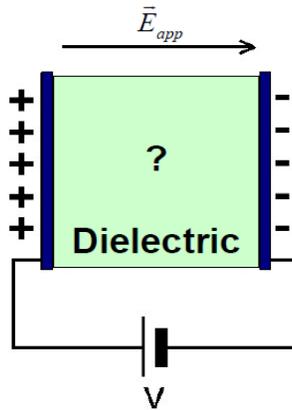


Dielectric Properties of Solids

Introduction (concept)

Capacitor (condenser)



For some materials $\sigma \rightarrow 0$ (at RT) upon \vec{E}_{app}
 → They are called **insulators or dielectrics**.

Charge **can not flow freely** in the direction of \vec{E}_{app} , but

\vec{E}_{app} can penetrate into their interiors and affect the internal structure of such materials.

macroscopically,

i) When no dielectric, $C_o = \frac{\epsilon_o A}{d}$

ii) When a dielectric is inserted, $C = \frac{\epsilon_o \epsilon_r A}{d}$

iii) The calculation of ϵ is an important aim of any microscopic theory of dielectrics.

iv) also, their response to the AC \vec{E} field reflected in

$\epsilon(\omega)$ and as $\omega \rightarrow$ optical range

→ It leads to optical properties of dielectrics

$$\therefore n = \sqrt{\epsilon}$$

v) In some ionic crystal, even when $\vec{E}_{app} = 0$, there may be long-range electrostatic force between the ions (in addition to the lattice potential)

Ex: Ferroelectricity, piezoelectricity

Electronic Polarizability

Let's limit our discussion to insulating extended solids. In the absence of charge carriers (ions or electrons) or molecules, we only need to consider the electronic and ionic polarizabilities.



The presence of an electric field polarizes the electron distribution about an atom creating a dipole moment,

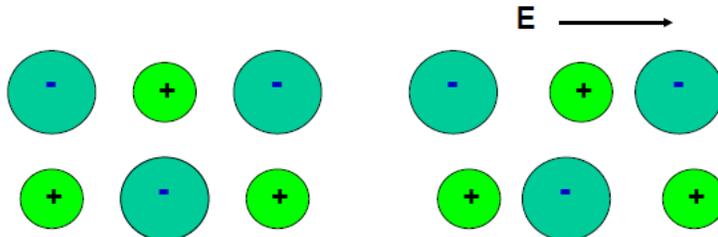
$$\mu = qx$$

The dipole moment per unit volume, P , is then given by

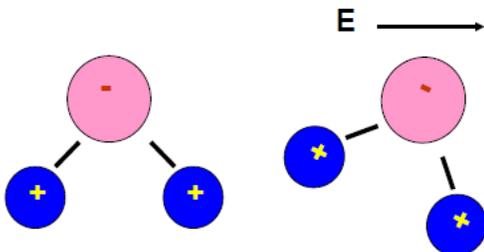
$$P = n_m \mu$$

where n_m is the number of atoms per unit volume.

https://chemistry.osu.edu/~woodward/ch754/lect2003/dielectrics_lect28.ppt



Ionic polarization occurs in all ionic solids: NaCl, MgO...

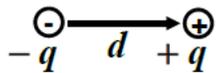


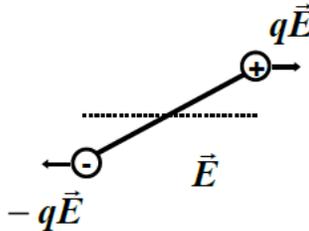
Molecular polarization, occurs in all insulating molecules; oils, polymers, H₂O...

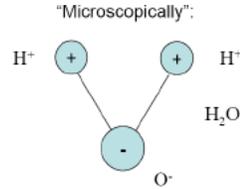
Review of basic formulas

In dielectrics, there are no free charges, but bound charges, i.e. electric dipoles are present.

Definition

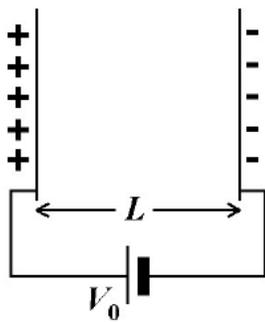

dipole moment $\vec{p} = q\vec{d}$ (- → +)


Torque felt $\vec{\tau} = \vec{p} \times \vec{E}$
Potential energy $V = -\vec{p} \cdot \vec{E}$



In discussing dielectric materials

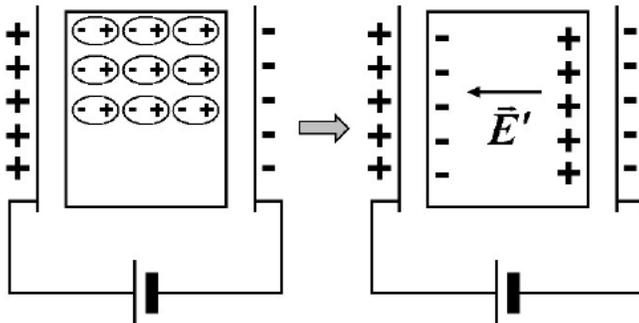
Polarization $\vec{P} = \# \text{ of dipole moment / unit volume}$
 $= N\vec{p}$ the **dipole moment density** : units of C/m²



Electric field inside the parallel plate :

$$\vec{E}_0 = \frac{V_0}{L}$$

Now, insert a slab of dielectric \Rightarrow modify the field to a new value \vec{E}



$$\vec{E}_0 - \vec{E}' = \vec{E}$$

\vec{E}' due to polarization change

$\vec{E}_0 - \vec{E}' = \vec{E}$: new field inside the slab

Now,

Electric displacement $\vec{D} = \epsilon_0 \vec{E}_0$ (just outside the dielectric) or

$$\vec{D} = \epsilon_0 \vec{E} + \vec{P} \quad (\text{inside dielectric})$$

$$\therefore \vec{E} = \vec{E}_0 - \frac{\vec{P}}{\epsilon_0}$$

also, $\vec{D} = \epsilon_0 \vec{E} + \vec{P} = \epsilon \vec{E} = \epsilon_0 \epsilon_r \vec{E}$

$$\text{where } \epsilon_r = \frac{\epsilon}{\epsilon_0}$$

Dielectric constant

All the dielectric and optical characteristics of substances are contained in this constant.

The dielectric constant and polarizability : the local field

The polarization of a medium is produced by the field

Dipole moment $\vec{p} = \alpha \vec{E}$
Polarizability

Polarization $\vec{P} = N\vec{p} = N\alpha\vec{E}$

and $\vec{D} = \epsilon_0 \vec{E} + \vec{P} = \epsilon_0 \vec{E} + N\alpha\vec{E}$
 $= \epsilon_0 \left(1 + \frac{N\alpha}{\epsilon_0} \right) \vec{E}$

Previously, $\vec{D} = \epsilon_0 \epsilon_r \vec{E}$

$$\therefore \epsilon_r = 1 + \frac{N\alpha}{\epsilon_0}$$

Define **electrical susceptibility** χ such that

$$\vec{P} = \epsilon_0 \chi \vec{E} \quad \text{cf.} \quad \vec{P} = N \alpha \vec{E}$$

then

$$\chi = \frac{N \alpha}{\epsilon_0} \quad \epsilon_r = 1 + \chi$$

In fact,

$$\vec{P} = \alpha \vec{E}_{local} \quad \text{instead of} \quad \vec{P} = \alpha \vec{E}_{Maxwell}$$

If this microscopic field is averaged, one obtains the **macroscopic or Maxwell field E** .

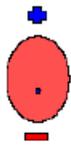
Table 9.1. DC dielectric constants of some materials

Potassium tantalate niobate	6000
Barium titanate (BaTiO ₃)	4000
Potassium Niobate (KNbO ₃)	700
Rochelle salt (NaKC ₄ H ₄ O ₆ · 4H ₂ O)	170
Water	81.1
Acetone	20
Silicon	11.8
GaAs	10.9
Marble	8.5
Soda-lime-glass	6.9
Porcelain	6.0
Epoxy	4.0
Fused silica	4.0
Nylon 6,6	4.0
PVC	3.5
Ice	3.0
Amber	2.8
Polyethylene	2.3
Paraffin	2.0
Air	1.000576

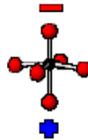
*) **Soda-lime glass**, also called **soda-lime-silica glass**, is the most prevalent type of **glass**, used for windowpanes, and **glass** containers (bottles and jars) for beverages, food, and some commodity items. [Source Wikipedia](#)

Contributions to Polarizability

$$\alpha = \alpha_e + \alpha_i + \alpha_d + \alpha_s$$



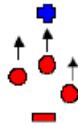
1. Electronic Polarizability (α_e)
Polarization of localized electrons



2. Ionic Polarizability (α_i)
Displacement of ions



3. Dipolar Polarizability (α_d)
Reorientation of polar molecules



4. Space Charge Polarizability (α_s)
Long range charge migration

Polarizability (α) increases

Response Time Increases (slower response)