

# The Theory of Solid



# Agenda today

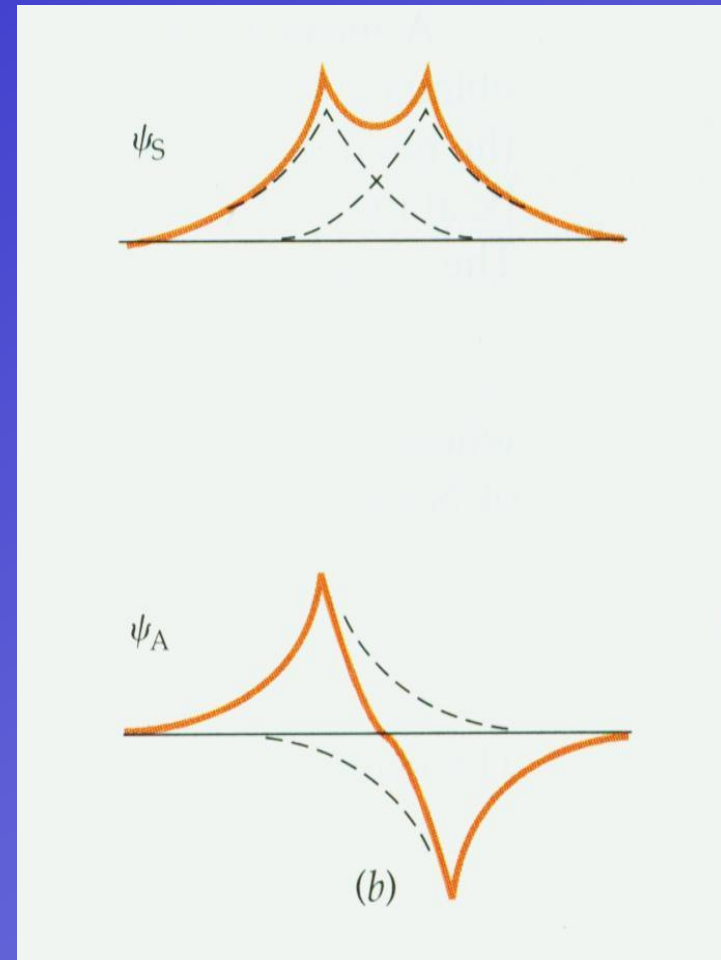
1. The behavior of electron in solid and molecules
2. Band theory
3. Conductor, Insulator, Semiconductor
4. Diodes and transistors

# Chemical bond

1. Ionic bond

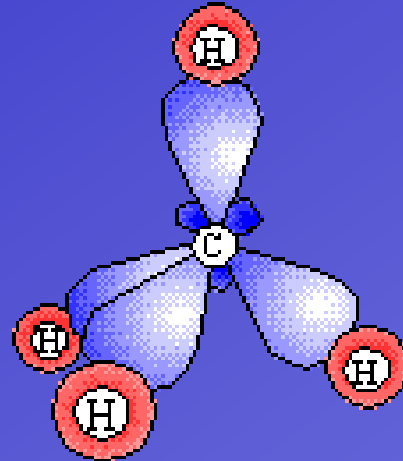
2. Covalent bond

Molecular orbit



Bonding orbit and anti-bonding orbit

hybridization

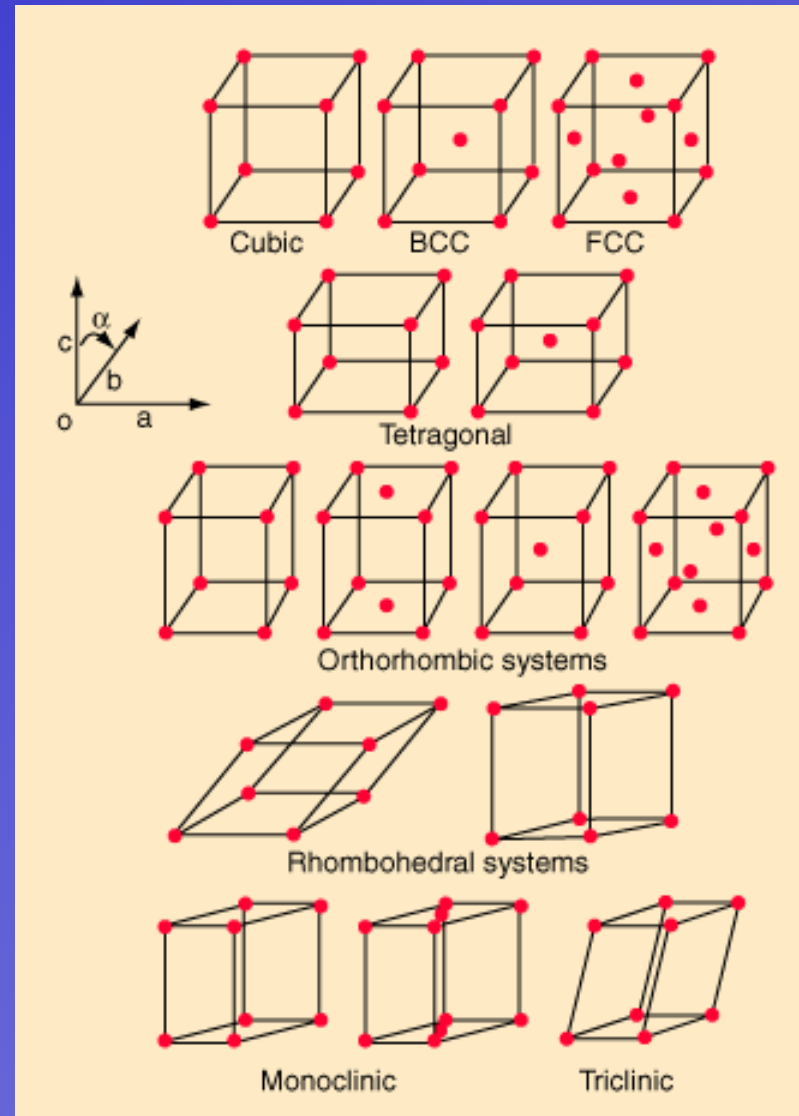


Metallic bond

Hydrogen bond

Van der Waals bond

# Crystal lattice

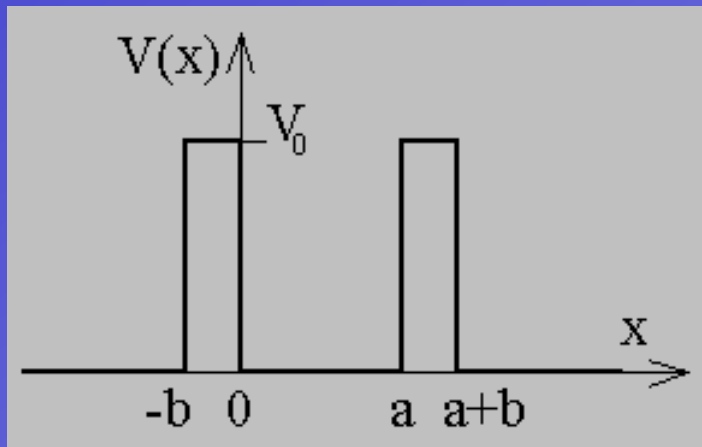


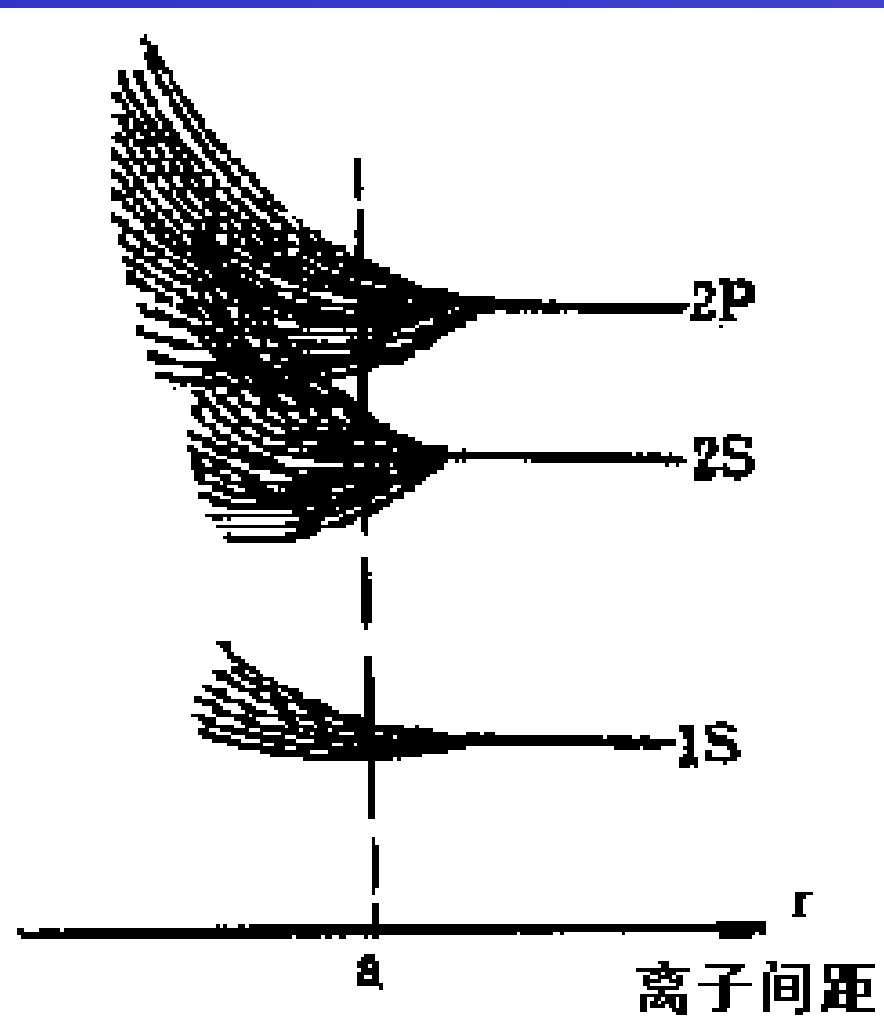
# Electron wave in periodic potential

Bloch wave

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

Kronig-Penney model



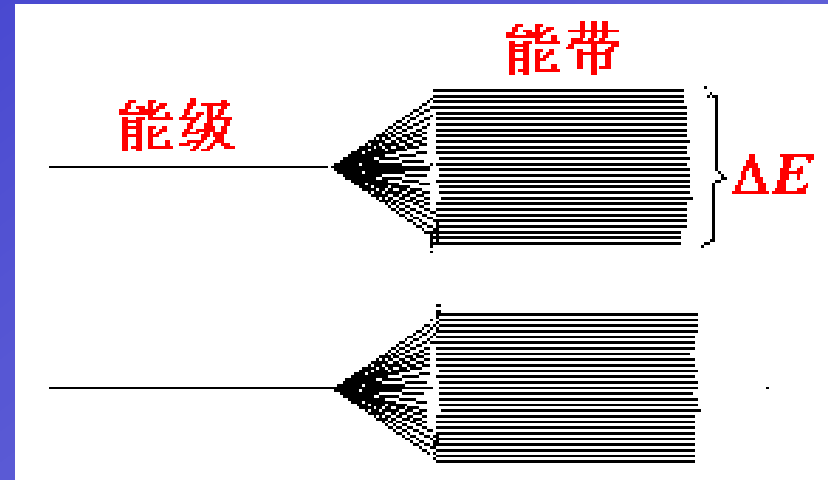


能带重叠示意图

1. 能带重叠示意图

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.

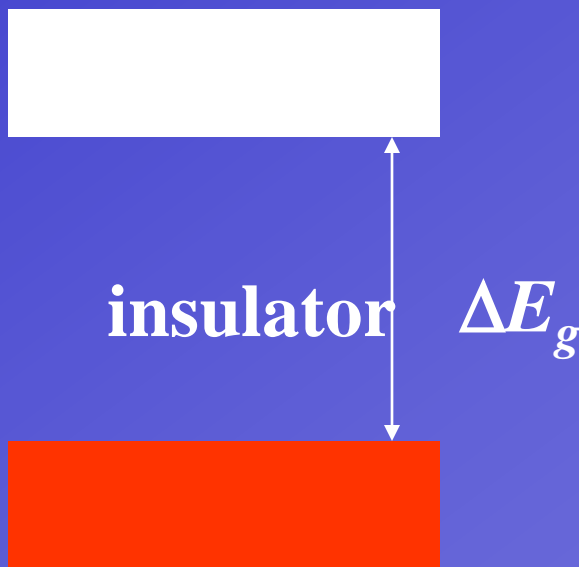
The energy gaps between bands are called  
forbidden band

The highest filled bands are called valence band.

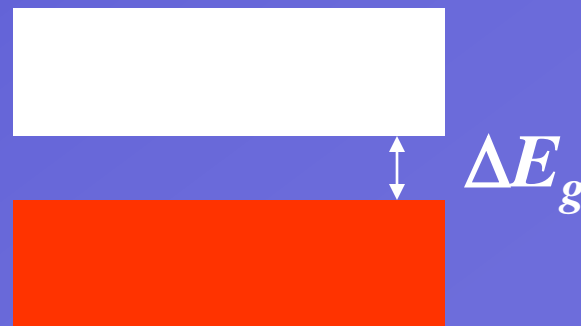
**conductor**



**insulator**



**semiconductor**



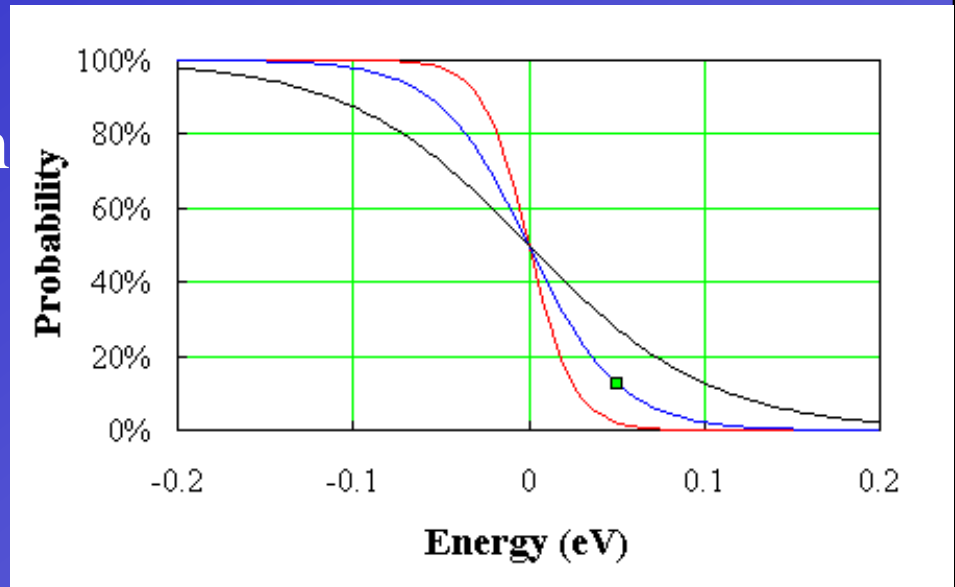
Occupancy probability  $P(E)$

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

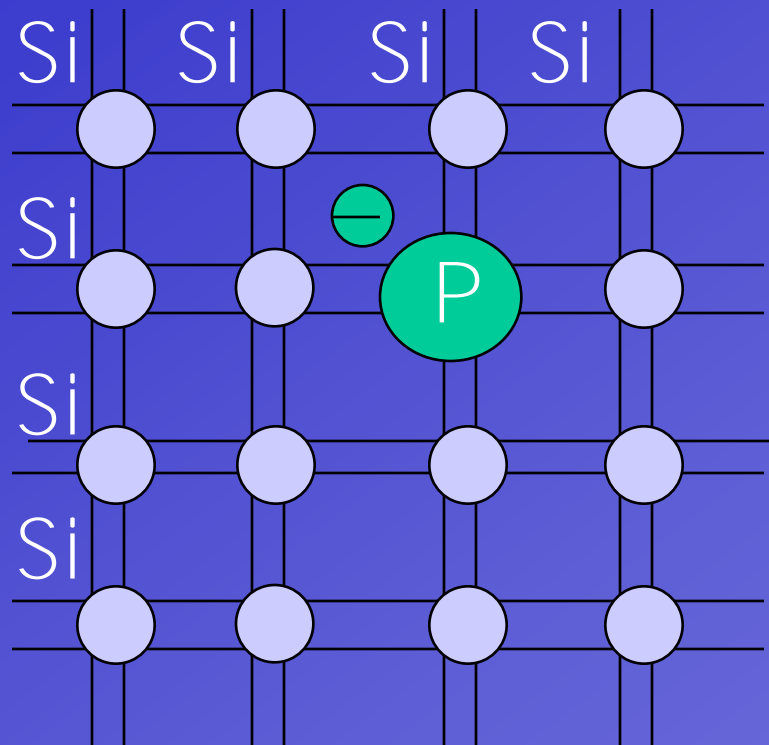
$$N(E) = \frac{8\sqrt{2}\pi m^{3/2}}{h^3} E^{1/2}$$

# Density of occupied states

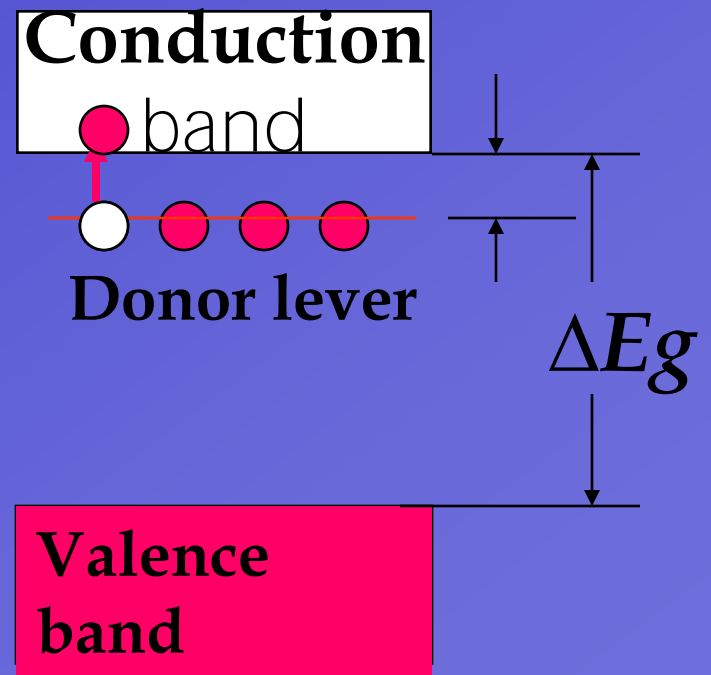
$$N_o(E) = P(E) * N(E)$$

# Doping (掺杂)

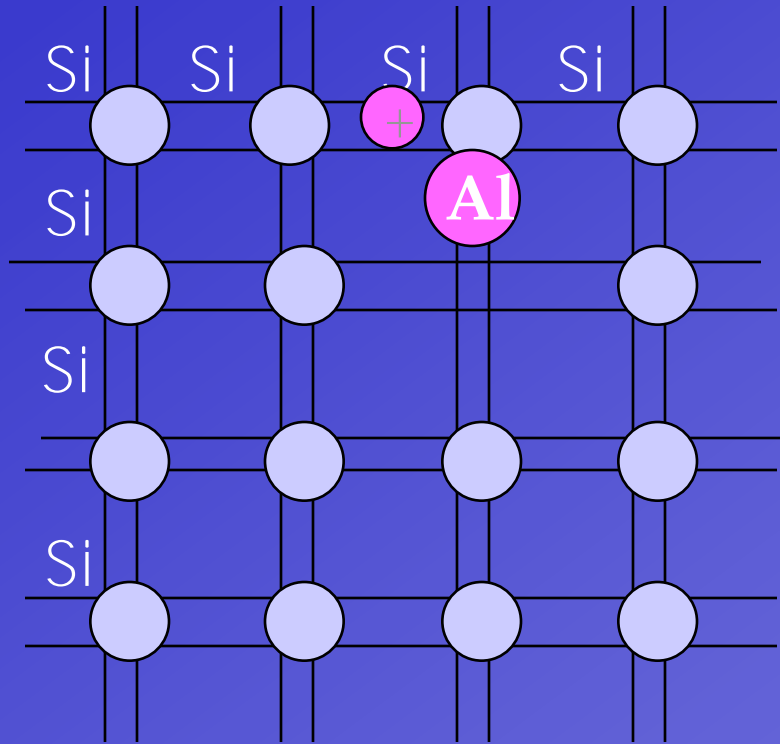
n-type semiconductor



Current carrier : electron



# P-type semiconductor



Conduction band

Acceptor level

Valance band

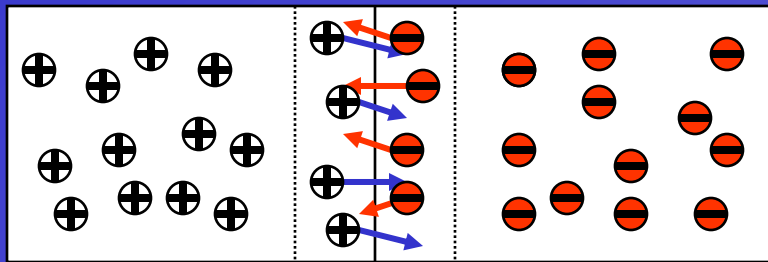
The current carrier : hole



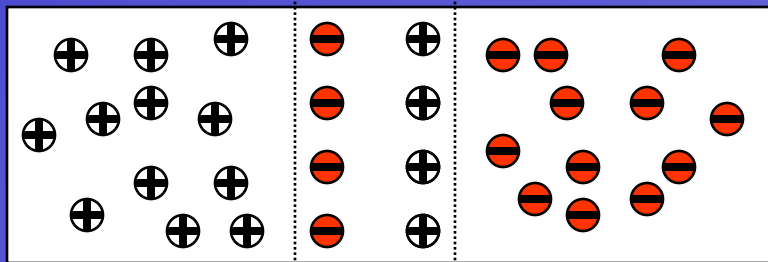
# P-N junction

**P type**

**N type**

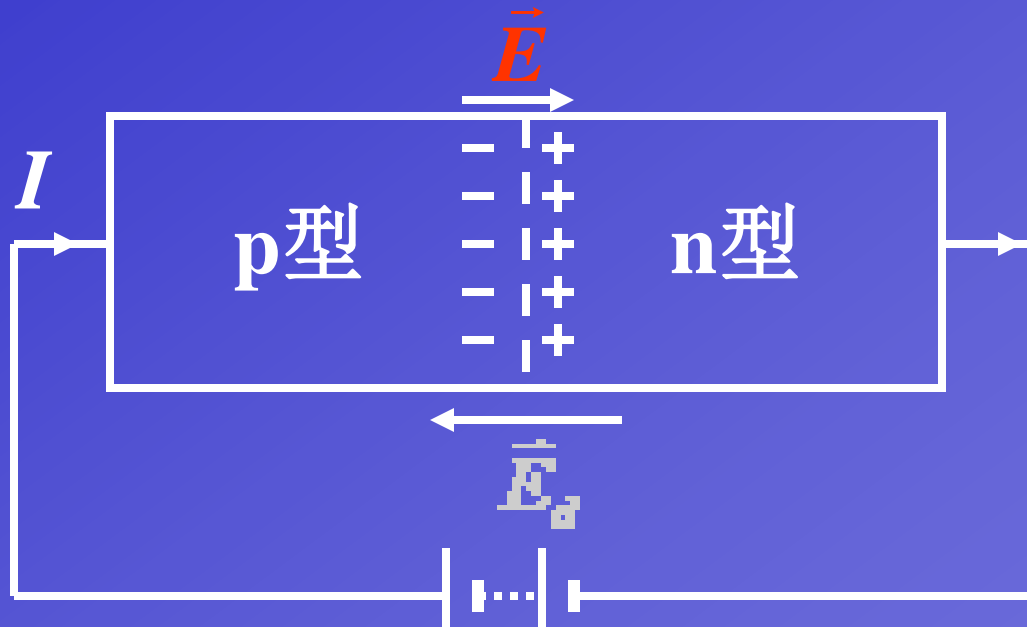


Depletion zone

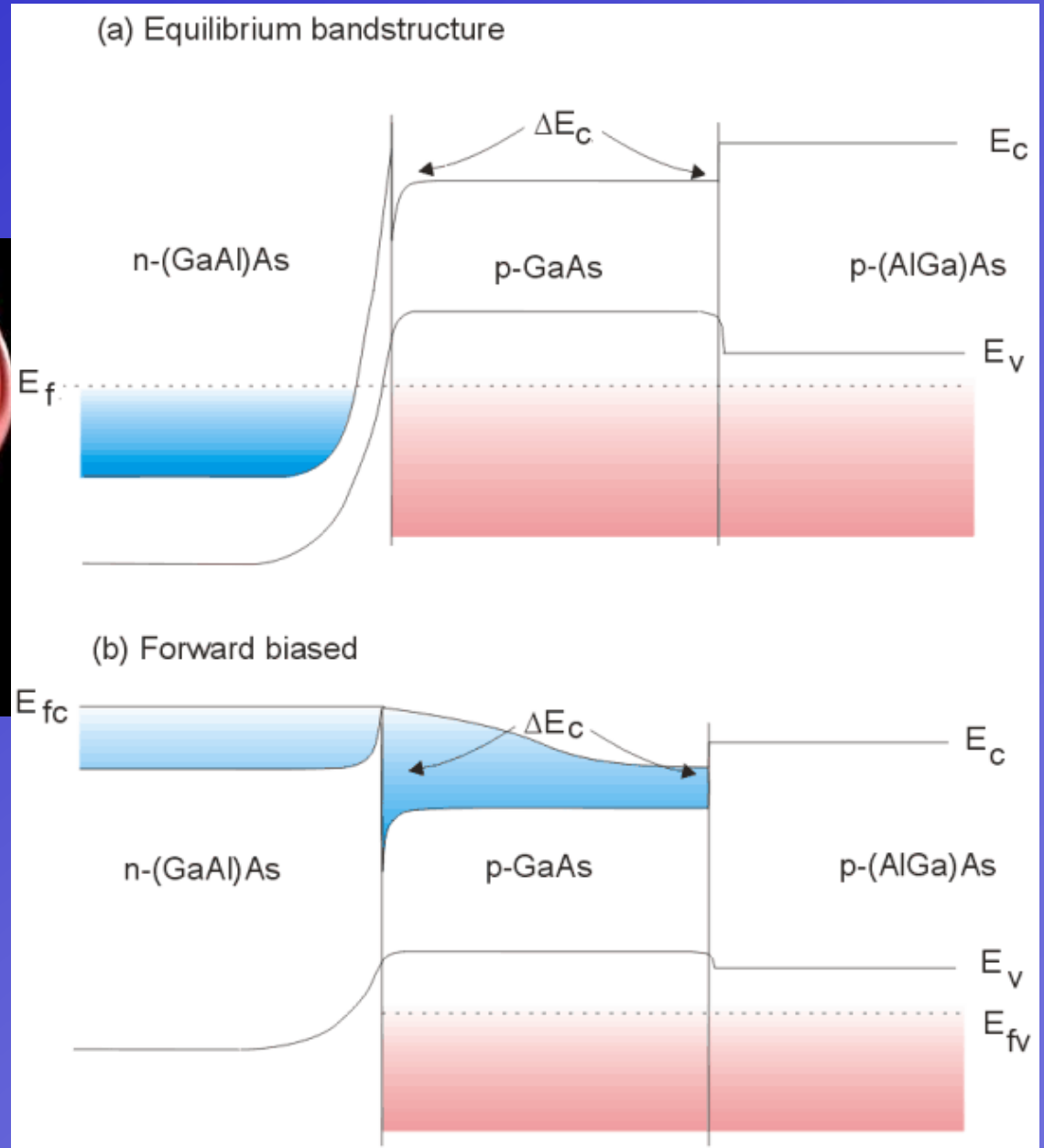
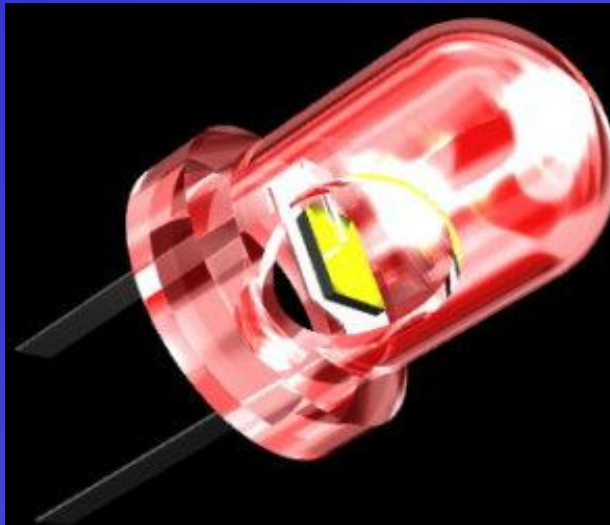


**P-N junction**

# The principle of diode



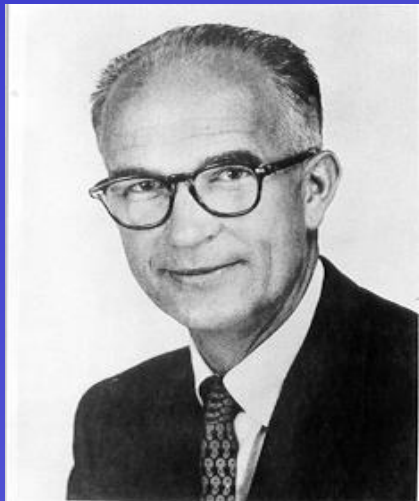
# Light-emit diode





*John Bardeen*

**Bardeen**



*W = Shockley*

**Shockley**



*Walter H. Brattain*

**Brattain**

The invention of transistor