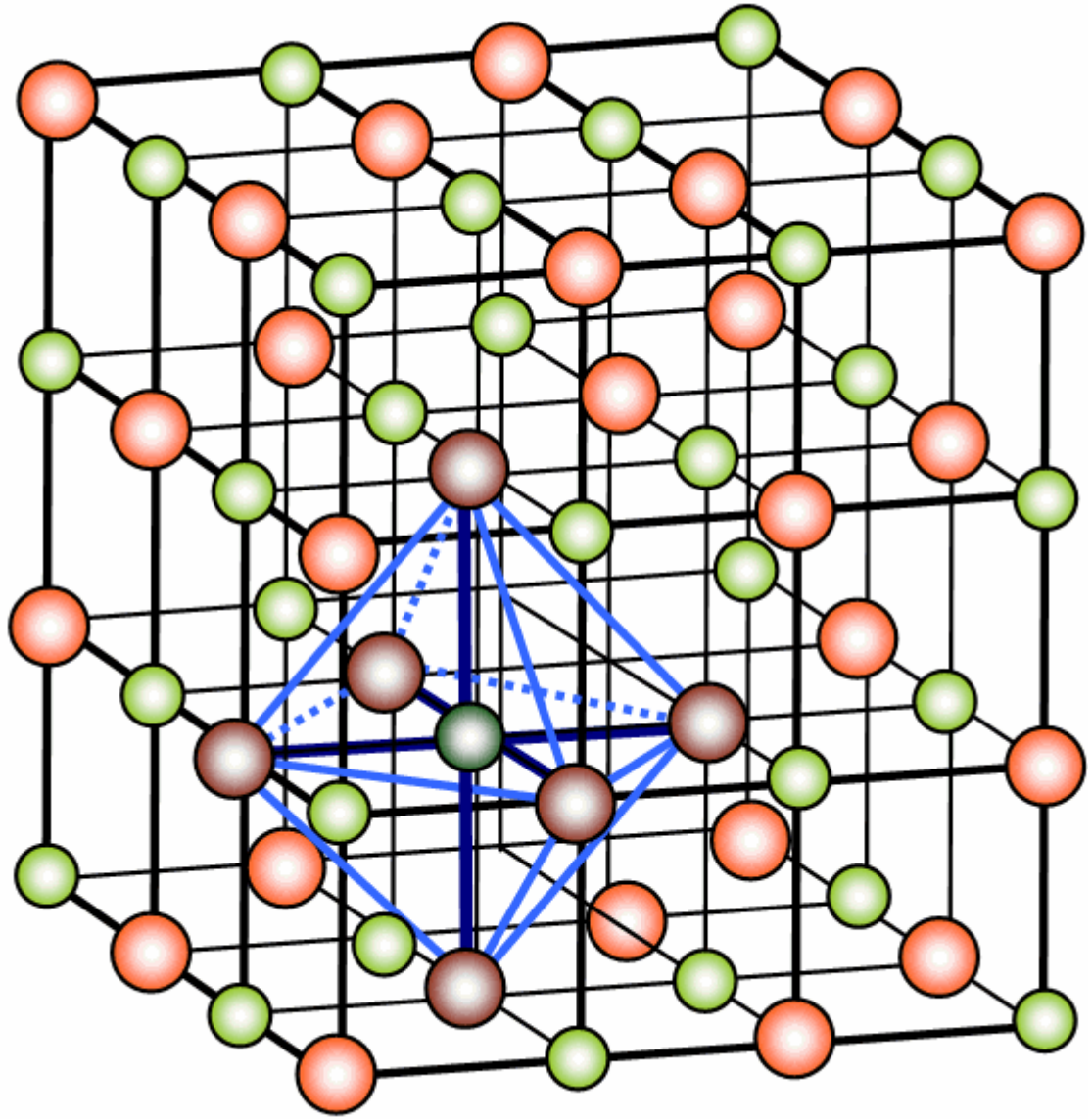
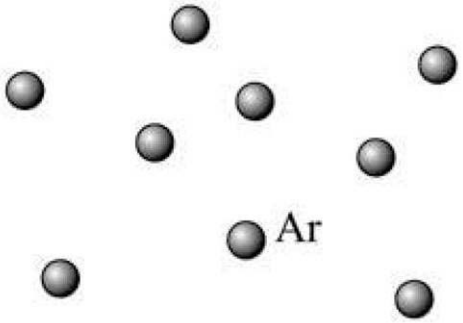
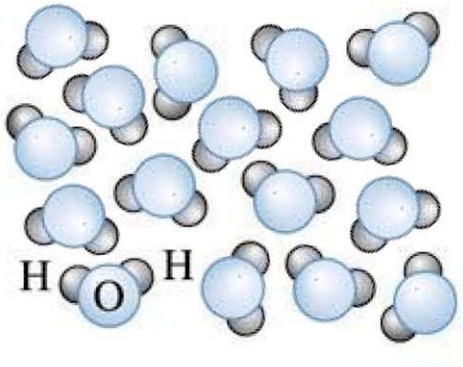
Introduction to Solid State Physics



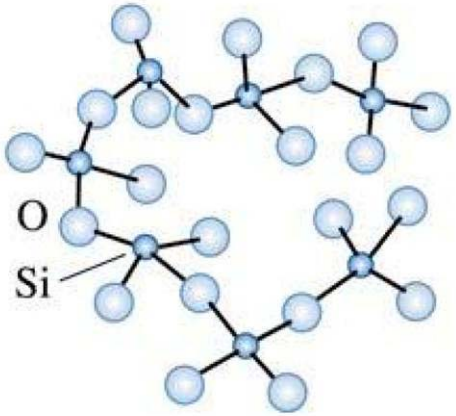
Atomic structures



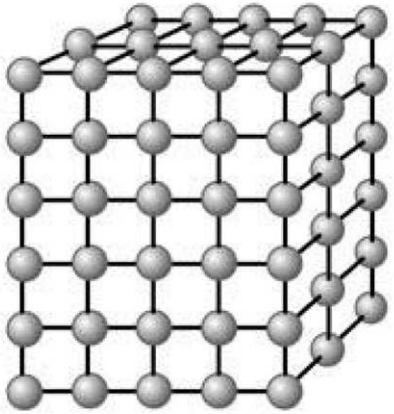
(a)



(b)



(c)



(d)

a) gases

b) liquids

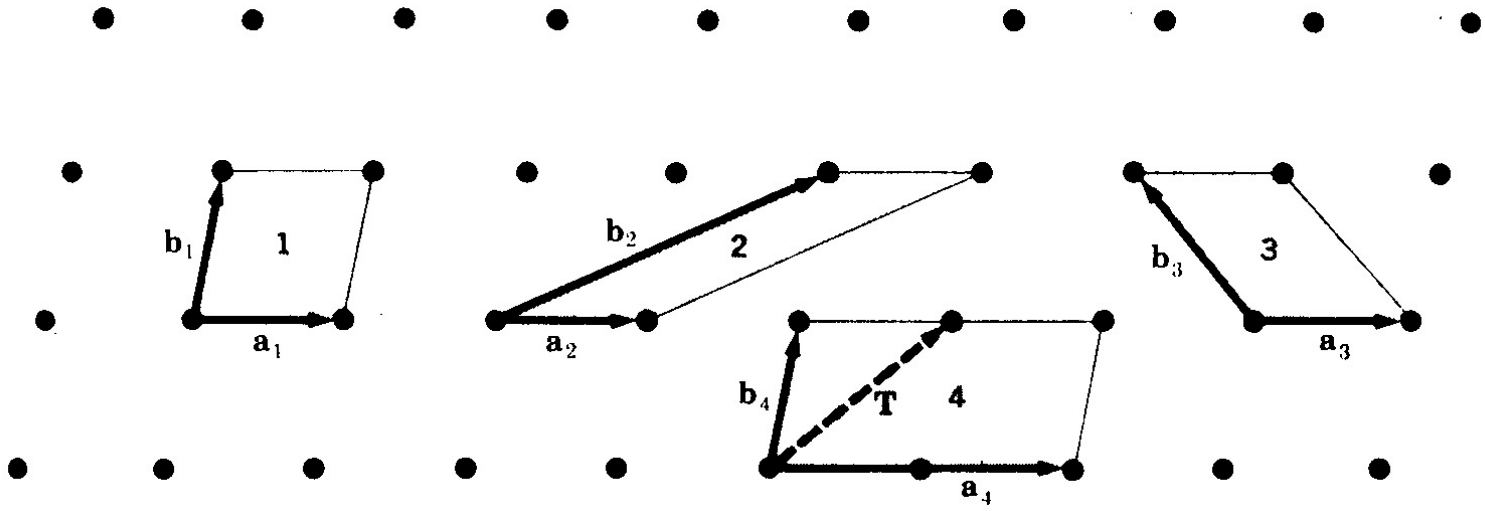
c) amorphous solids

d) crystalline solids

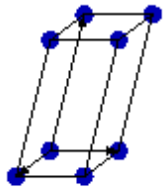
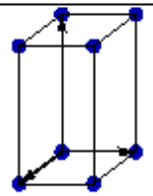
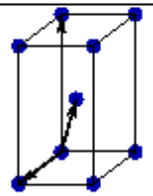
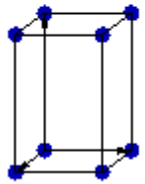
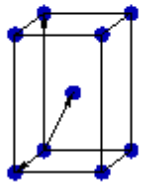
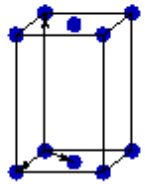
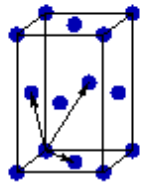
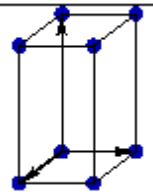
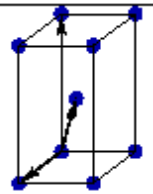
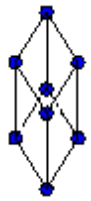
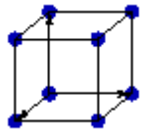
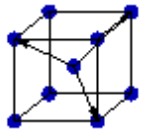
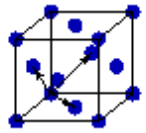
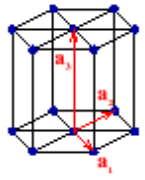
Crystal structures

Arrangement of equal spheres: close packing
symetries
interactions (bonds)

$\vec{T} = u\vec{a} + v\vec{b} + w\vec{c}$ Translational vectors; indices of the point groups

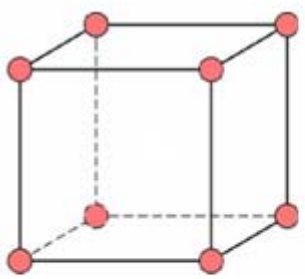


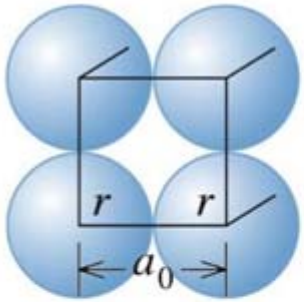
$V = \left(\vec{a} \times \vec{b}\right) \cdot \vec{c}$ unit cell volume

Bravais lattice	Parameters	Simple (P)	Volume centered (I)	Base centered (C)	Face centered (F)
Triclinic	$a_1 \neq a_2 \neq a_3$ $\alpha_{12} \neq \alpha_{23} \neq \alpha_{31}$				
Monoclinic	$a_1 \neq a_2 \neq a_3$ $\alpha_{23} = \alpha_{31} = 90°$ $\alpha_{12} \neq 90°$				
Orthorhombic	$a_1 \neq a_2 \neq a_3$ $\alpha_{12} = \alpha_{23} = \alpha_{31} = 90°$				
Tetragonal	$a_1 = a_2 \neq a_3$ $\alpha_{12} = \alpha_{23} = \alpha_{31} = 90°$				
Trigonal	$a_1 = a_2 = a_3$ $\alpha_{12} = \alpha_{23} = \alpha_{31} < 120°$				
Cubic	$a_1 = a_2 = a_3$ $\alpha_{12} = \alpha_{23} = \alpha_{31} = 90°$				
Hexagonal	$a_1 = a_2 \neq a_3$ $\alpha_{12} = 120°$ $\alpha_{23} = \alpha_{31} = 90°$				

Cubic lattice

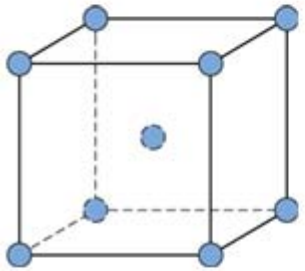
sc

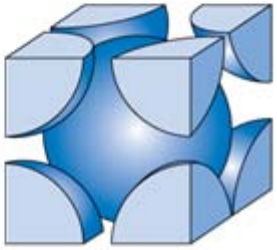


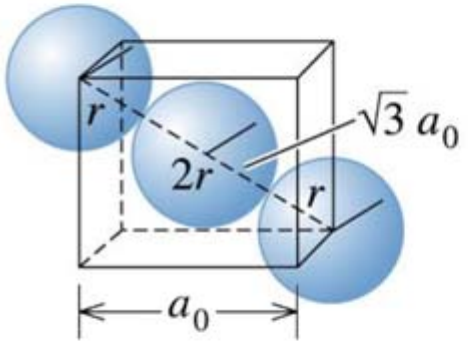


Polonium, Mn-α

bcc

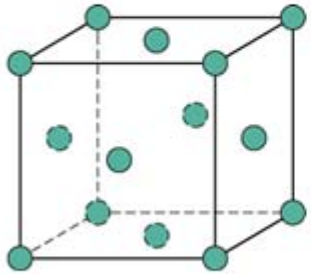


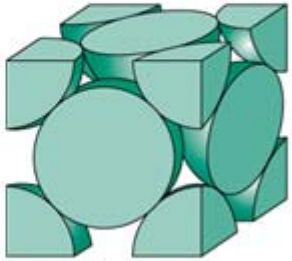


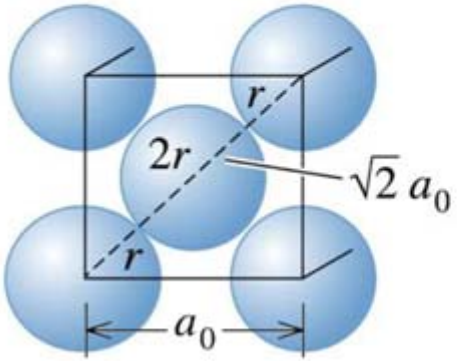


Fe-α, Ti, V, W, Cr, Mo, Nb, Ta

fcc







Fe-γ, Cu, Ni, Pb, Au, Ag, Pt,

Miller indices

Indexing of crystallographic directions
and planes
=
orientation of the unit cell in the space

1. **Indices of crystallographic directions**

   one specific direction **[uvw]**

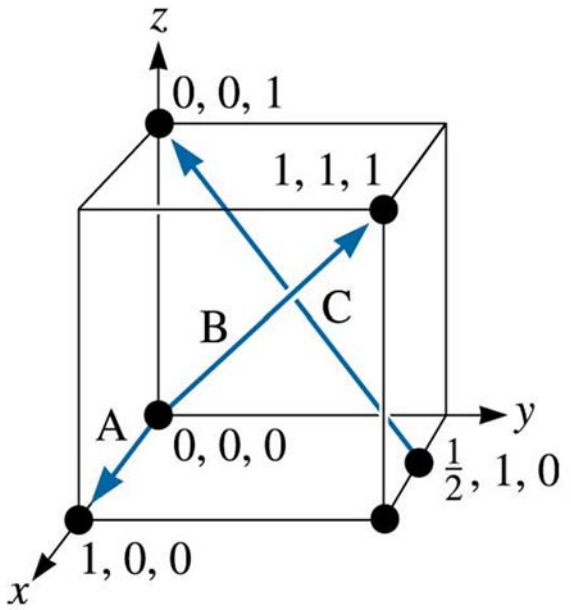
   group of directions **<uvw>**

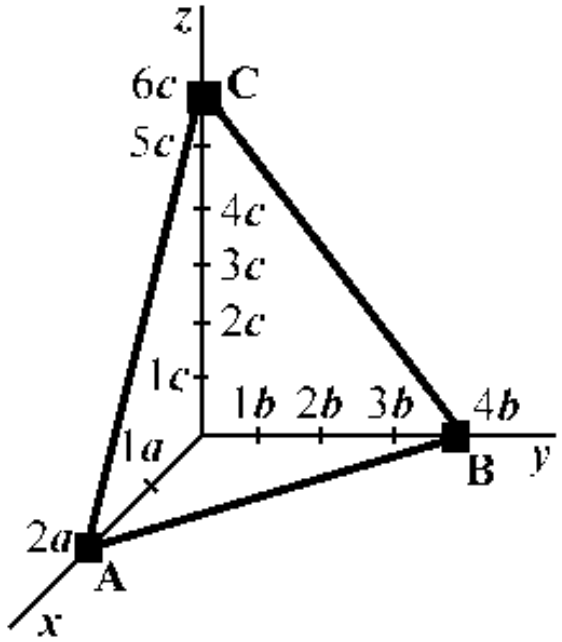
2. **Indices of crystallographic planes**

   one specific plane **(hkl)**

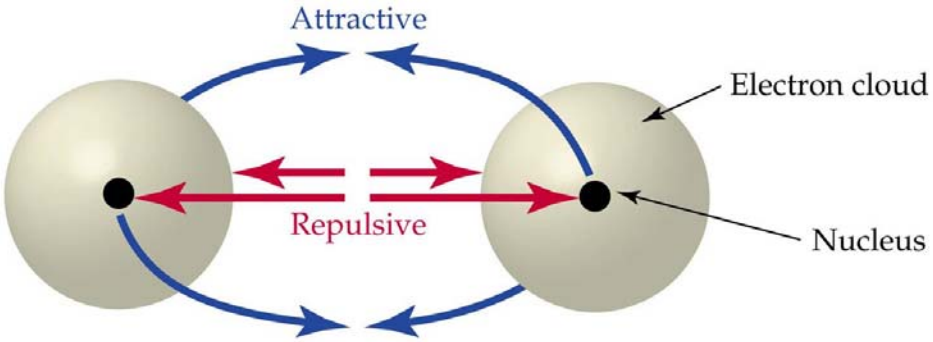
   group of planes **{hkl}**

Indexing of planes $h : k : l = \frac{1}{r} : \frac{1}{s} : \frac{1}{t}$



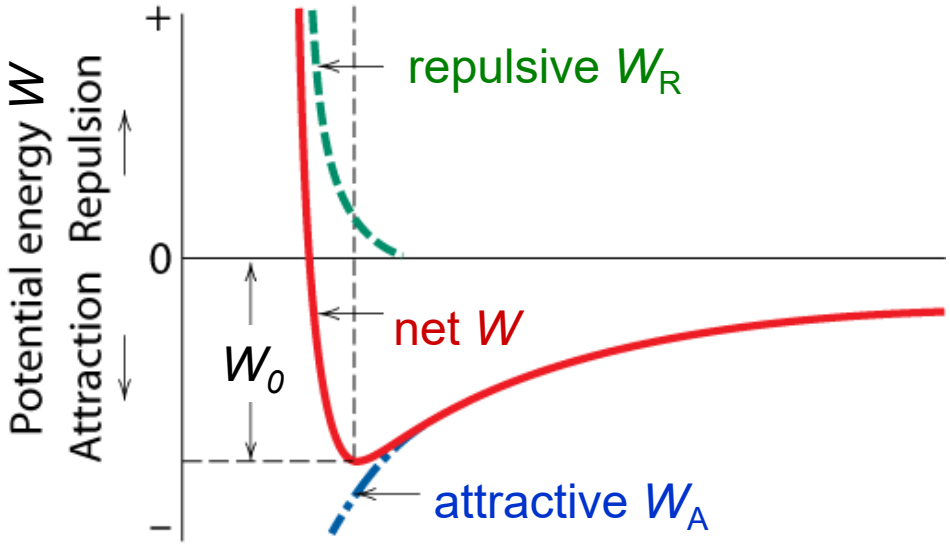


Bonding in the solid matter



$$\vec{F} = -\text{grad}\, W = -\frac{dW}{dr}\frac{\vec{r}}{|\vec{r}|}$$

$$\frac{dW}{dr} = 0 \Rightarrow R_0$$



for two atoms

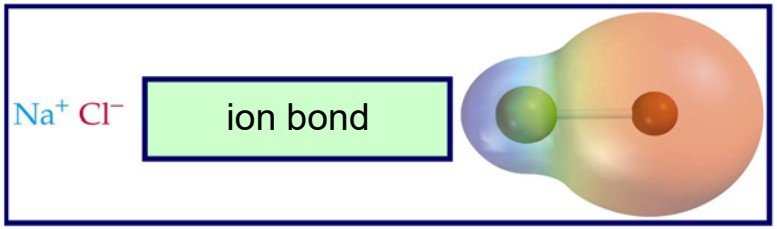
$$W(r) = \frac{A}{r^m} - \frac{B}{r^n}$$

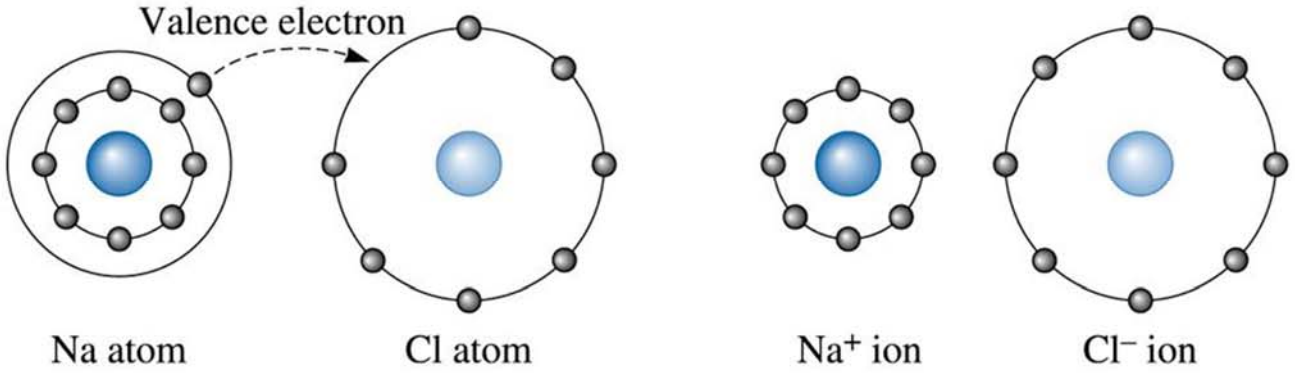
ion
covalent
metallic
Van der Waals

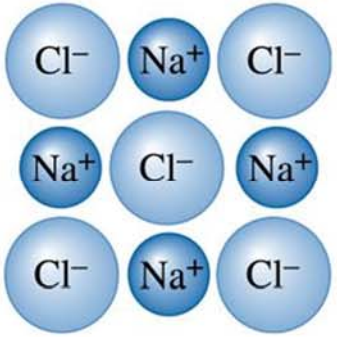
Ion bond

ionization; electrostatic force

Bonding energy $1{,}6 \cdot 10^{-18}$ J ·atom^{-1}

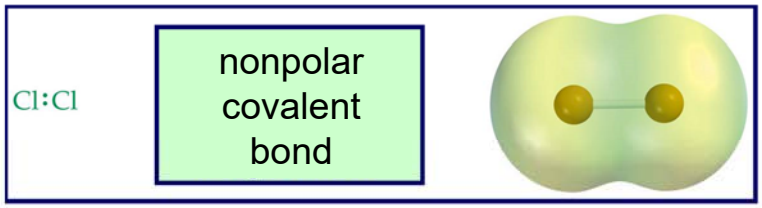


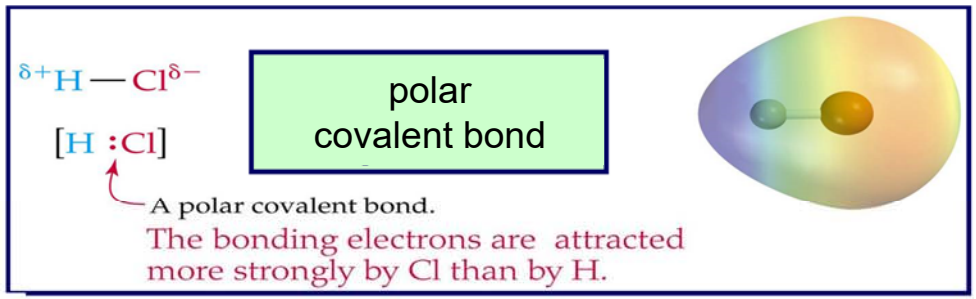


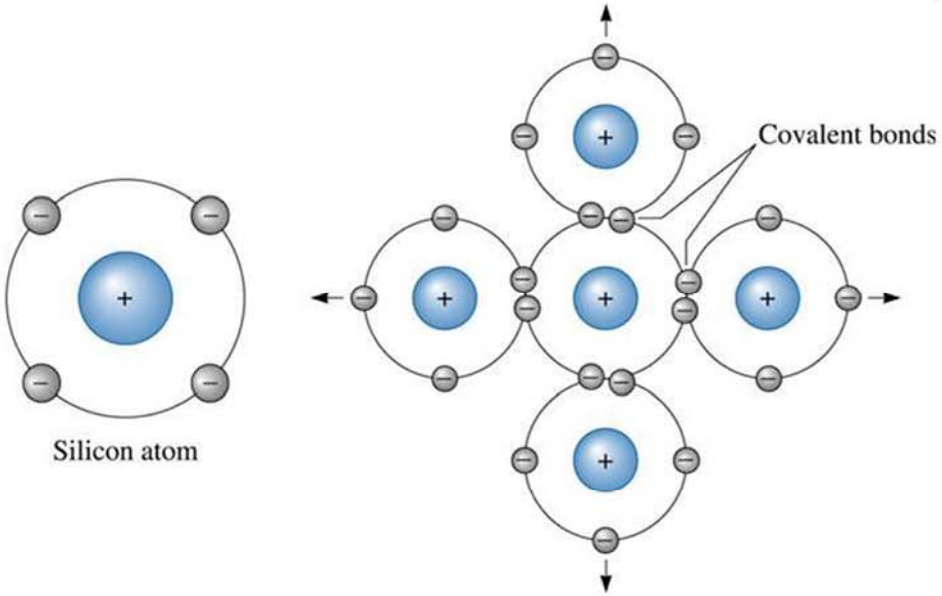


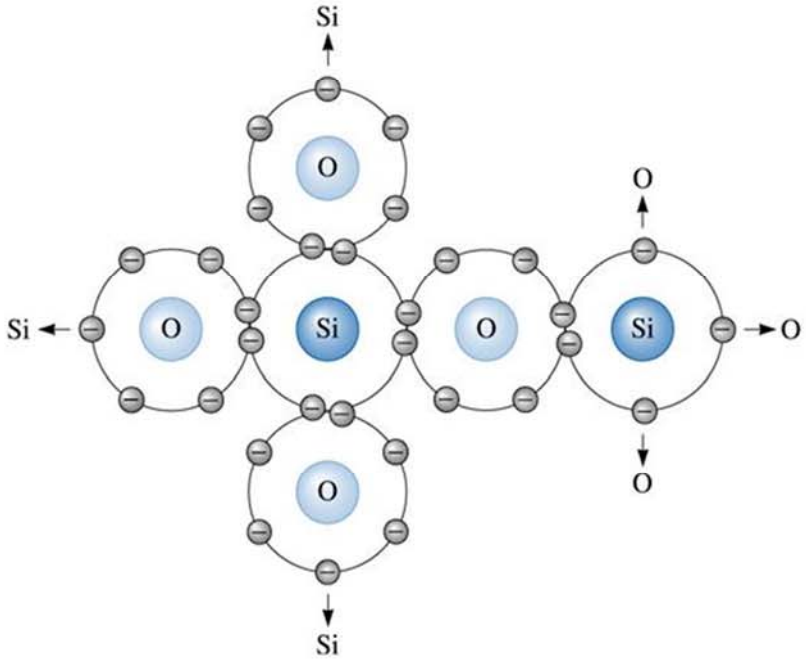
Covalent bond

$(5 – 8)\cdot10^{-19}$ J·atom^{-1}









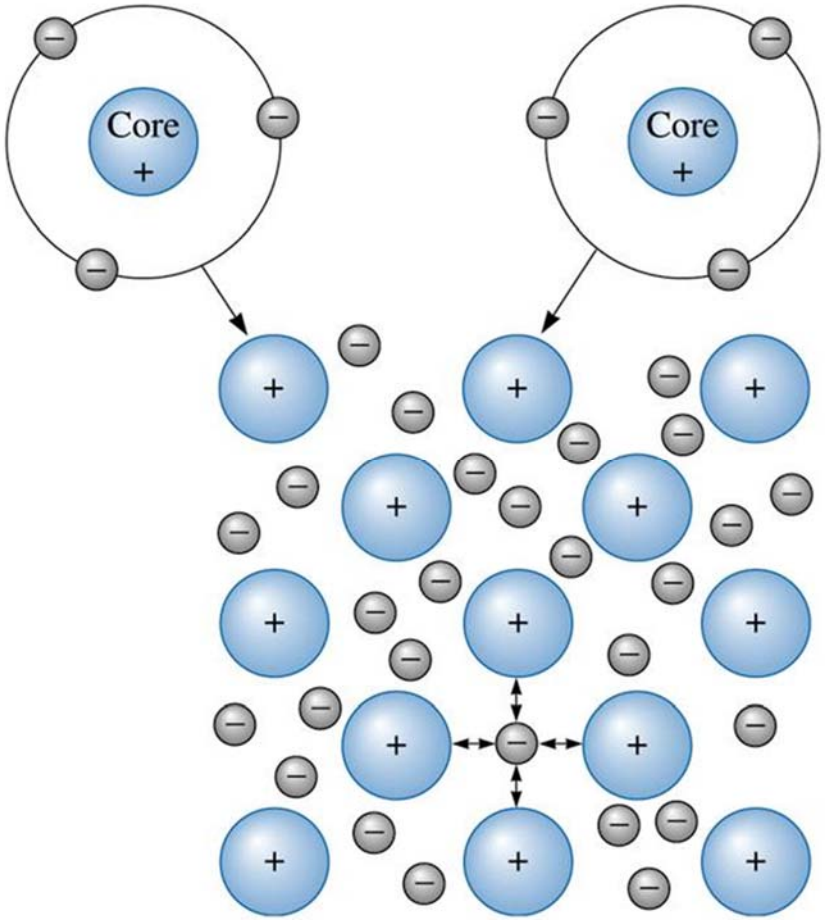
C -$1s^2 2s^2 2p^2$

sharing of electrons to form electron pairs

diamond

Metallic bond

$(1{,}6 – 8)\cdot 10^{-19}$ J ·atom^{-1}



electron cloud = free floating electrons

I. – III. column of the periodic table

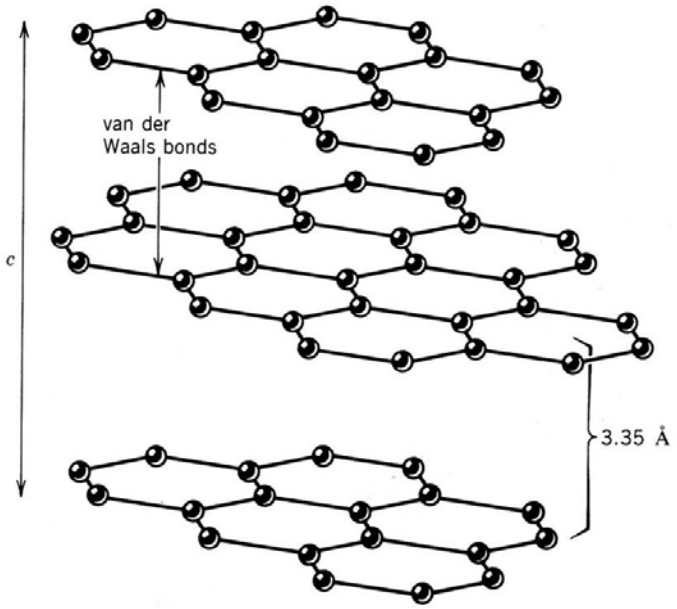
no preference in direction

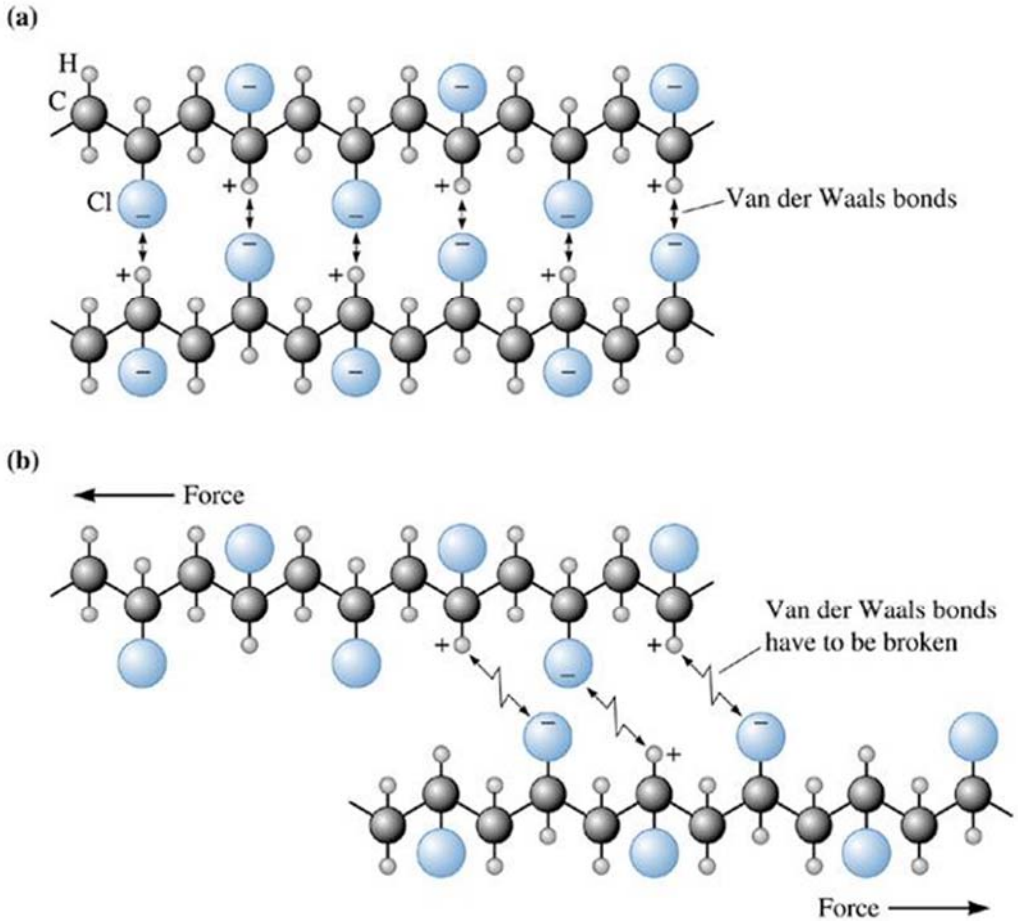
=

solubility and compound formation

Van der Waals force

$1{,}6 \cdot 10^{-20}$ J ·atom^{-1} dipole moment – el. field formation $F \approx \frac{1}{r^7}$



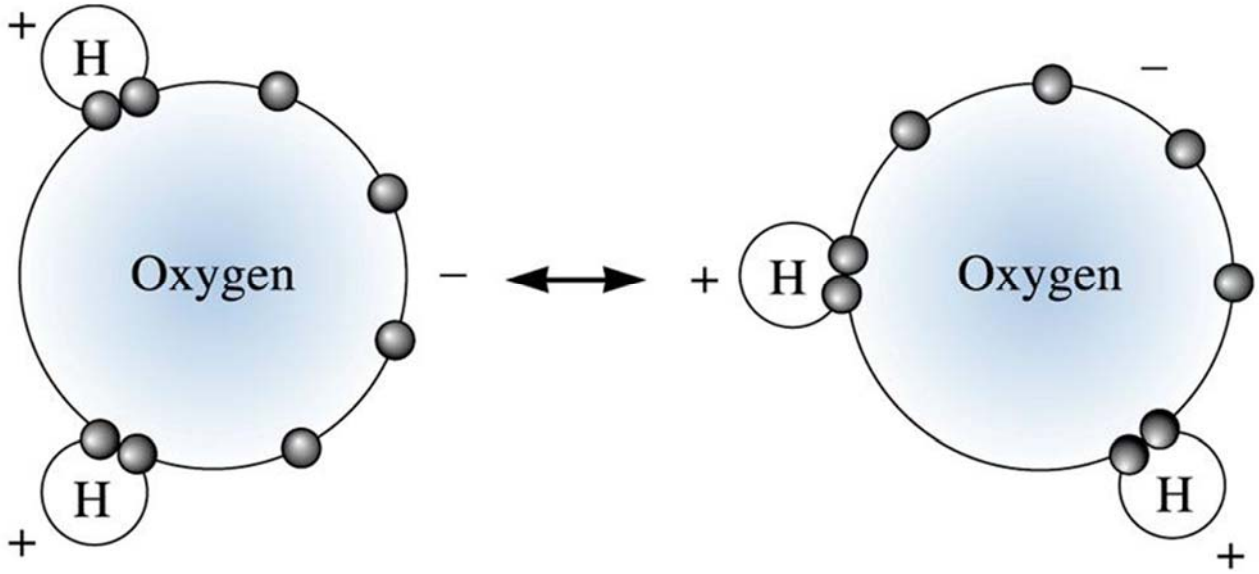


Inert gases crystals
graphite

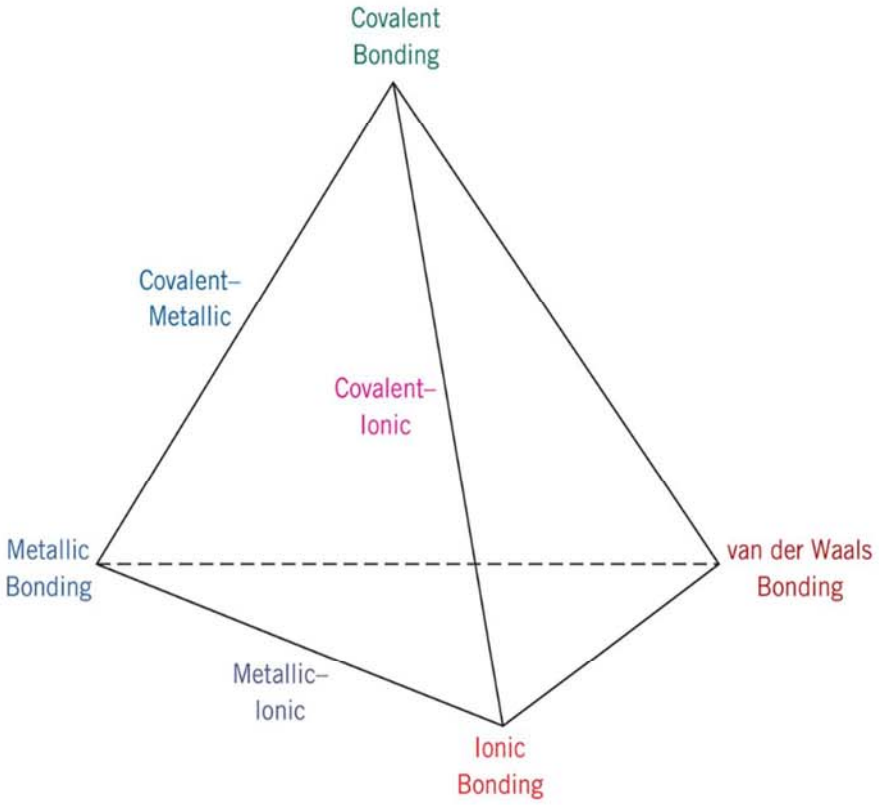
Hydrogen bridge bonds

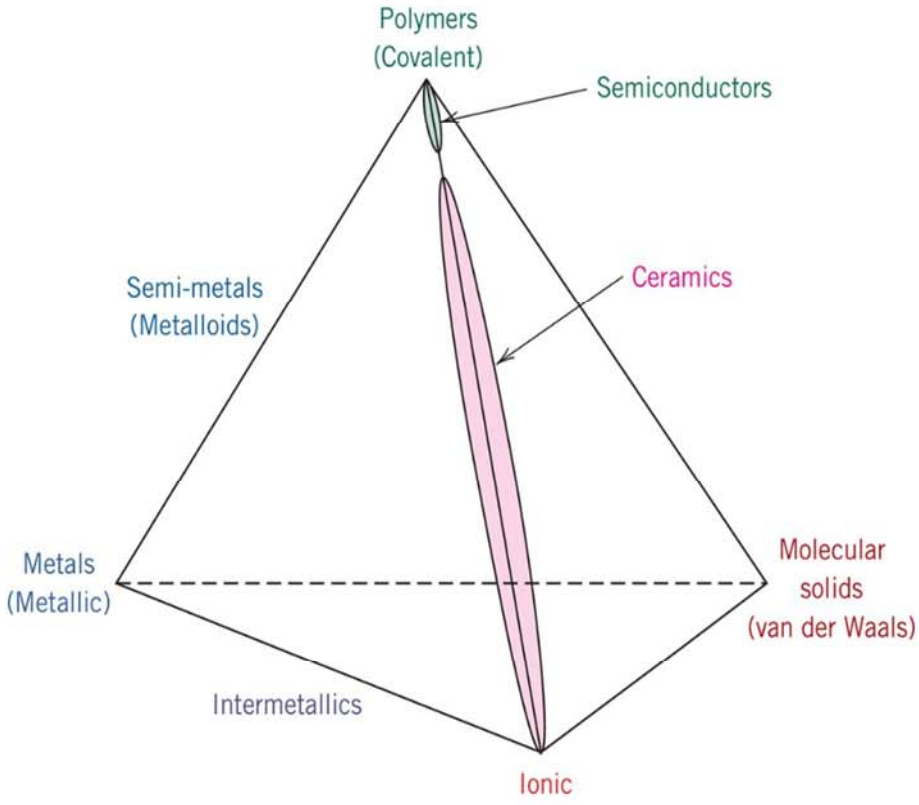
0,1 eV/atom = $1{,}6 \cdot 10^{-20}$ J ·atom^{-1}

H_2O molecules



Mixed bonds - classification





Conductivity of solids

resistivity ρ

temperature coefficient of conductivity α

density of charge carriers n

insulators = very high resistivity

semiconductors = low density of carriers

negative coefficient of conductivity

metals = positive coefficient of conductivity

Energy levels in crystalline solids

HRW: Ch41

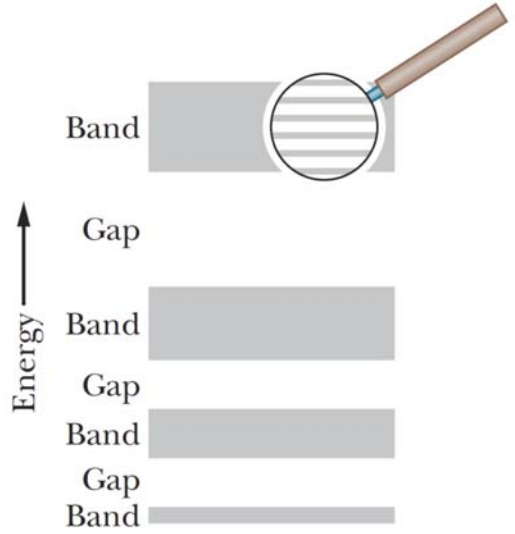
single-atom subshell – max. $2(2l+1)$ of electrons

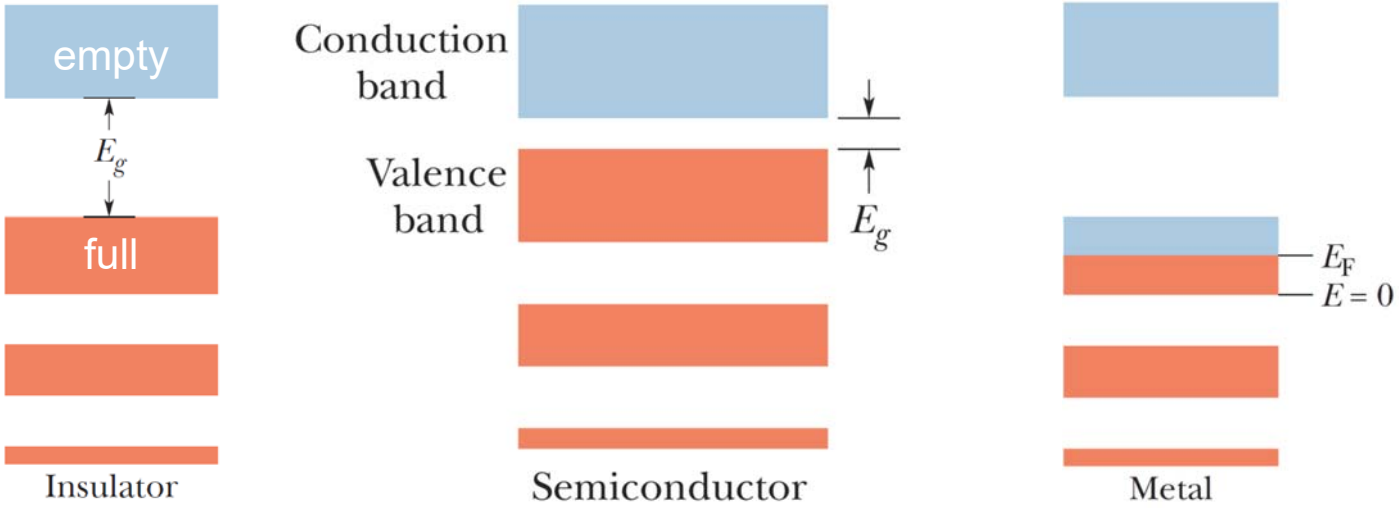
two-atom system ≠ **two** independent atoms

energy levels will separate **into 2 levels**

lattice - energy levels will form **bands and gaps**

bands – allowed levels of energy (few eV)
gaps – forbidden levels of energy

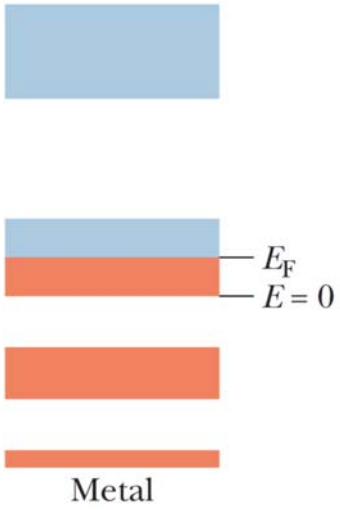


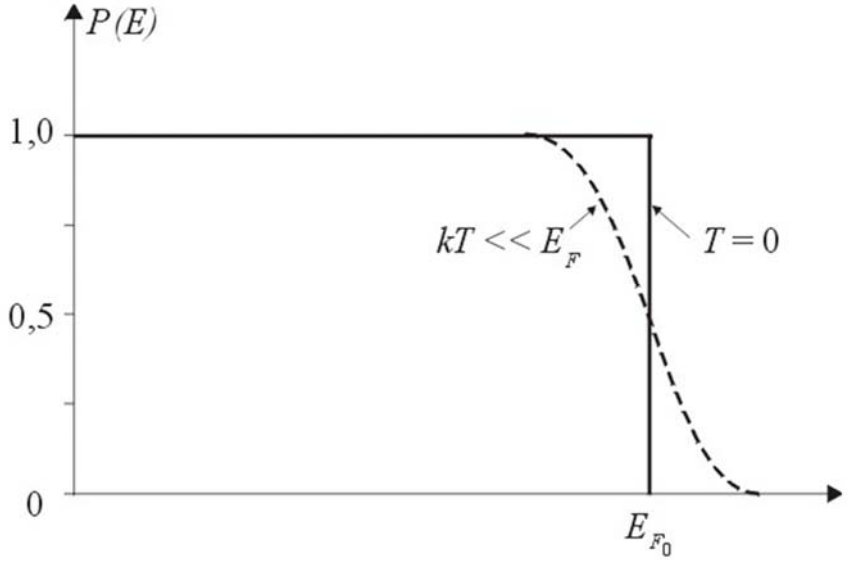


Metals

Fermi level

Fermi energy



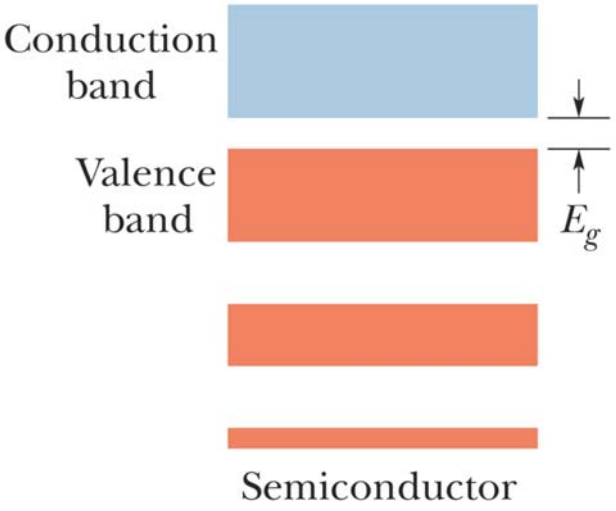


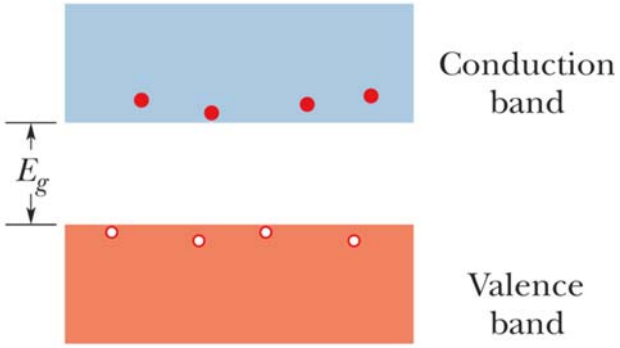
Fermi-Dirac statistics

$$P(E) = \frac{1}{e^{(E-E_F)/kT} + 1}$$

The Fermi energy of a given material is the energy of a quantum state that has the probability 0.5 of being occupied by an electron.

Semiconductors

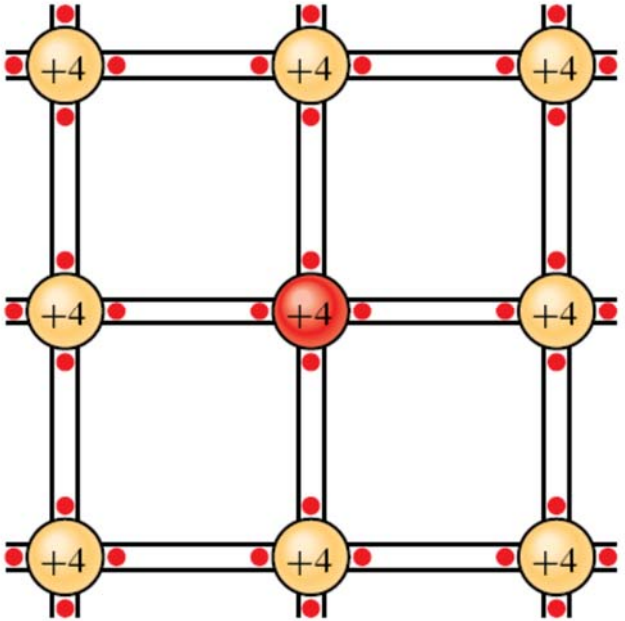




electrons and holes

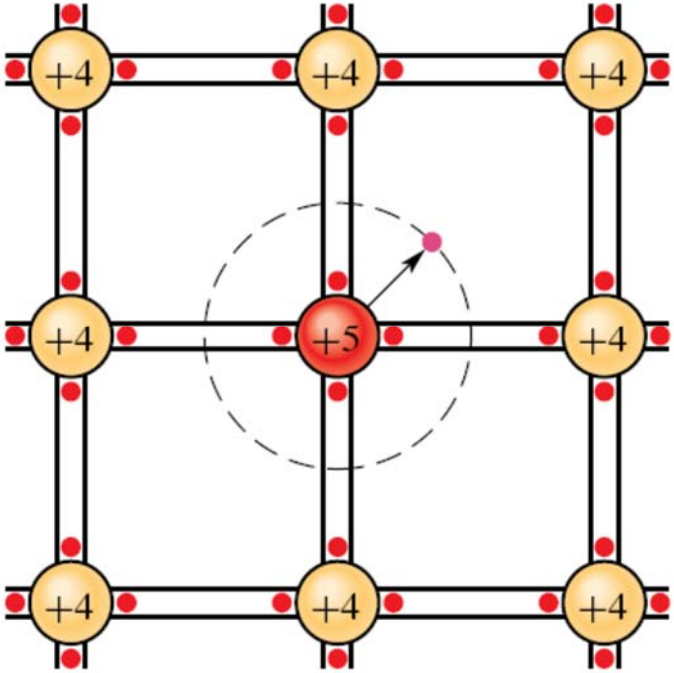
Types of semiconductors

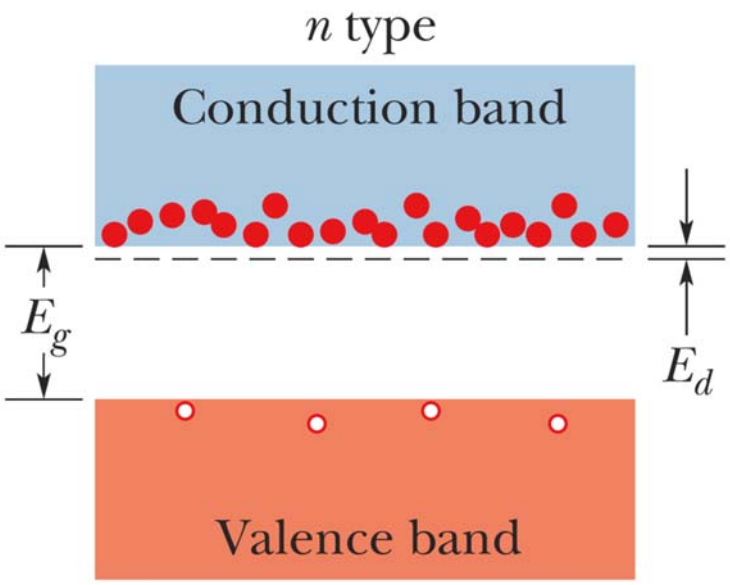
- intrinsic (pure)
- doped: n-type, p-type



Doped semiconductors

Si + P = 1 extra electron in valence band (P is a **"donor"**)

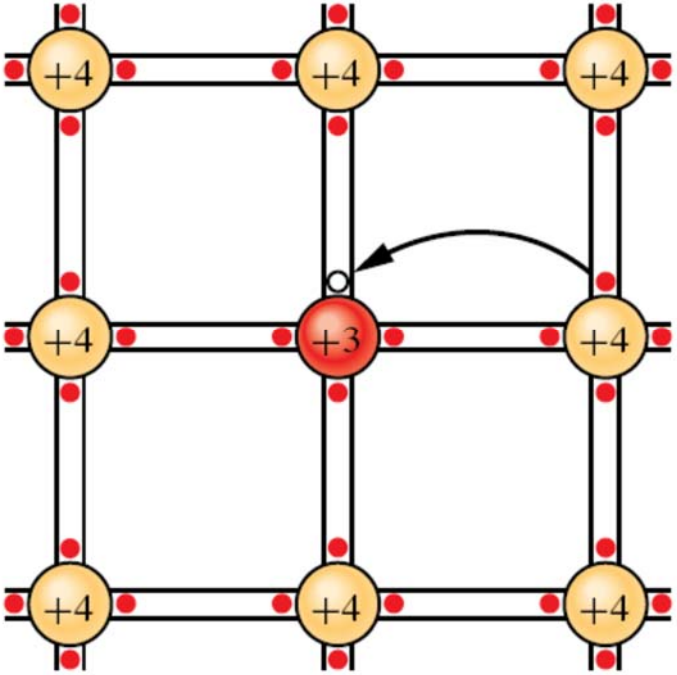


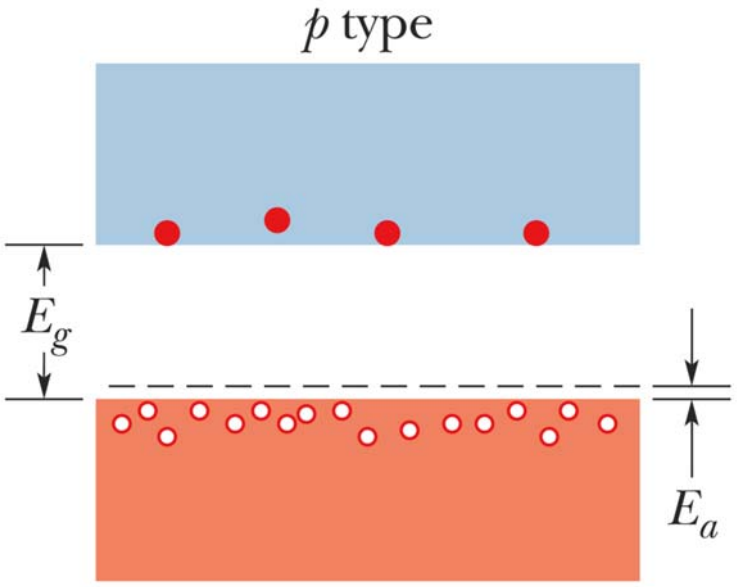


n-type semiconductor

Doped semiconductors

Si + Al = 1 electron in valence band missing (Al is an **"acceptor"**)

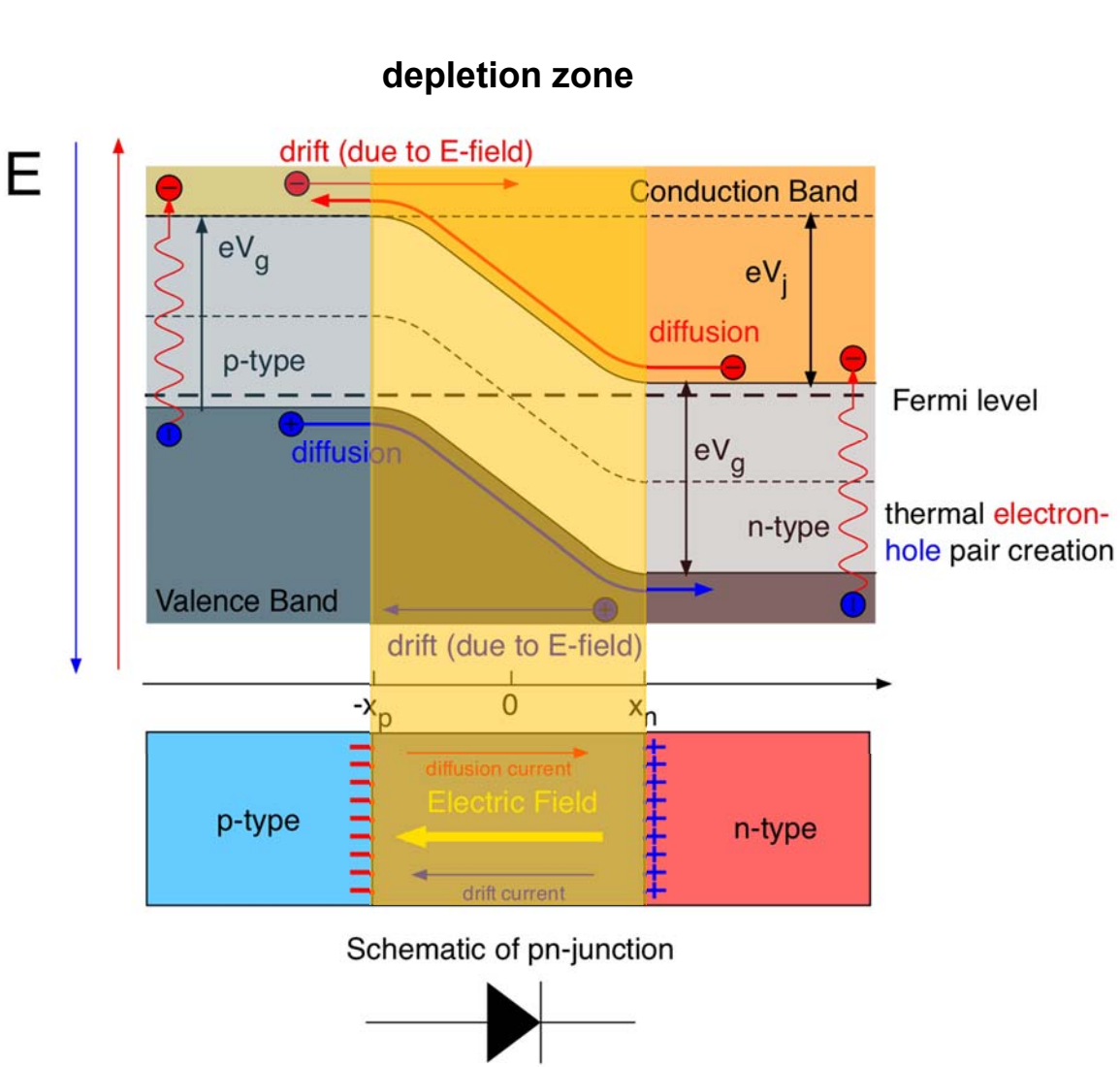


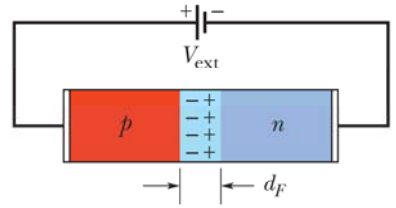


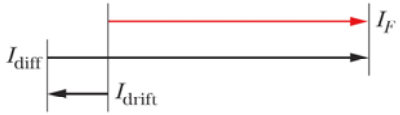
p-type semiconductor

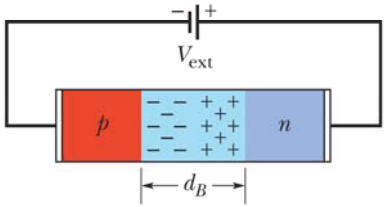
HRW: Ch41

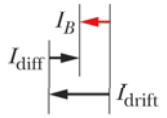
p-n junction

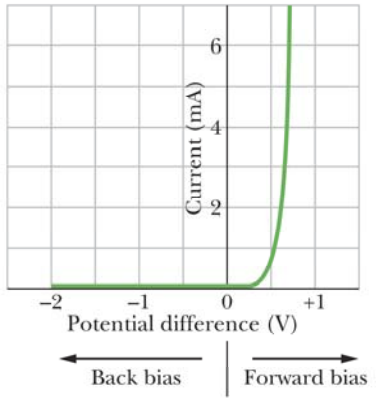










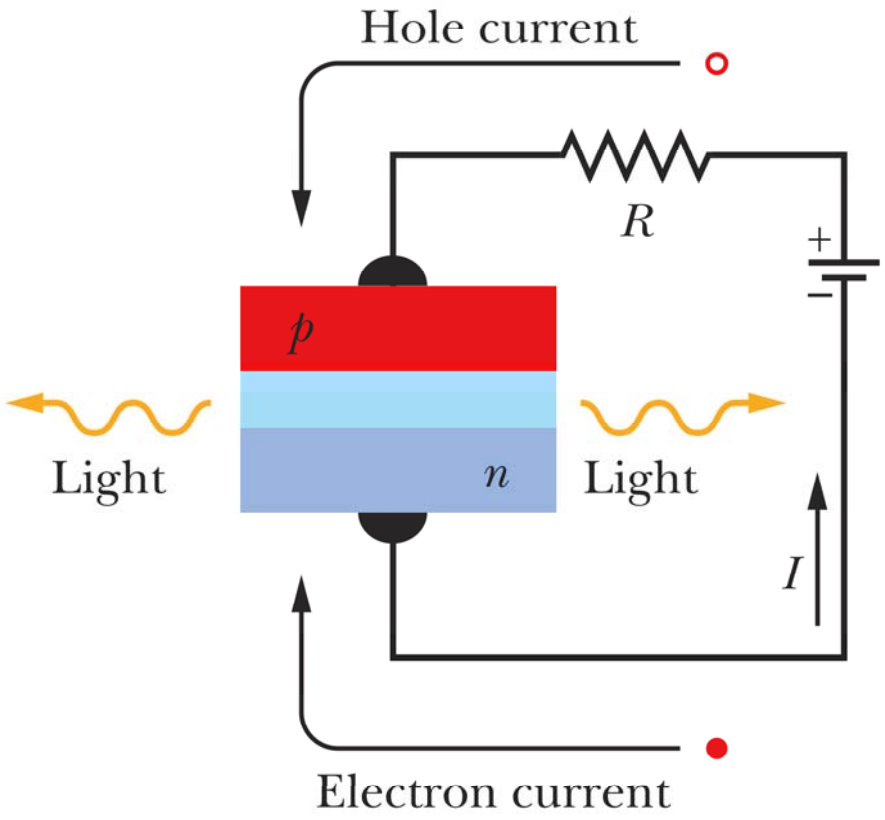


Light-Emitting-Diode (LED)

p–*n* junction, forward bias

electron-hole pairs recombination in narrow depletion zone

$$\frac{hc}{\lambda} = E_g \Rightarrow \lambda = \frac{hc}{E_g}$$



Photodiode, junction laser