

The Theory of Solid



Agenda today

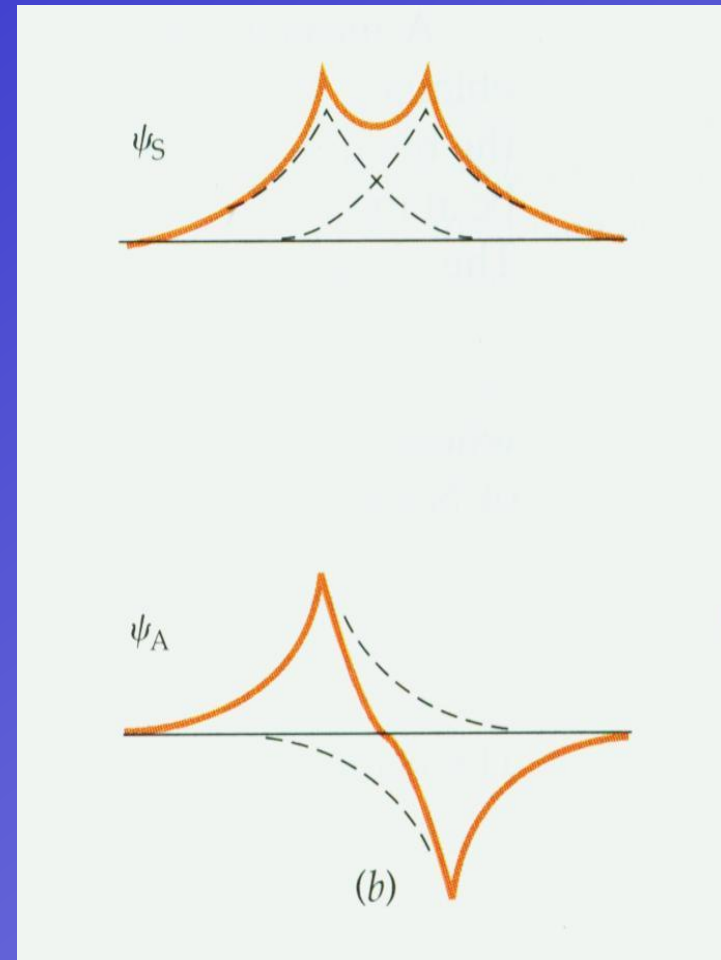
1. The behavior of electron in solid and molecules
2. Band theory
3. Conductor, Insulator, Semiconductor
4. Diodes and transistors

Chemical bond

1. Ionic bond

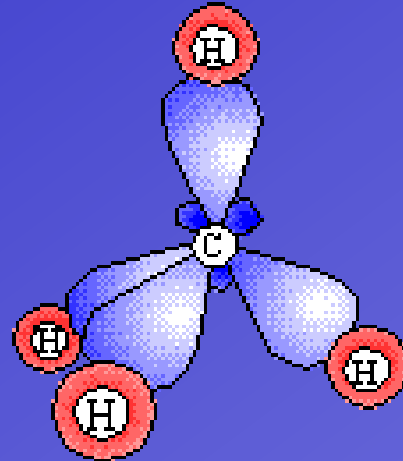
2. Covalent bond

Molecular orbit



Bonding orbit and anti-bonding orbit

hybridization

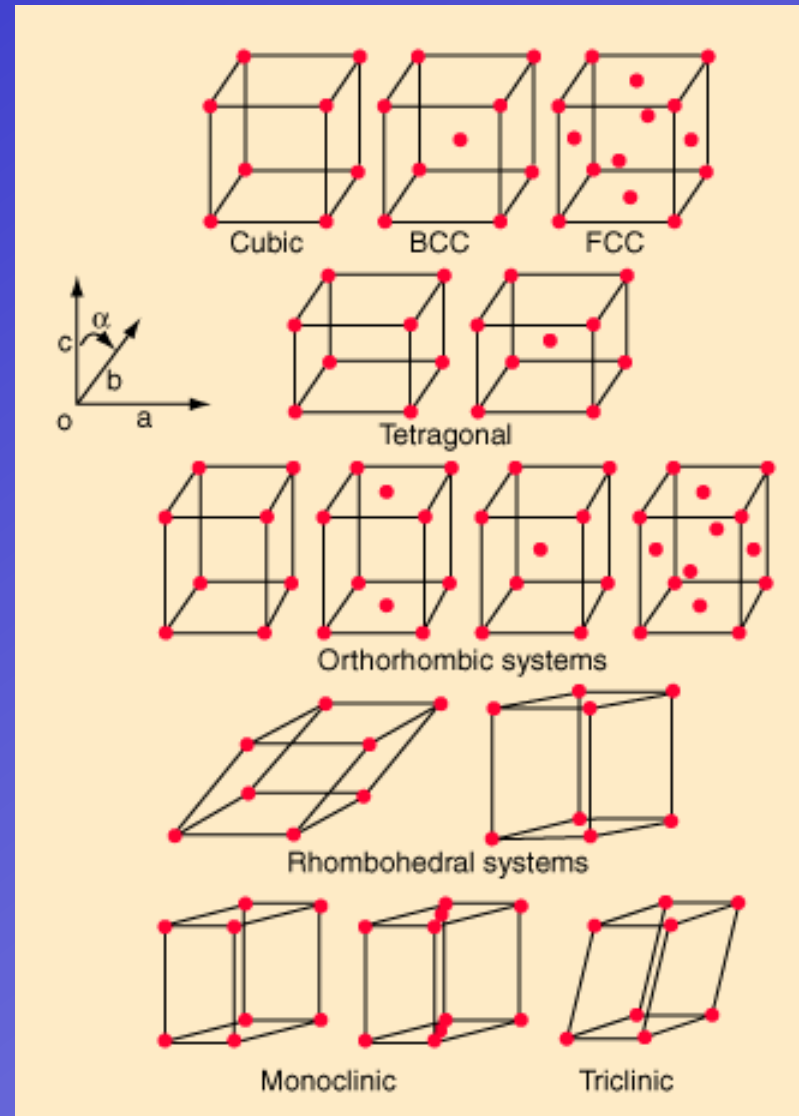


Metallic bond

Hydrogen bond

Van der Waals bond

Crystal lattice

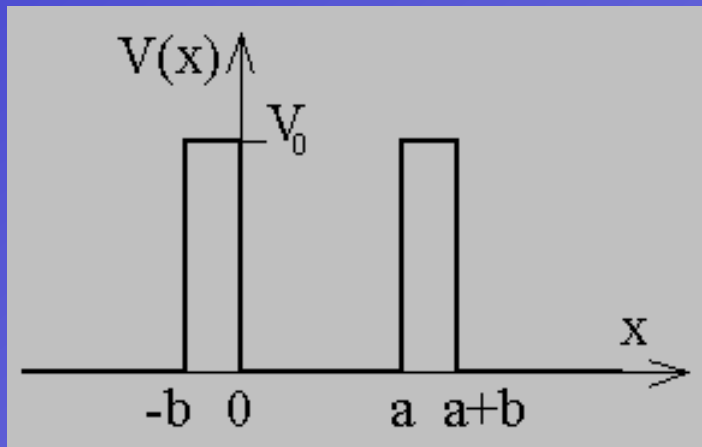


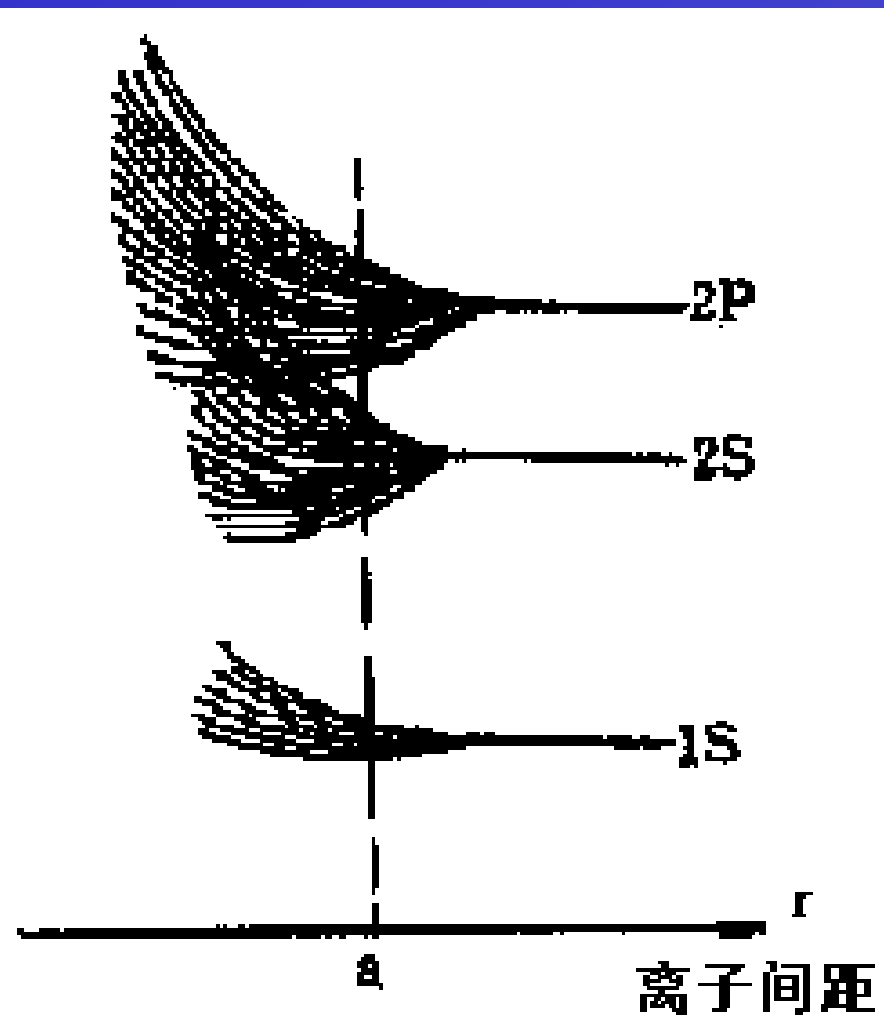
Electron wave in periodic potential

Bloch wave

$$\Psi_k(r) = u_k(r) \exp(iK \cdot r)$$

Kronig-Penney model



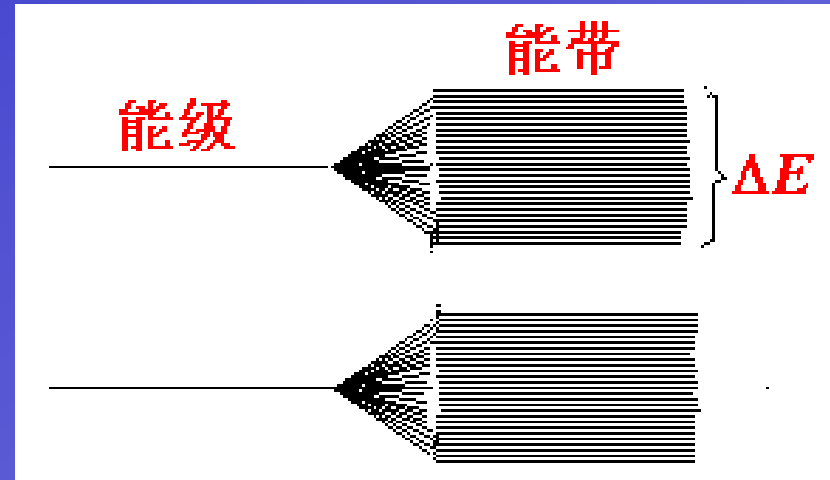


能带重叠示意图

Figure 1. Energy band overlap diagram.

Band (能带) theory:

Energy levels split up when atoms interact with each other.



The higher the energy level is, the wider is the energy band.

The smaller the distance between atoms is, the wider the energy band

Conduction band, forbidden band, valence band
导带，禁带，价带

Bands unfilled or half-filled are called conduction band.

The energy gaps between bands are called
forbidden band

The highest filled bands are called valence band.

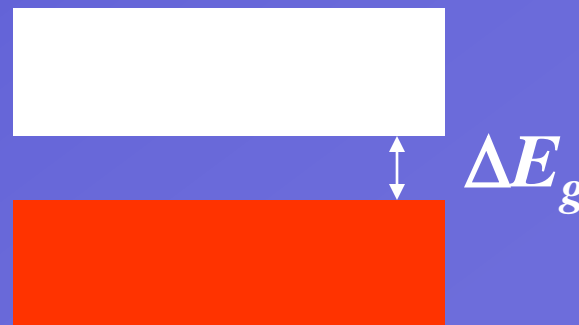
conductor



insulator

ΔE_g

semiconductor



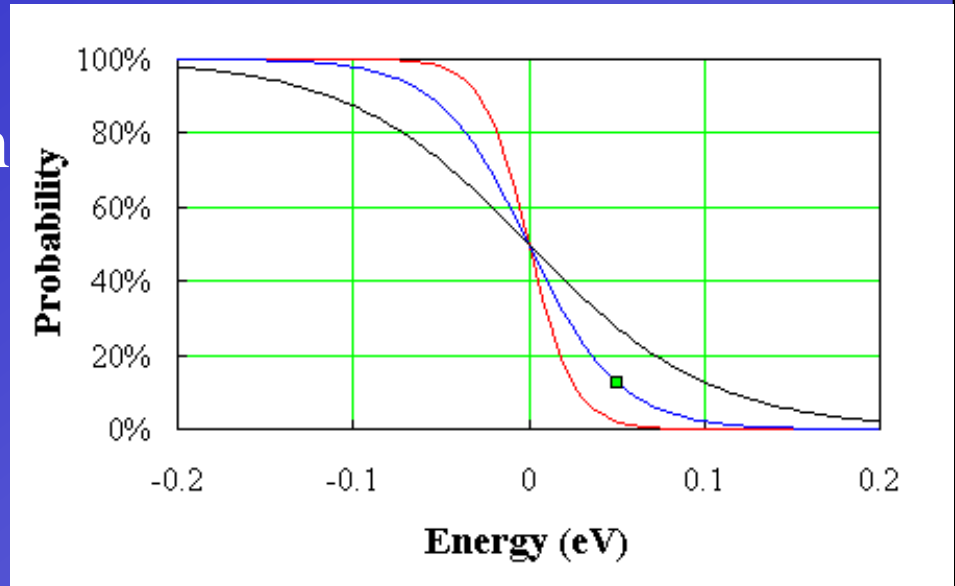
Occupancy probability $P(E)$

Bose-Einstein distribution

$$\langle n \rangle = \frac{1}{\exp(\hbar\omega / kT) - 1}$$

Fermi-dirac distribution

$$\langle n \rangle = \frac{1}{e^{(E-u)/k_B T} + 1}$$



For Metal

Fermi energy

$$N = \frac{V}{3\pi^2} k_F^3$$

$$E_F = \frac{\hbar^2 k_F^2}{2m} = \frac{\hbar^2}{2m} \left(\frac{3\pi^2 N}{V} \right)^{2/3} = \frac{0.121 \hbar^2}{m} n^{2/3}$$

Density of states(DOS)

Number of orbital per unit energy

For metal

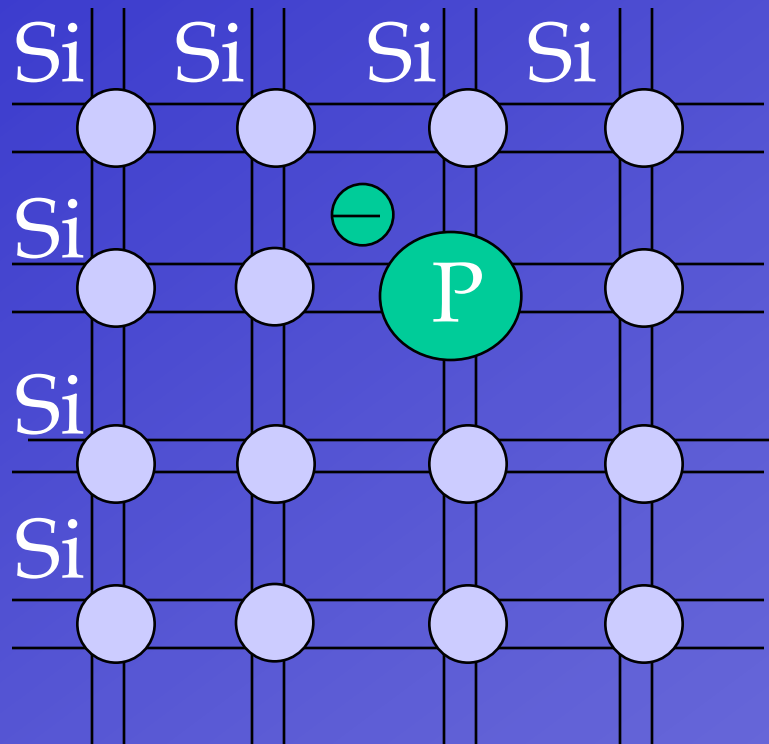
$$N(E) = \frac{8\sqrt{2}\pi m^{3/2}}{h^3} E^{1/2}$$

Density of occupied states

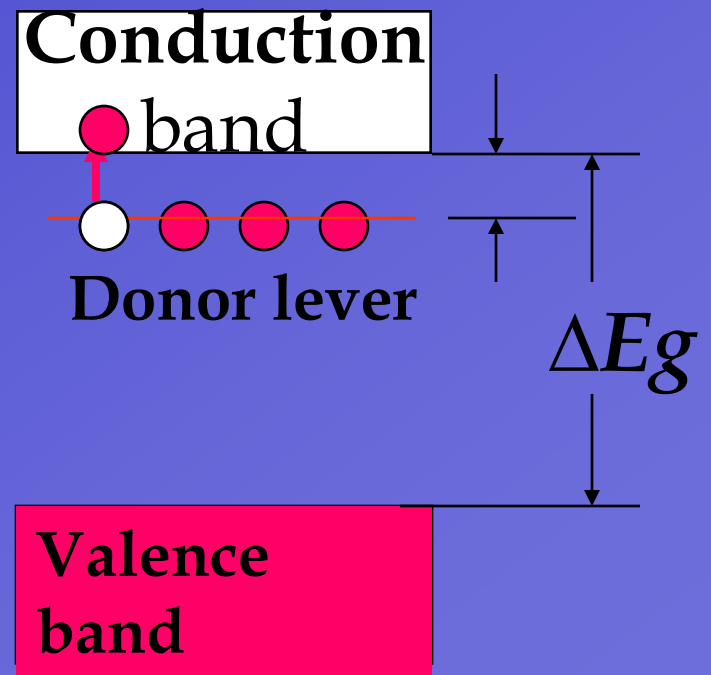
$$N_o(E) = P(E) * N(E)$$

Doping (掺杂)

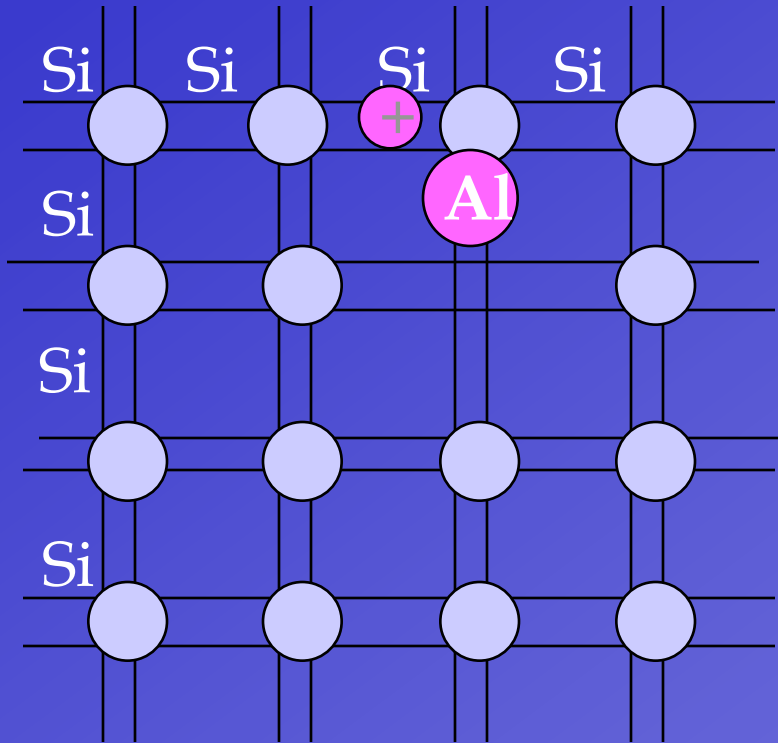
n-type semiconductor



Current carrier : electron

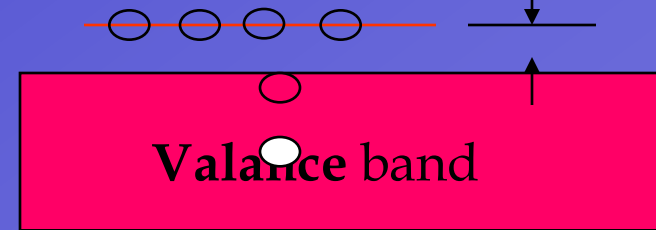


P-type semiconductor



Conduction band

Acceptor level

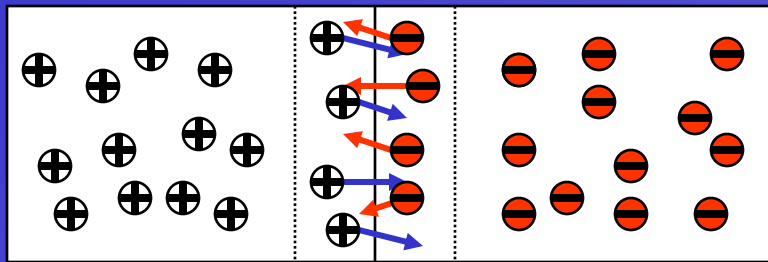


The current carrier : hole

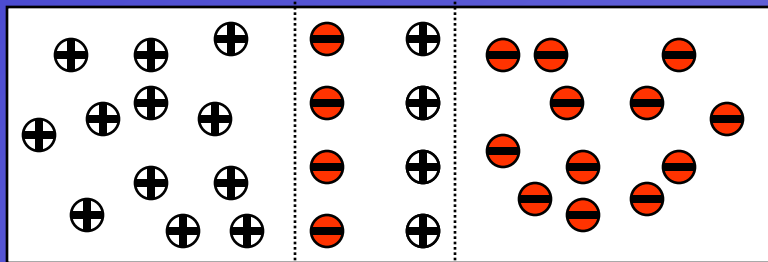
P-N junction

P type

N type

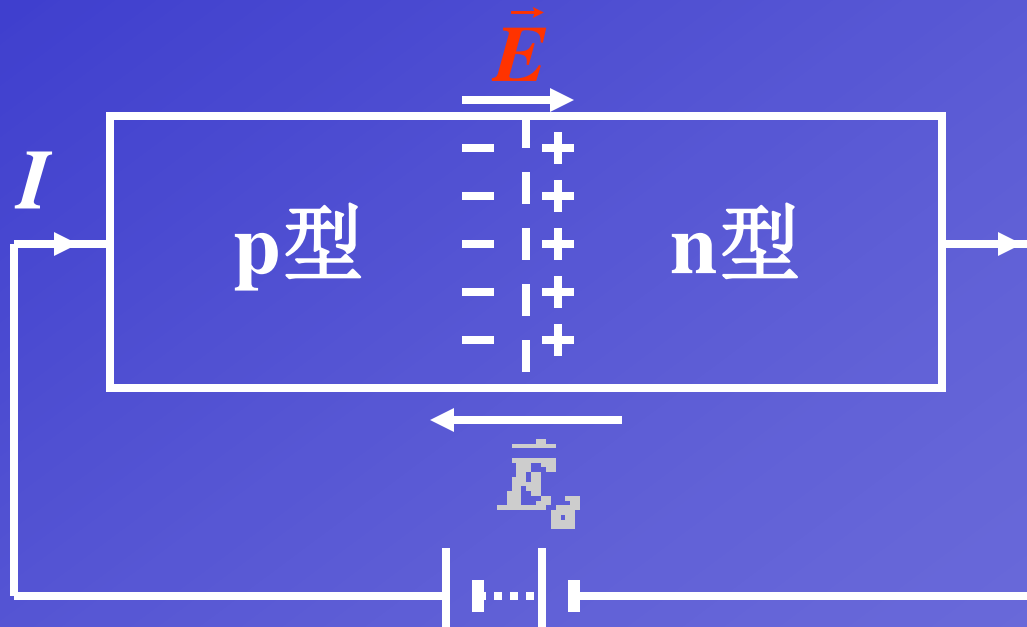


Depletion zone

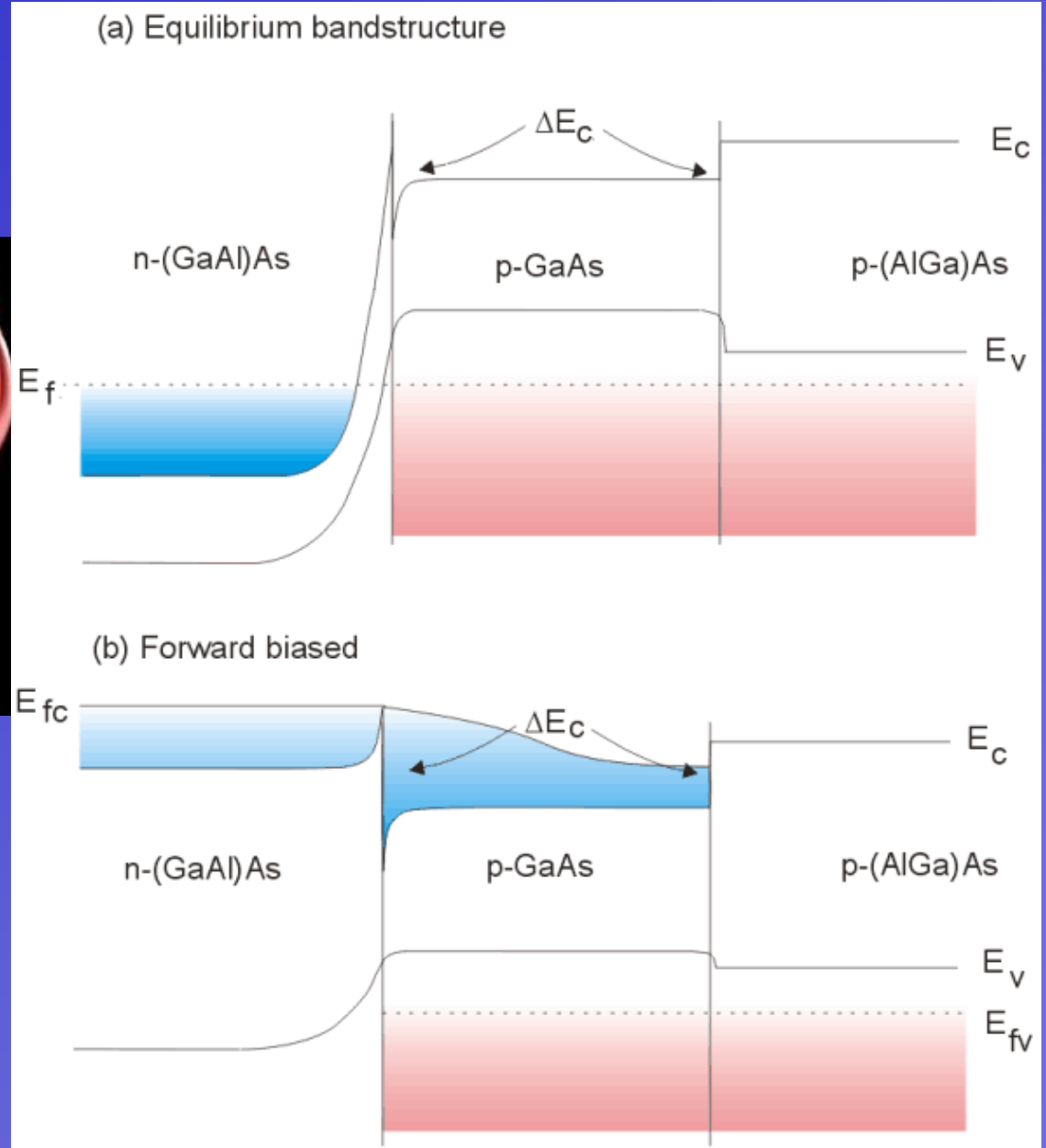
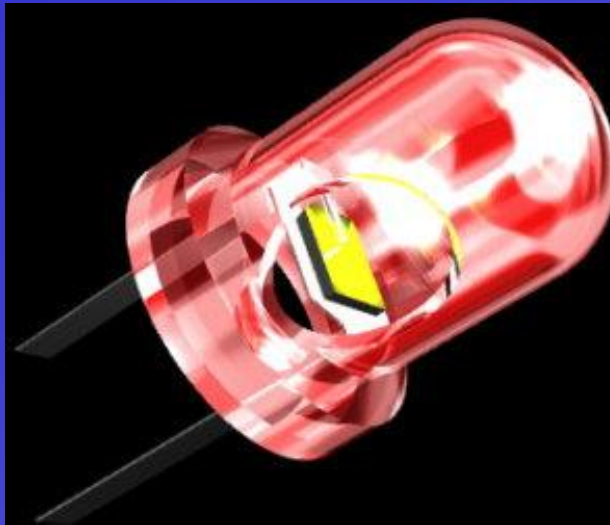


P-N junction

The principle of diode



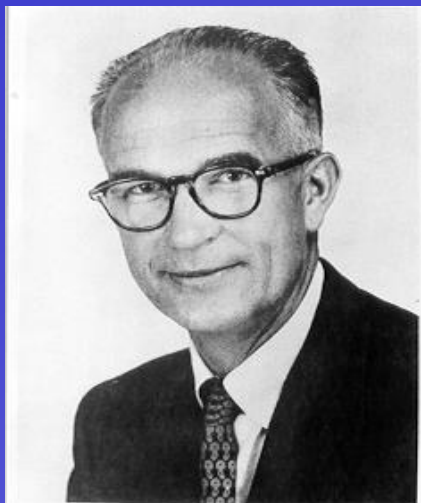
Light-emit diode





John Bardeen

Bardeen



W = Shockley

Shockley



Walter H. Brattain

Brattain

The invention of transistor