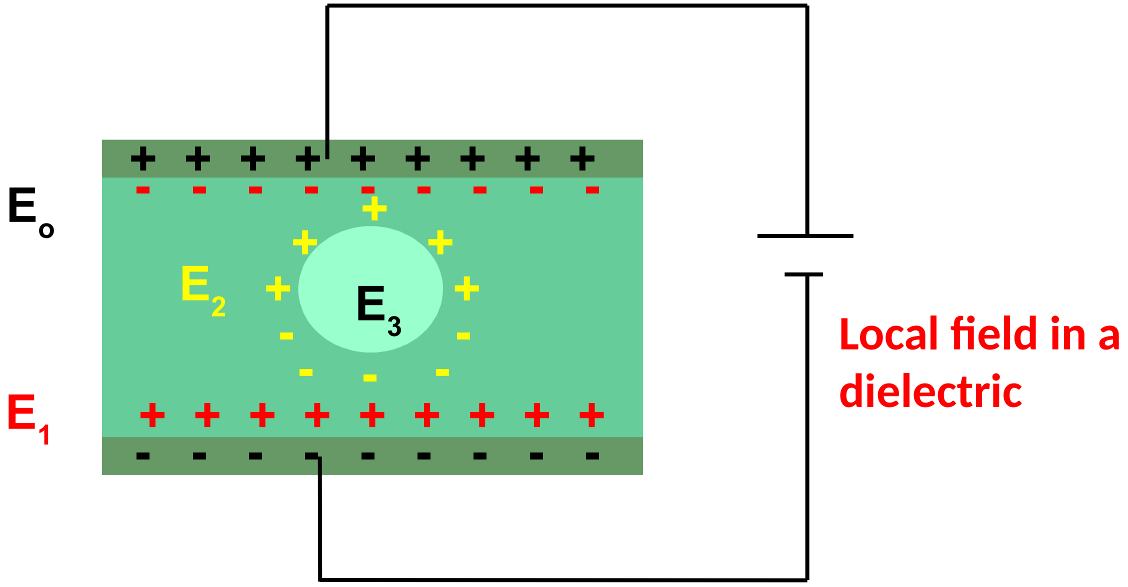
Local electric field in a dielectric material

E_o → External electric field

E_1 → Depolarization field

E_2→ Lorentz field on the surface of the spherical cavity

E_3→ Internal field due to other dipoles lying within the sphere



Clausius-Mosotti relation

- *In the case of a dielectric with a cubic structure the effective field is,* $\vec{E}_{in} = \frac{\vec{P}}{3\epsilon_o}$
- *Net field across the dielectric* $\vec{E}_{loc} = \vec{E} + \frac{\vec{P}}{3\epsilon_o}$
- *Polarization* $\mathrm{P} = \mathrm{N}\alpha\left(\vec{E} + \frac{\vec{P}}{3\epsilon_o}\right) = \epsilon_o(\epsilon_r - 1)\vec{E}$
- *On solving, we obtain* $\frac{N\alpha}{3\epsilon_o} = \frac{\epsilon_r - 1}{\epsilon_r + 2}$

  This is the Clausius-Mossotti relation
- *It relates the macroscopic dielectric constant to the microscopic polarizability of the material*

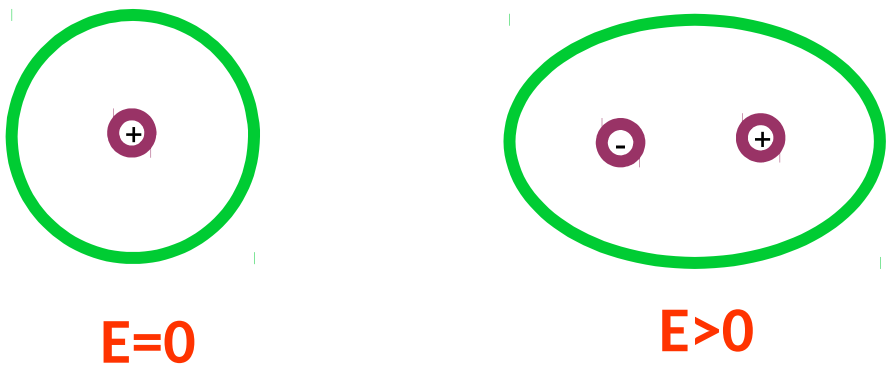
Types of Polarization

- *Any separation of charges leads to polarization*
- *It could happen due to vibration of atoms or ions or due to applied electric field or migration of charges…*
- *Polarization phenomena which occurs in dielectrics are*

1. *Electronic polarization*
2. *Ionic polarization*
3. *Orientation or dipole polarization*
4. *Space charge or interfacial polarization*

Electronic Polarization

- *Electronic polarization is present in all the materials*
- *In the absence of E, the centres of positive and negative charges coincide*
- *Electron cloud gets displaced from the nucleus in response to the applied field*
- *The separation of charges creates a dipole moment (μ_e)*



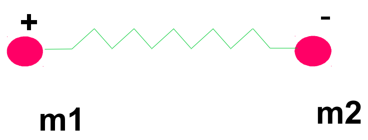
Electronic polarization

- *Occurs even at very high frequencies (~10^{15} Hz)*
- *Electronic polarizability,* $\alpha_e = 4\pi\epsilon_o R^3$
- *where R is the radius of the atom*
- *Larger atoms and ions have higher electronic polarizability*
- *Higher the electronic polarizability, higher is the refractive index of the material*
- *Electronic polarization*

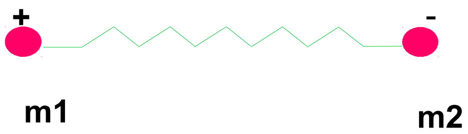
$$\overrightarrow{P_e} = \mathrm{N}\vec{\mu}_e = \mathrm{N}\alpha_e\vec{E}$$

Ionic Polarization

- ***Relative displacement of ions in ionic crystals (ex: NaCl) giving rise to additional polarization***
- ***Permanent dipole moment ($r_o e$) exists even in the absence of applied field***
- ***But net polarization will be zero***
- ***In the presence of E, positive and negative ions are displaced in opposite directions***



E=0



E→

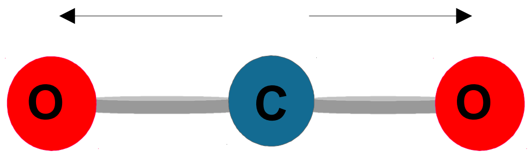
Ionic polarization

- *Ionic polarization is independent of temperature*
- *Dipoles are not free to rotate*
- *For frequencies below infrared, molecules just manage to keep in phase with the field polarity*
- *At optical frequencies, there will be no ionic polarization*
- *Ionic polarizability is an order of magnitude less than electronic polarizability*
- *Dipole moment due to ionic polarization,* $\vec{\mu}_i = \frac{e^2}{\omega_0^2}\left(\frac{1}{m_1} + \frac{1}{m_2}\right)\vec{E} = \alpha_i \vec{E}$

where ω_o is the angular frequency of vibration of molecule and α_i is the ionic polarizability

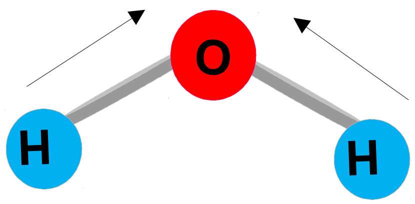
Orientational/molecular polarization

- *It occurs only in polar molecules*
- *Examples: HCl, $H_2$0, HF …*
- *Within a molecule each polar bond has a bond dipole*
- *It depends on the geometry of the molecule*
- *In the absence of E and at thermal equilibrium, no net dipole moment exists*
- *There are no forces to oppose the force due to external field*



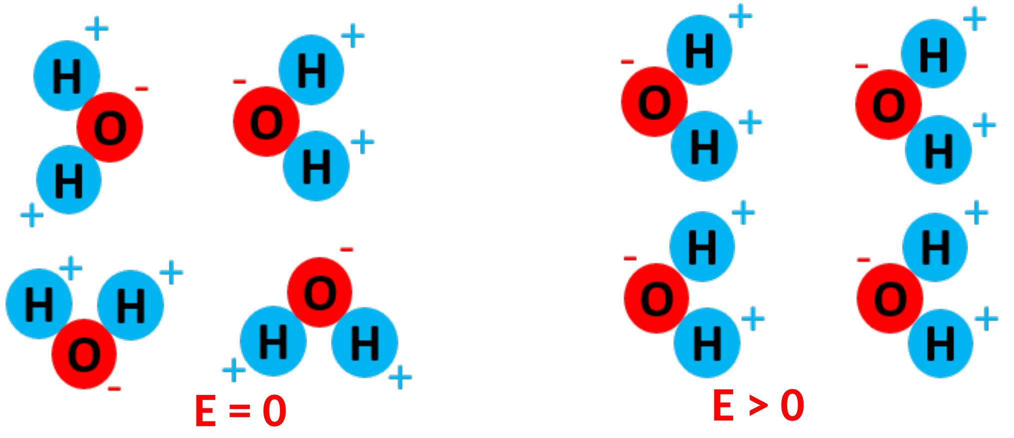
Non Polar molecule

Polar molecule



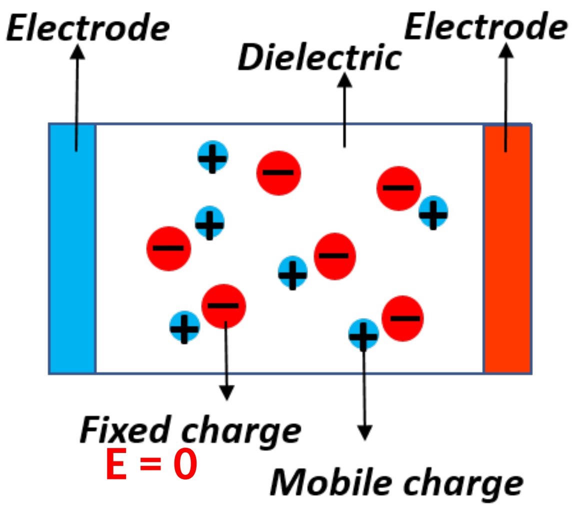
Orientational/molecular polarization

- *In the presence of E, molecular dipole moments can rotate about their axis of symmetry and align with it*
- *This gives rise to orientation polarization* $\vec{P_o} = \frac{N\vec{\mu}^2\vec{E}}{3kT} = \alpha_o\vec{E}$
- *It is dependent on the temperature*
- *It occurs only till radio frequencies*



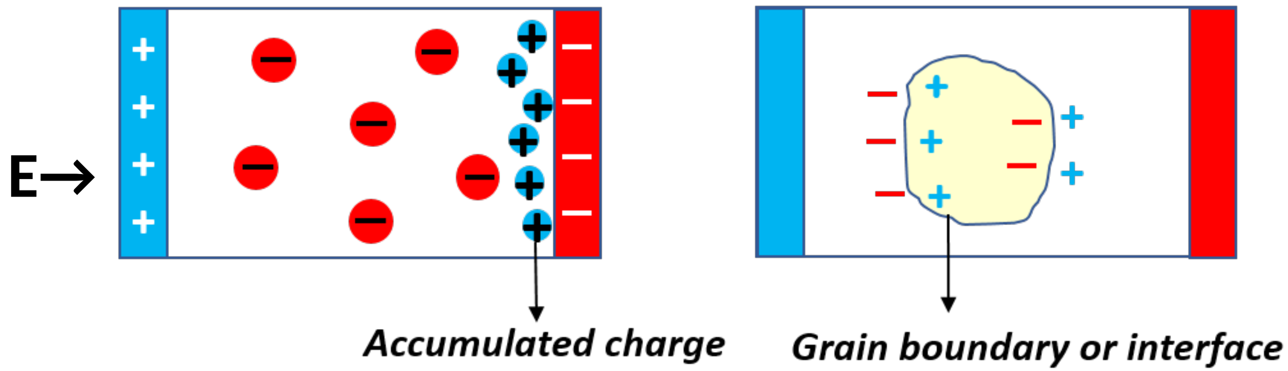
Space-charge polarization

- *It is usually associated with the presence of migrating charges, like electrons or ions*
- *Occurs at physical boundaries such as defects, voids, impurities, grain or phase boundaries*
- *Accumulated charges distort the local electric field*



Space-charge polarization

- *It is different as it affects bound charges as well as free charges*
- *It is observed only at lower frequencies*
- *In the presence of E, positive ions migrate to the negative electrode and pile up at the interface*
- *Positive charges at the interface attract more electrons to the negative electrode*
- *This gives rise to interfacial polarization*



Class #53 …….. Quiz….

The concepts related to the polarization mechanism in dielectrics which are true are…

1. Polarization is net dipole moment per unit area
2. Dielectric constant depends on the micro structure
3. Electronic polarisation is dependent on temperature
4. Orientational polarisation occurs only in polar molecules
5. Ionic polarization occurs even at optical frequencies
6. Space charge polarisation affects free as well as bound charges

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THANK YOU

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