6

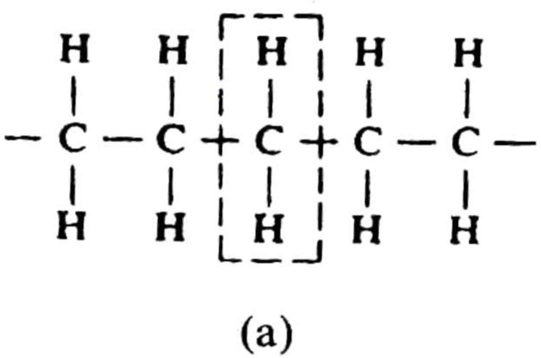
Electrical Properties of Polymers, Ceramics, Dielectrics

11월 19일: 중간고사시험(저녁 7시-8시30분)

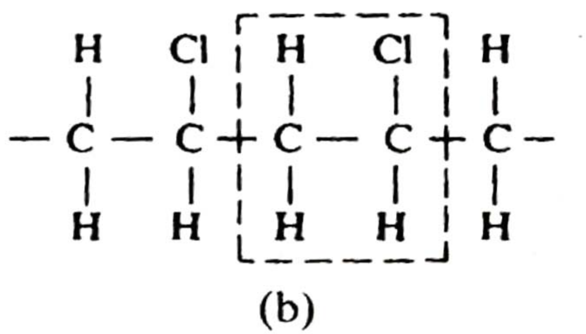
6.1 Conducting Polymers and Organic Metals

Most polymeric materials have insulating properties.

In 1970's, it was discovered that some polymers and organic substances show electrical properties resembling those of semiconductors, metals, or even superconductors.

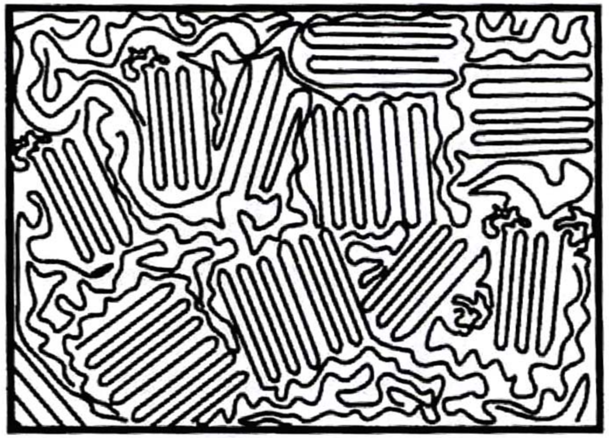


polyethylene



Polyvinylchloride (PVC)

➔ Polymers consist of (macro)molecules which are long and chainlike. Several atoms combine and form a specific building block, called a monomer, and thousands of monomer combine to a polymer.



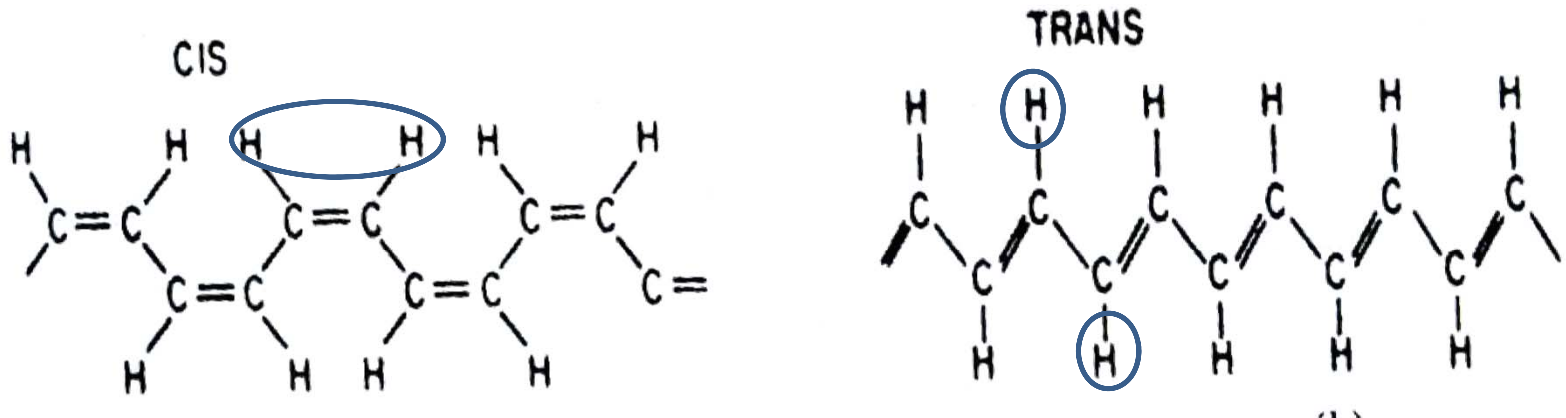
The binding force between individual atoms within a chain

covalent(mostly) + ionic in nature

The binding force between macromolecules:

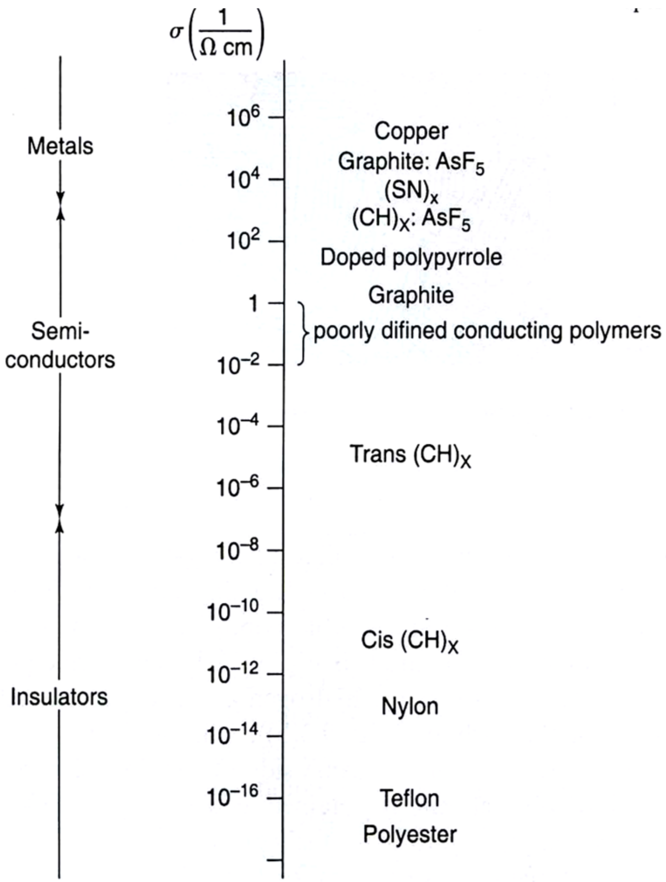
Van der Walls type(weak)

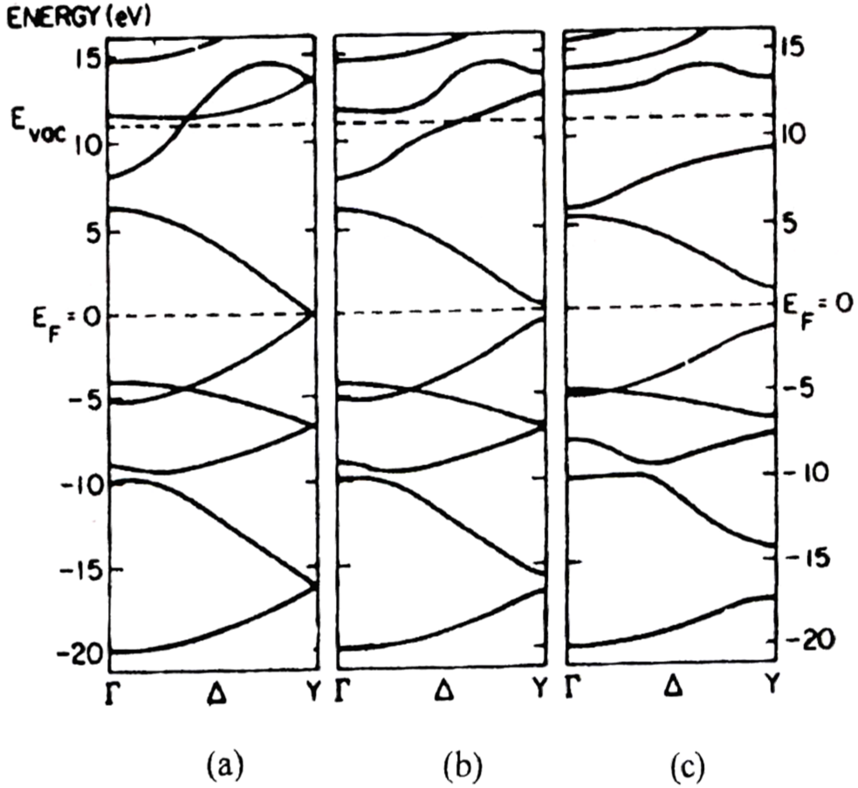
Polyacetylene: show a high degree of crystalinity and a relatively high conductivity (**conjugated organic polymer**: having alternating single and double bonds



(a) (b)

Trans-polyacetylene is obtained as silvery flexible film that has a conductivity comparable to that of silicon

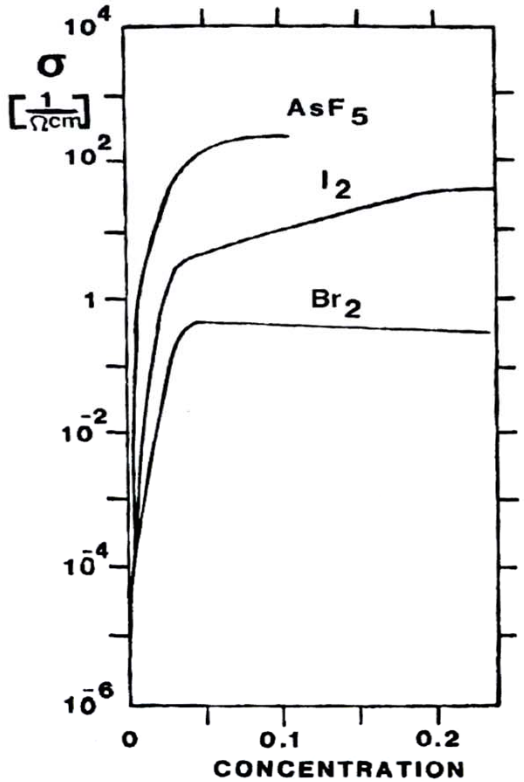




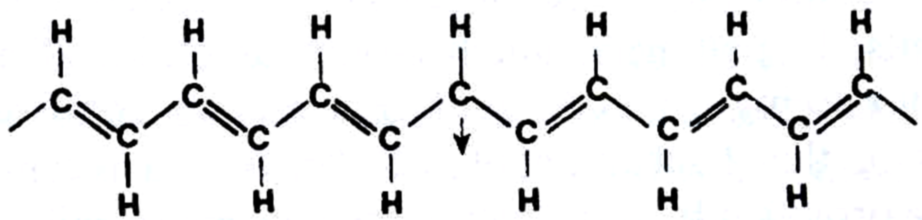
Calculated band structure of trans-(CH)x for different carbon-carbon bond length: (a) uniform (1.39A), (b) **weakly alternating,** and (c) strongly alternating

Where are the free electrons in the conduction band coming from?

- the electrons in the double bond of a conjugated polymer (π-electron)



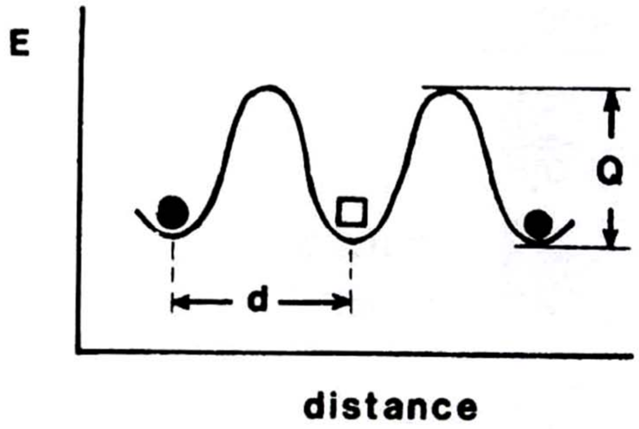
Conductivity increase by doping in polymer-based semiconductor



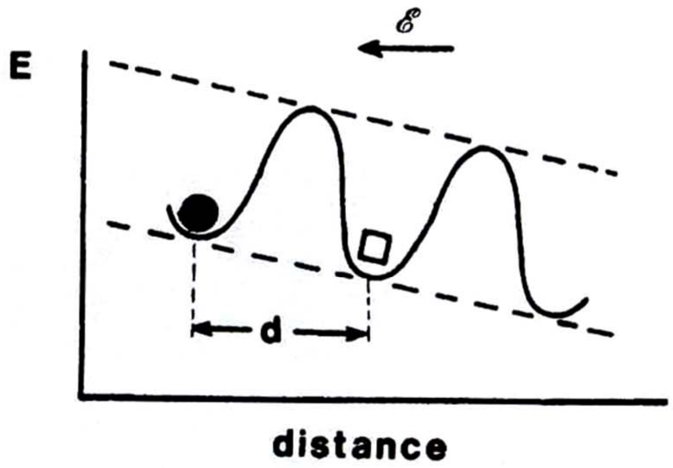
"soliton" is a structural distortion in a conjugated polymer and is generated when a single bond meets another single bond

a localized non-bonding electron state is generated.

6.2 Ionic Conduction



(a)



(b)

The ionic conduction is caused by the movement of some charged ions which hop from lattice site to lattice site under the influence of electric field.

$$\sigma_{\text{ion}} = N_{\text{ion}} e \mu_{\text{ion}}$$

N_{ion} **depends on vacancy concentration in the crystal** ➔ **Diffusion Theory**

$$D = D_0 \exp\left[-\left(\frac{Q}{k_B T}\right)\right],$$ → **Diffusion Theory**

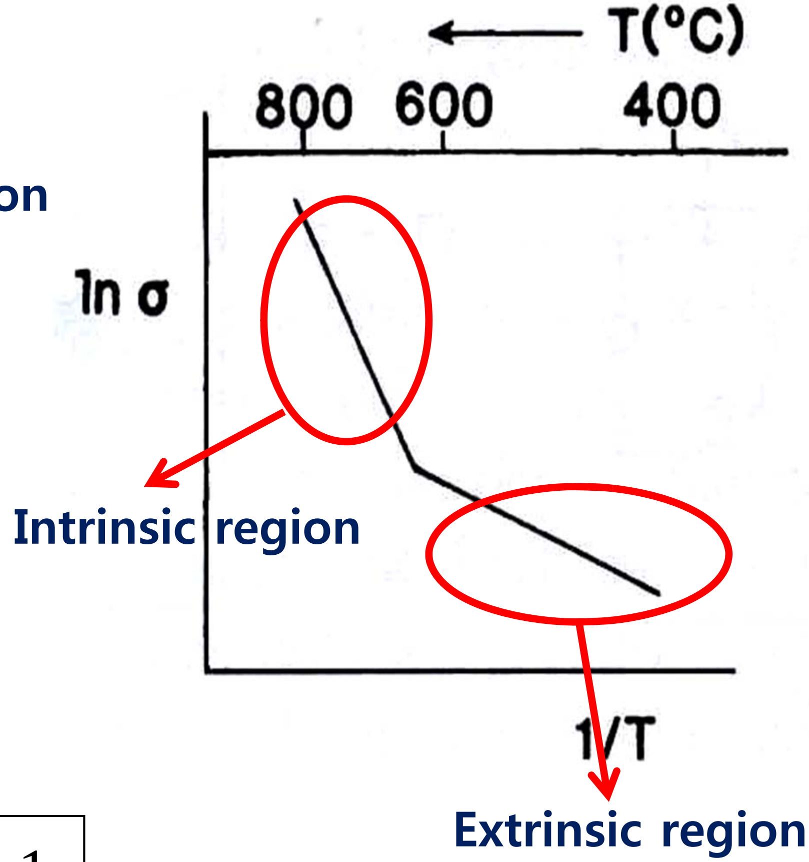
$$\mu_{ion} = \frac{D_e}{k_B T}.$$ → **Einstein Relation**

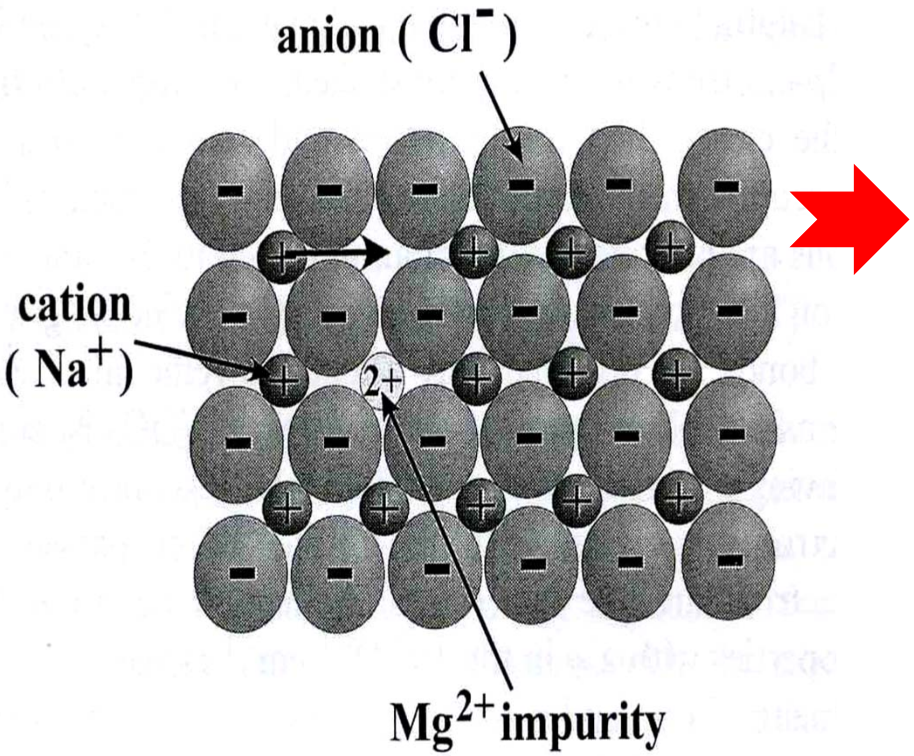
↓

$$\sigma_{ion} = \frac{N_{ion} e^2 D_0}{k_B T} \exp\left[-\left(\frac{Q}{k_B T}\right)\right].$$

$$\sigma_{ion} = \sigma_0 \exp\left[-\left(\frac{Q}{k_B T}\right)\right].$$

$$\therefore \; \ln \sigma_{ion} = \ln \sigma_0 - \left(\frac{Q}{k_B}\right)\frac{1}{T}.$$





Whenever vacant lattice site is created, an overall **charge neutrality** needs to be maintained.

Both a cation and anion are removed from a lattice

Formation of vacancy- interstitial pair (**Frenkel defect**)

6.3 Conduction in Metal Oxides

Metal oxide can be insulating, have metallic conduction properties, or be semiconducting : For understanding the mechanisms involved in metal oxides, their electronic configuration in the orbital (or band structure) should be considered. (Appendix 3. p.409)

1. TiO_2 (O : $1s^2\ 2s^2 2p^4$, Ti: $[Ar]3d^2 4s^2$)

- Noble gas configuration, insulator

- **insulator with wide band gap.**

2. TiO (O : $1s^2\ 2s^2 2p^4$, Ti: $[Ar]3d^2 4s^2$)

- Metallic

3. ZnO (O : $1s^2\ 2s^2 2p^4$, Zn: $[Ar]3p^{10} 4s^2$)

- **Insulator for stoichiometric**

- ***n*-type semiconductor for non-stoichiometric**

4. SnO_2 (some times doped with In_2O_3)

- Transparent in the visible region and which is a reasonable conductor in the 1 $\Omega^{-1}cm^{-1}$ range

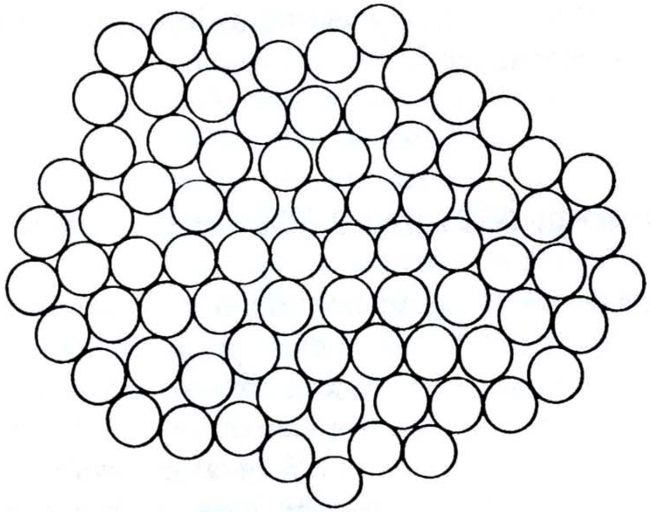
- Optoelectronics to provide electrical contacts without blocking the light from reaching a device: indium-tin-oxide (ITO)

5. NiO (O :$1s^2\ 2s^2 2p^4$,Ni: $[Ar]3p^8 4s^2$)

-Insulator for stoichiometric

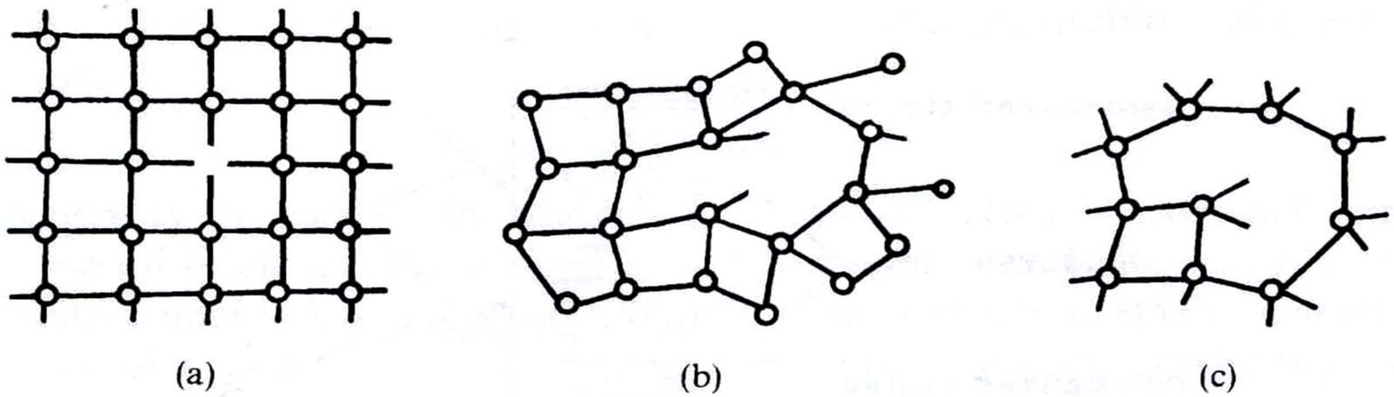
- *p*-type semiconductor for nonstoichiometric

6.4 Amorphous Materials (Metallic Glasses)

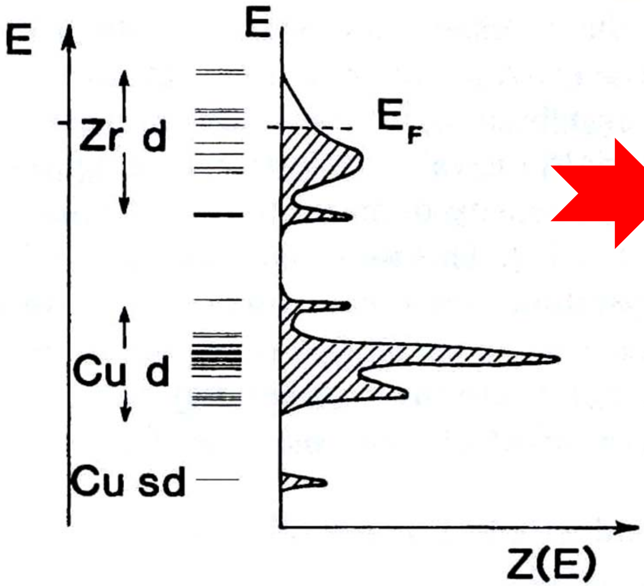


Atomic structure of amorphous metals and alloy

Dense random packing of hard spheres model (Bernal model)

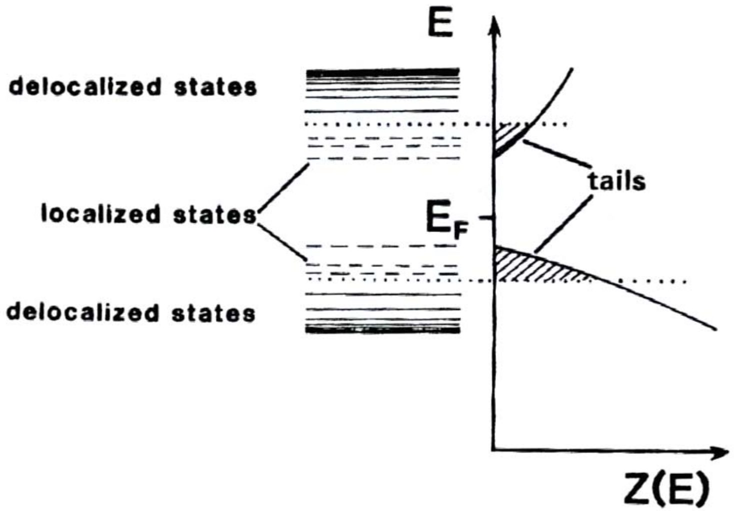


Defect in crystalline **Defect in amorphous**



Cluster Model (for amorphous Cu-Zr)

A series of clusters were assumed which exhibit the symmetry of closed-packed lattice fcc (as Cu) and hcp (as for Zr)



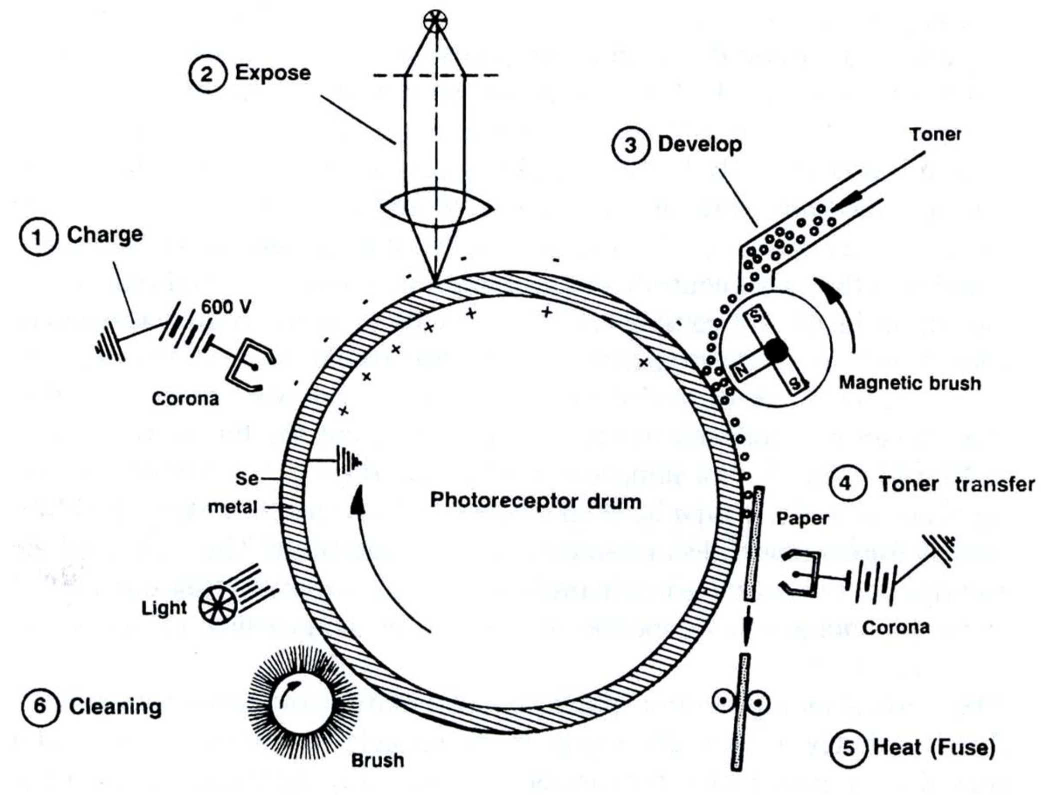
Localize and delocalized states and density of states Z(E) for amorphous semiconductor

Electrical conductivity for amorphous semiconductors

$$\sigma_A = N_A e \mu_A .$$

$$\sigma_A = \sigma_0 \exp\left[-\left(\frac{Q_A(T)}{k_B T}\right)\right].$$

6.4.1 Xerography



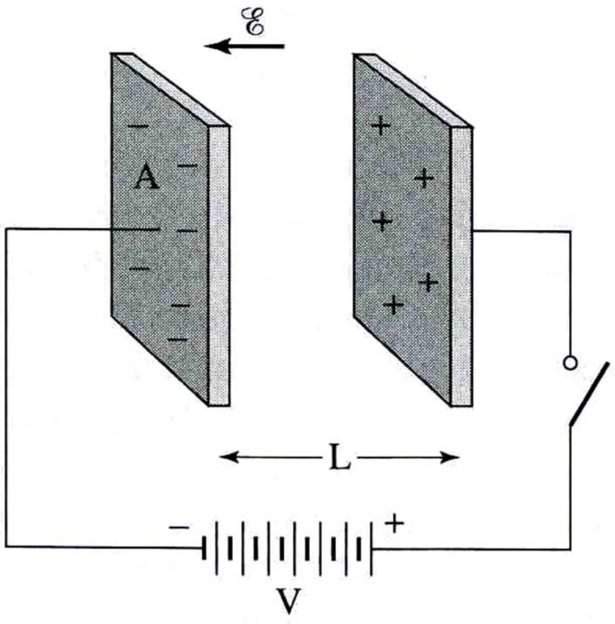
When deposited on a cylindrically shaped metallic substrate, constitutes the photoreceptor drum

6.5 Dielectric Properties

$$C = \frac{q}{V},$$

Capacitance, *C*

the ability to store an electric charge, q per unit applied voltage, V.



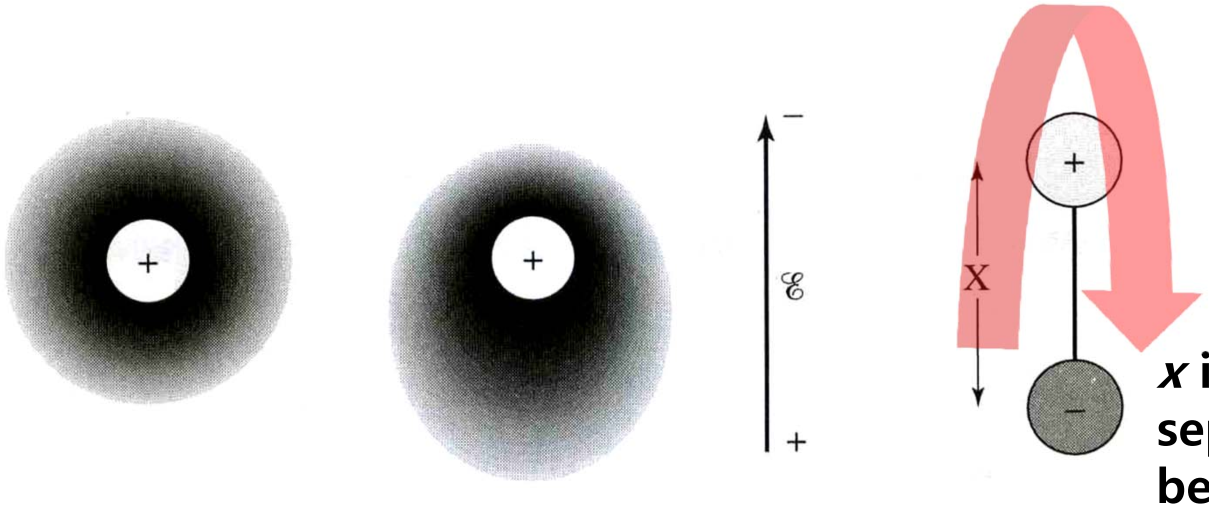
$$C = \varepsilon\ \varepsilon_0 \frac{A}{L} \qquad \varepsilon = \frac{C}{C_{\mathrm{vac}}}$$

ε : dielectric constant (unitless), or ***relative permittivity,***

ε_r ε_0 : permittivity of empty space , 8.85 x 10^{-12} F/m

Table 9.1. DC dielectric constants of some materials

Potassium tantalate niobate	6000	
Barium titanate ($BaTiO_3$)	4000	Ferroelectric
Potassium Niobate ($KNbO_3$)	700	
Rochelle salt ($NaKC_4H_4O_6 \cdot 4H_2O$)	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	Dielectric
Nylon 6,6	4.0	
PVC	3.5	
Ice	3.0	
Amber	2.8	
Polyethylene	2.3	
Paraffin	2.0	
Air	1.000576	



(a) (b) (c)

x **is the separation between the positive and negative charge**

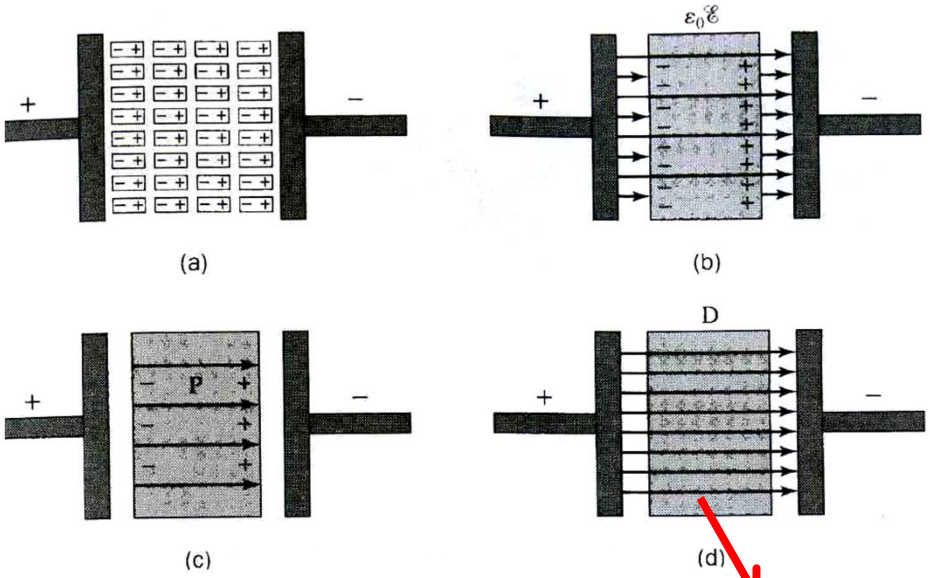
$$p = q \cdot x,$$ **Electric dipole moment**

$$E = \frac{E_{vac}}{\varepsilon}, \qquad D = \varepsilon\varepsilon_0 E = \frac{q}{A}.$$

Within a dielectric material the electric field strength, E, is replaced by the dielectric displacement D.

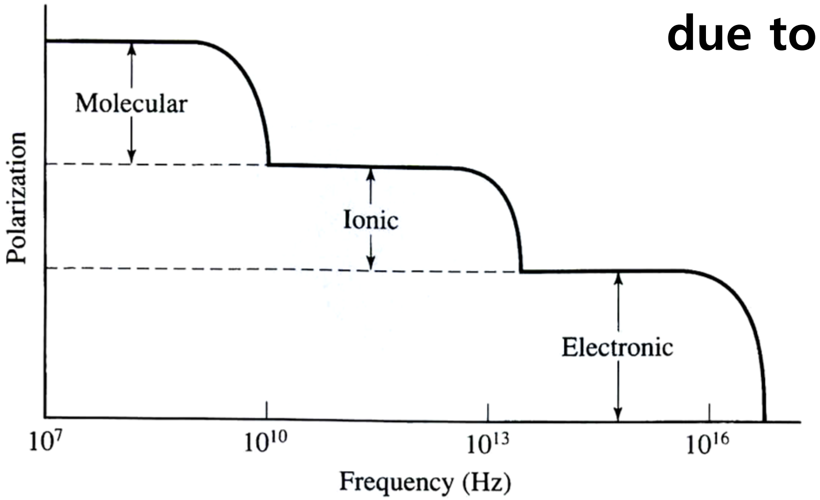
$$D = \varepsilon_0 E + P,$$

Polarization : the process of dipole formation (or alignment of already existing dipoles) under the influence of an external electric field that has an electric field strength, *E*



-Dipole formation of all involved atoms within a dielectric material cause a charge redistribution so that the surface nearest to the positive capacitor plate is negatively charge (and vice versa)

due to polarization



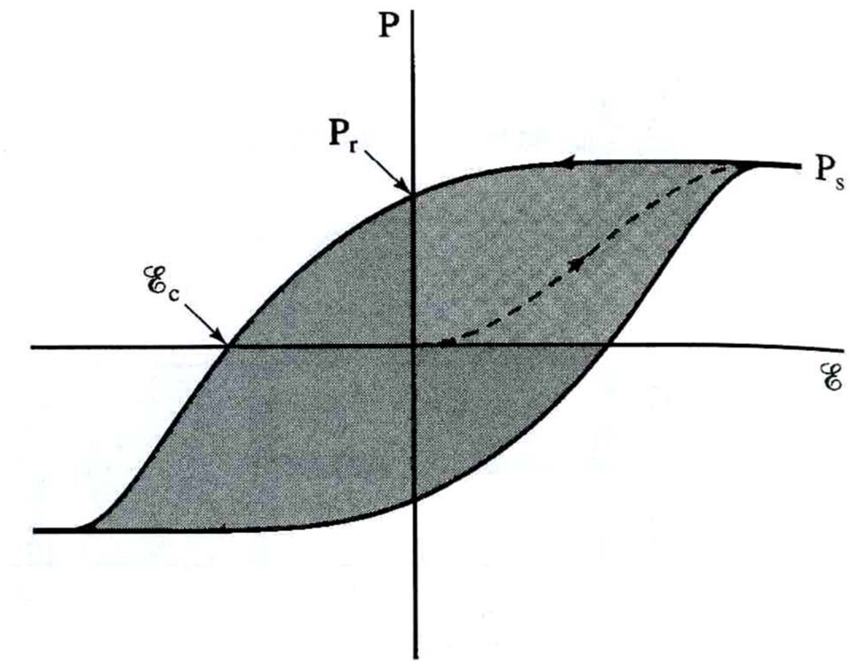
How quickly do the dipoles to reorient or to align under a rapidly changing electric filed (in alternating circuit)

Polarization mechanisms which can respond equally quick to an alternating electric field

6.6 Ferroelectricity, Piezoelectricity, and Electrostriction

Ferroelectric materials

A spontaneous polarization without the presence of an external electric field :suitable for the manufacturing of small sized, highly efficient capacitors



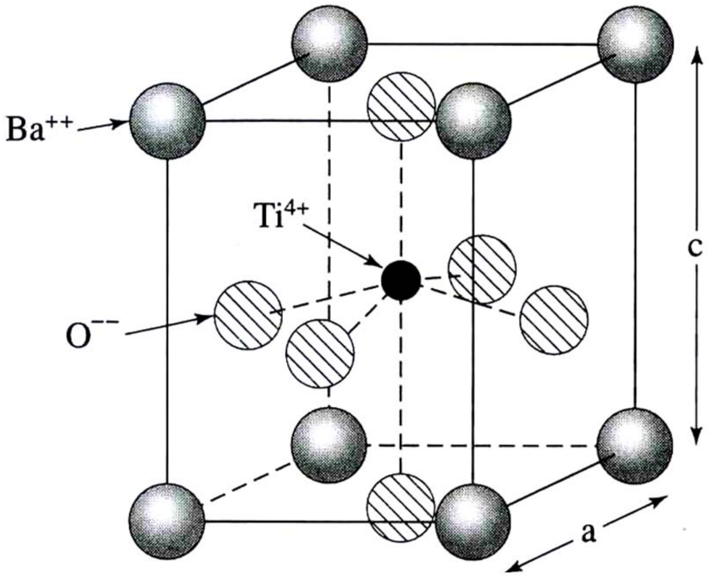
Hysteresis loop

P_S: saturation polarization

P_r : remanent polarization

E_C : coercive filed

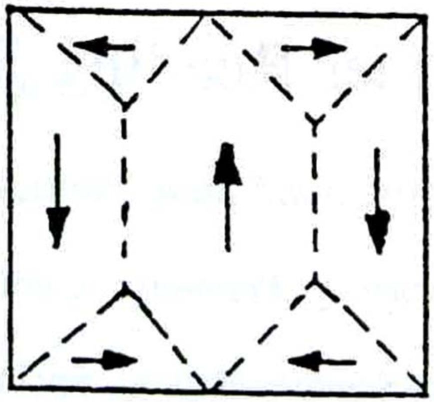
Mechanism for spontaneous polarization



Tetragonal $BaTiO_3$:

A large number of such dipole moment line up in a clusters (also called ***domains***) In the virgin state, the polarization directions of the individual domains are randomly oriented: no net polarization

An external field orients the dipoles of favorably oriented domains parallel to *E*: those domains in which the dipoles are already nearly parallel to *E* at the expense of unfavorably oriented domains



Spontaneous alignments of electric dipoles within a domain and random alignment of the dipole moments of several domains in a ferroelectric material