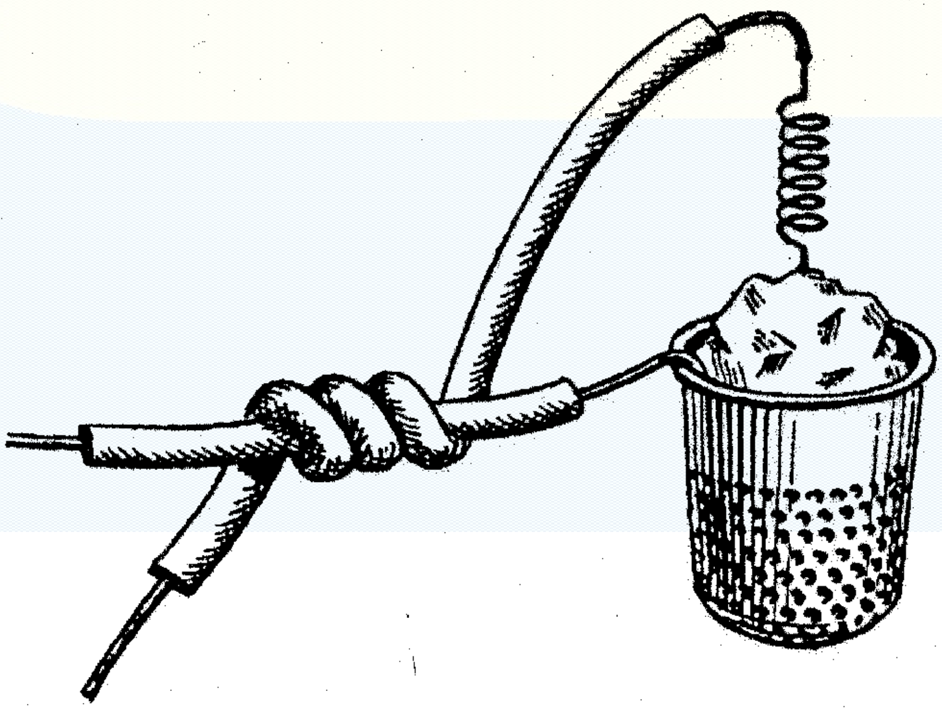
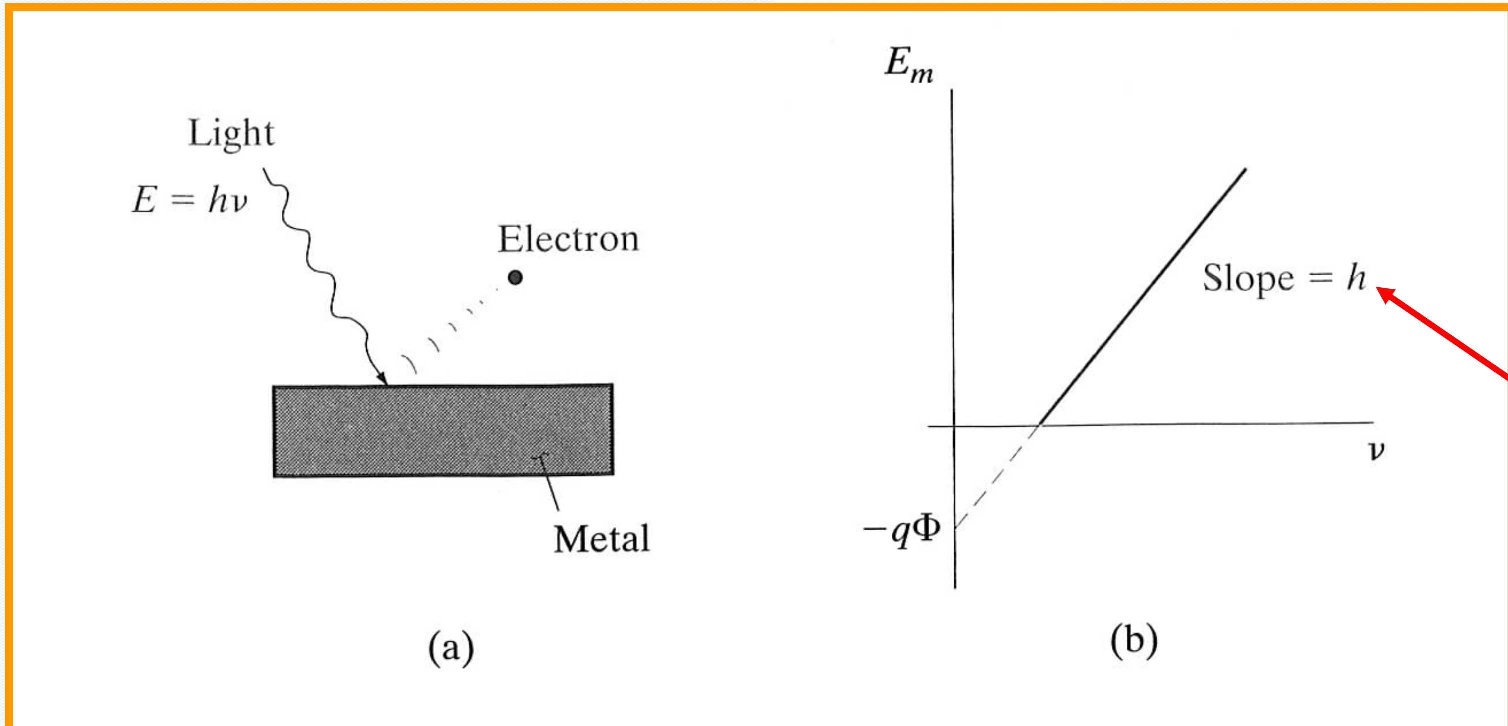
Introduction to Semiconductor Technology



Outline

- Atoms and Electrons
- Energy Bands and Charge Carrier in Semiconductors

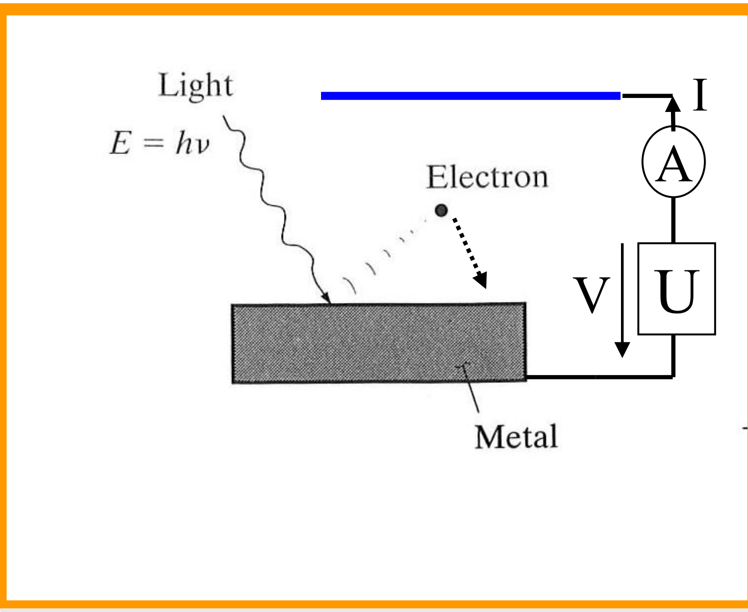
The Photoelectric Effect



$$E_m = h\nu - q\Phi$$

$q\Phi$ Work function

Planks constant



U is adjusted so I=0, V gives then Em in eV

Schrödinger's equation simple example

Particle in a potential-box

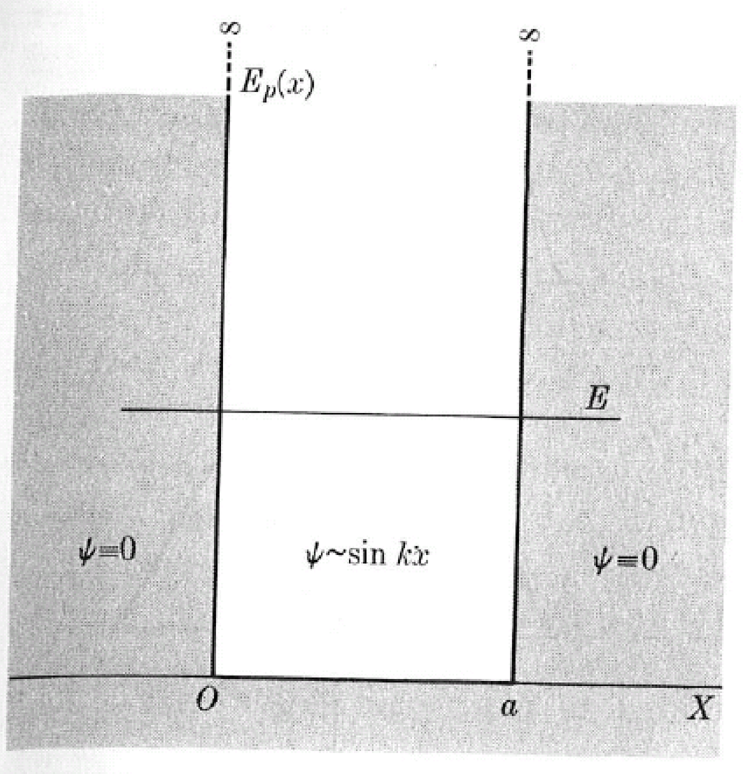
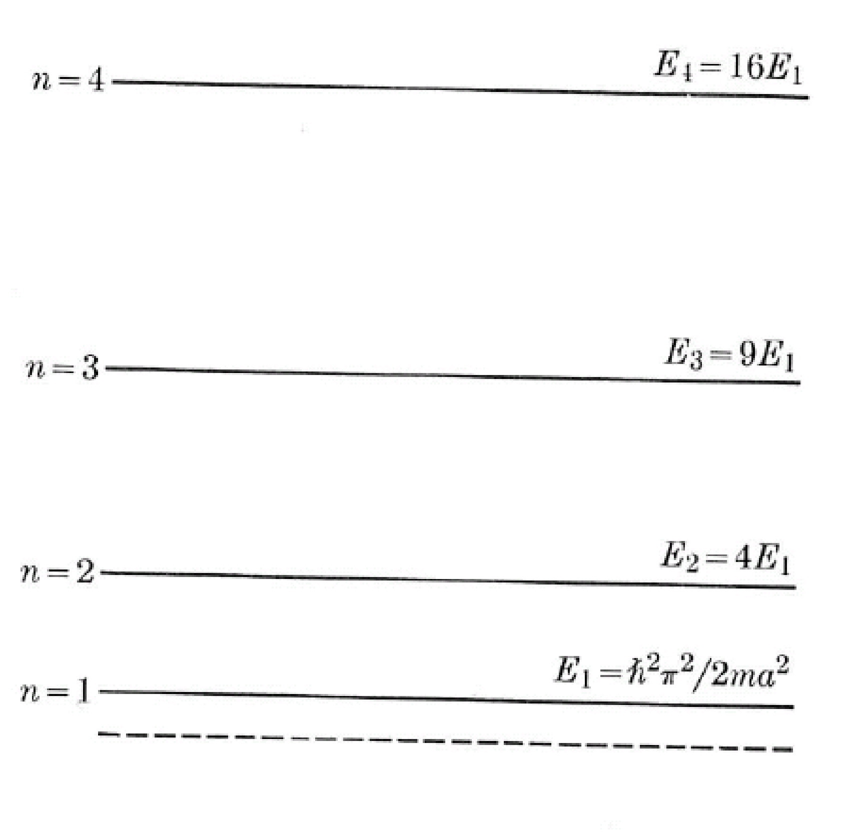


Fig. 2–6. One-dimensional potential box of width *a*.

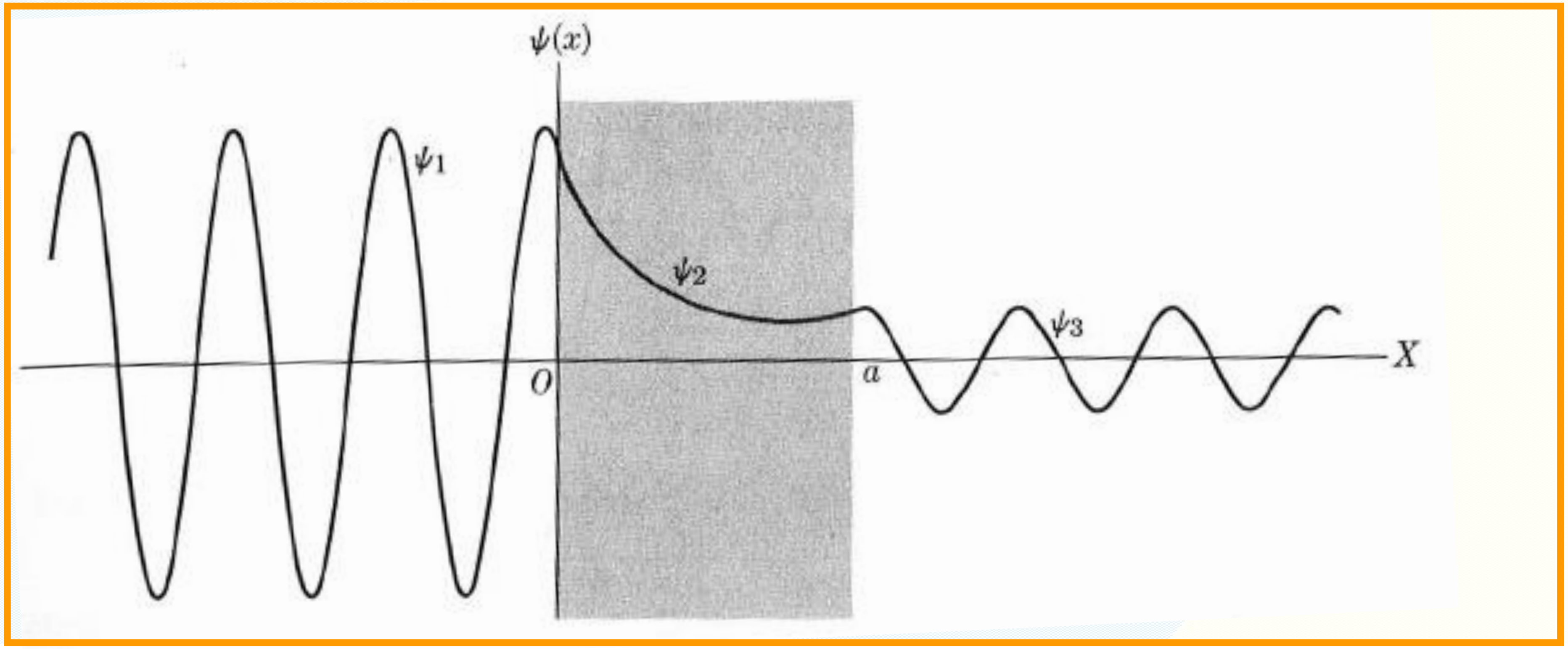
Energy levels for a particle in a potential-box



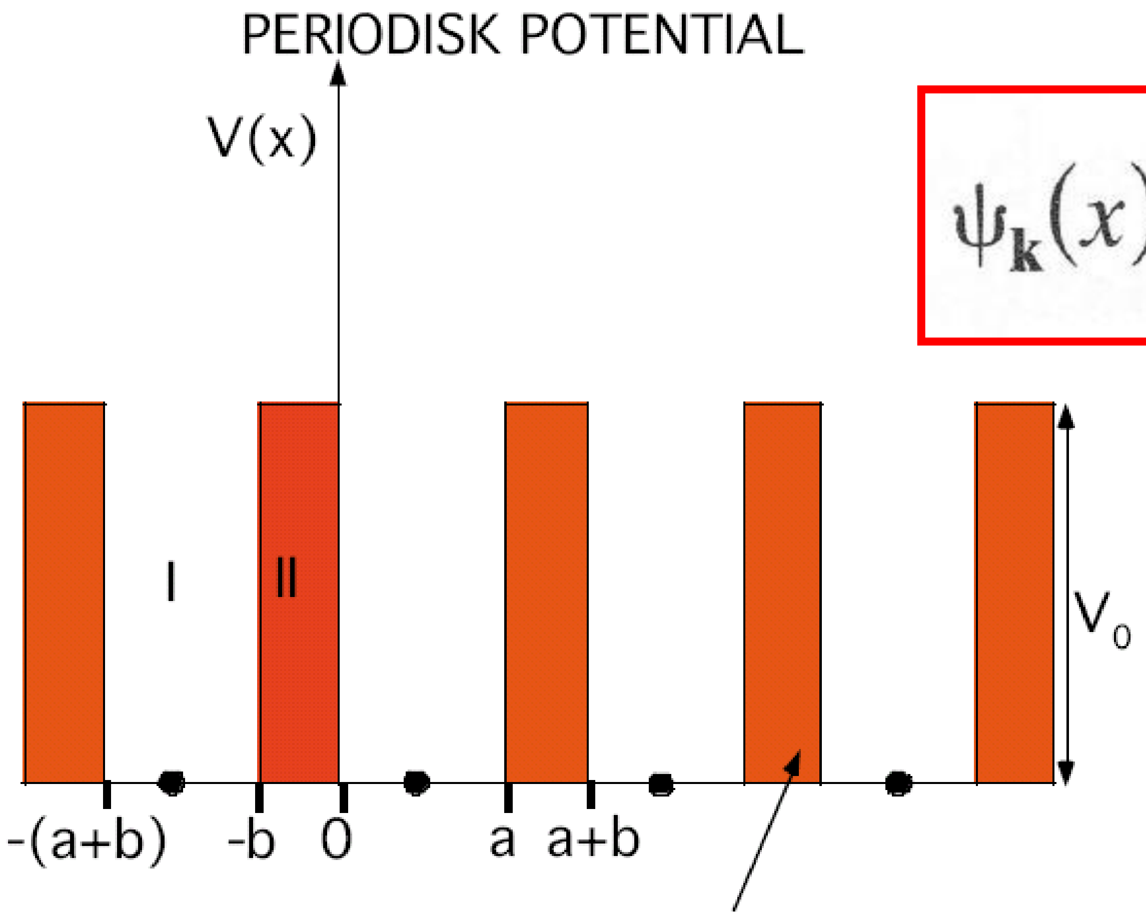
$\boxed{k=2\pi/\lambda \text{ wave-vector}}$

Schrödinger's equation simple example

Wave function for a “thin” potential barrier



Schrödinger's equation simple example



$$\psi_{\mathbf{k}}(x) = U(\mathbf{k}_x, x)e^{j\mathbf{k}_x x}$$

Potentialbarriär mellan jonerna. Men barriären är inte oänligt hög eller bred vilket gör det möjligt för valenselektronerna att tunnla genom den.

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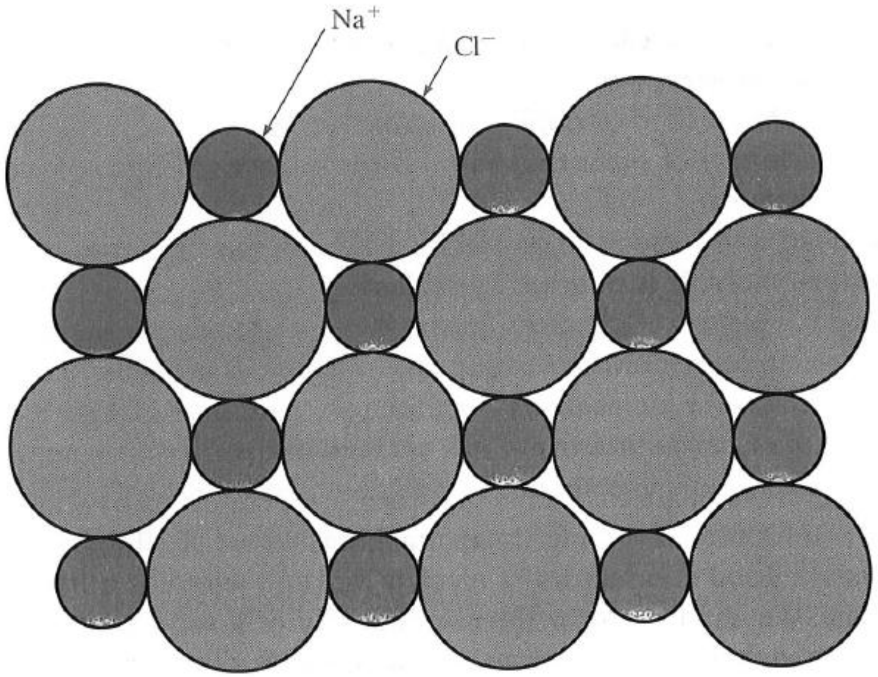
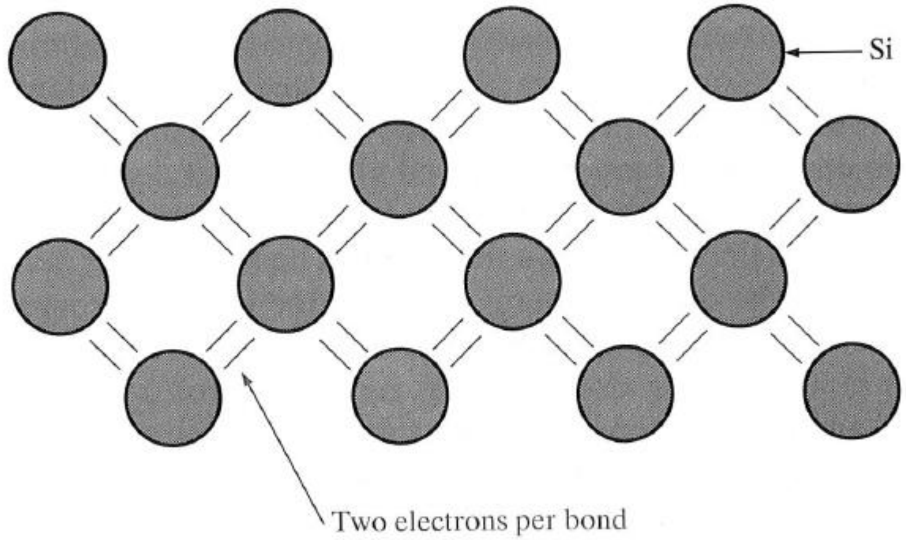
Crystal Bonds

Ion Bonds



(a)

Kovalent Bonds



(b)

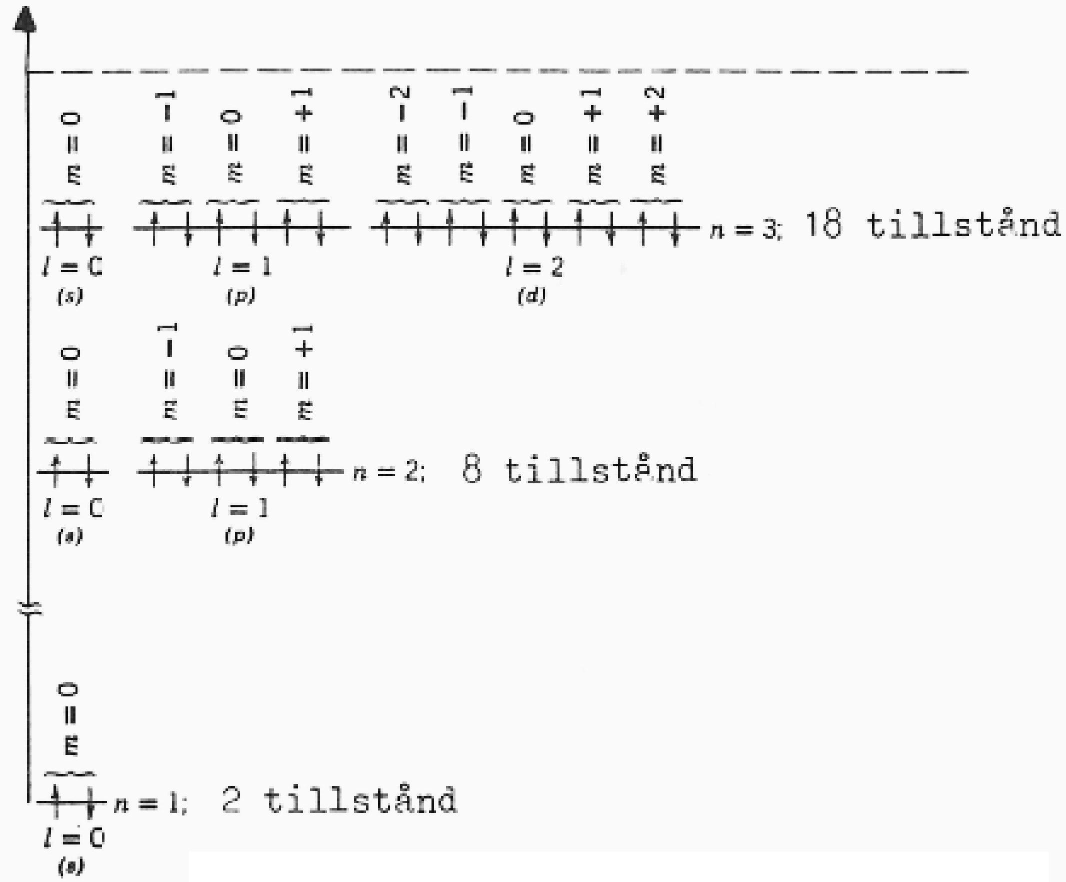
Pauli principle

n = huvudkvanttalet = 1,2,3,.......

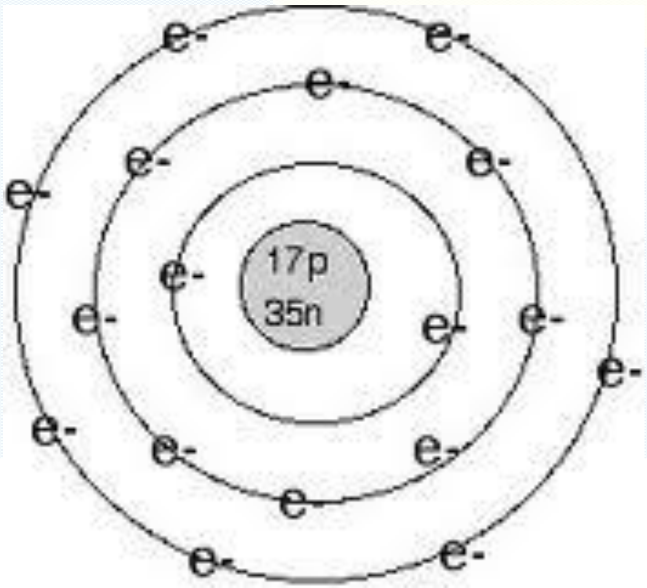
l = impulsmomentkvanttalet = 0,1,2,3,........(n-1)

m_l = magnetiskt kvanttal = $0, \pm1, \pm2, \pm3, \ldots\ldots\ldots \pm l$

m_s =magnetiska spinkvanttalet = $\pm$ 1/2

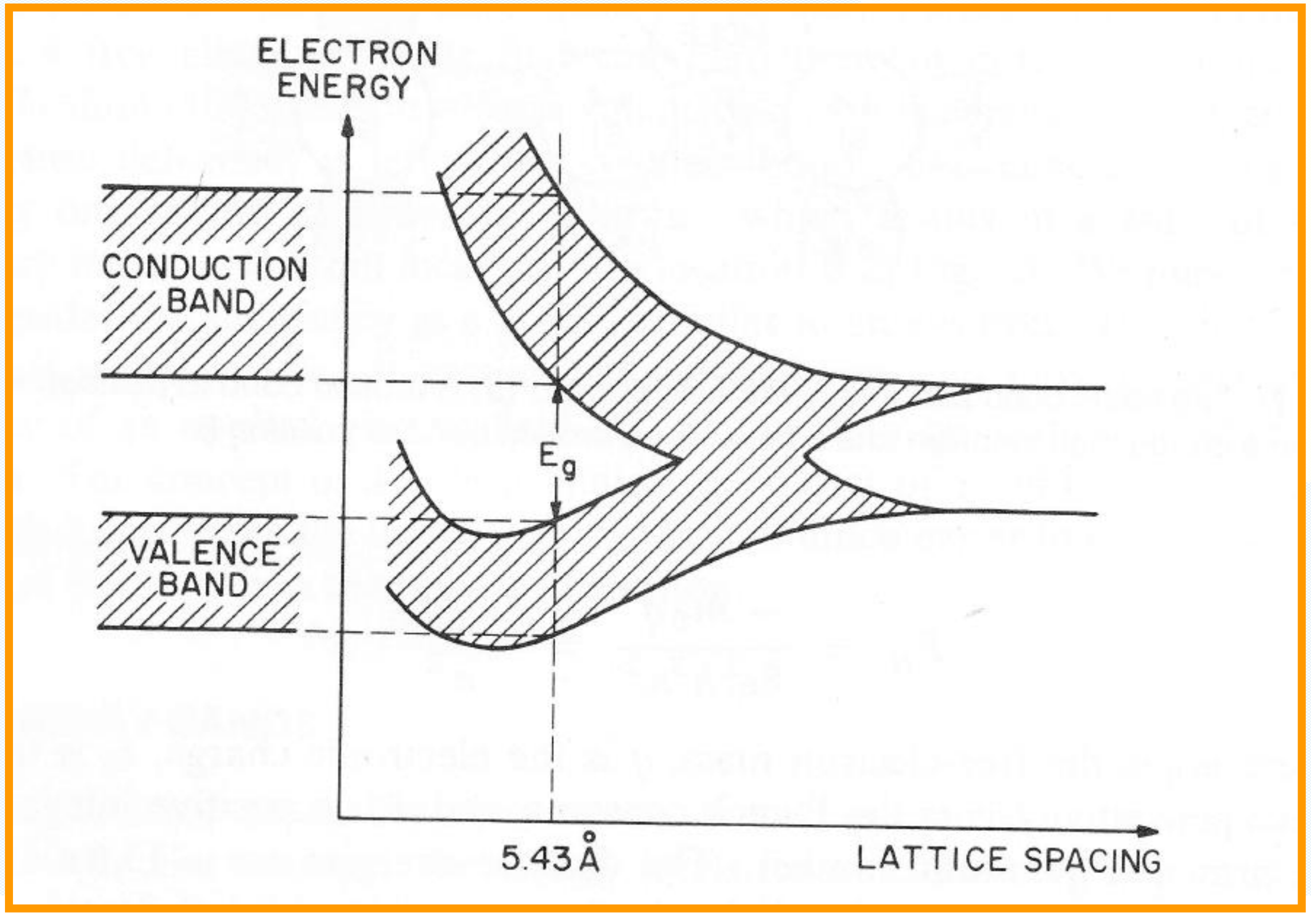


Chlorine



l =angular momentum quantum number

Energy band (Silicon)



- •Pauli principle
- •For the formation of the crystal, the wave functions overlaps so the electrons are split up into energy bands with 4N state. Which result in a valence band and a conduction band

Energy band

Det verkliga avståndet mellan atomerna i halvledarna germanium och kisel framgår av fig. 4.8. Energigapet E_g är för kisel ca 1,1 eV och för germanium ca 0,72 eV.

E_g(diamant)=5 eV

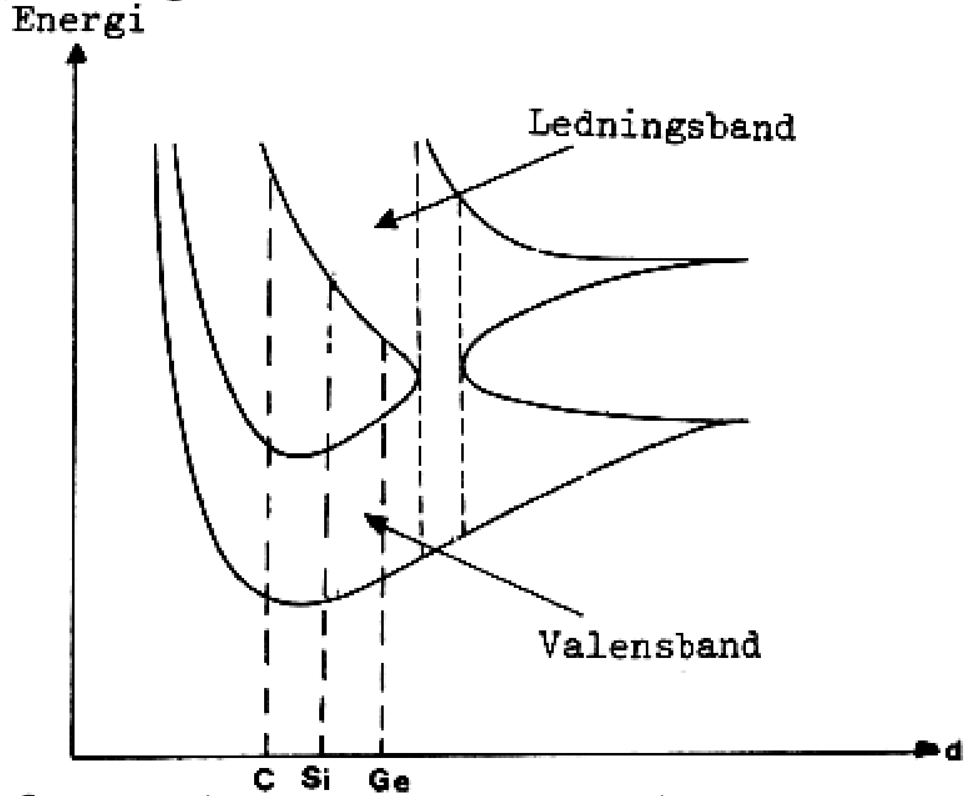
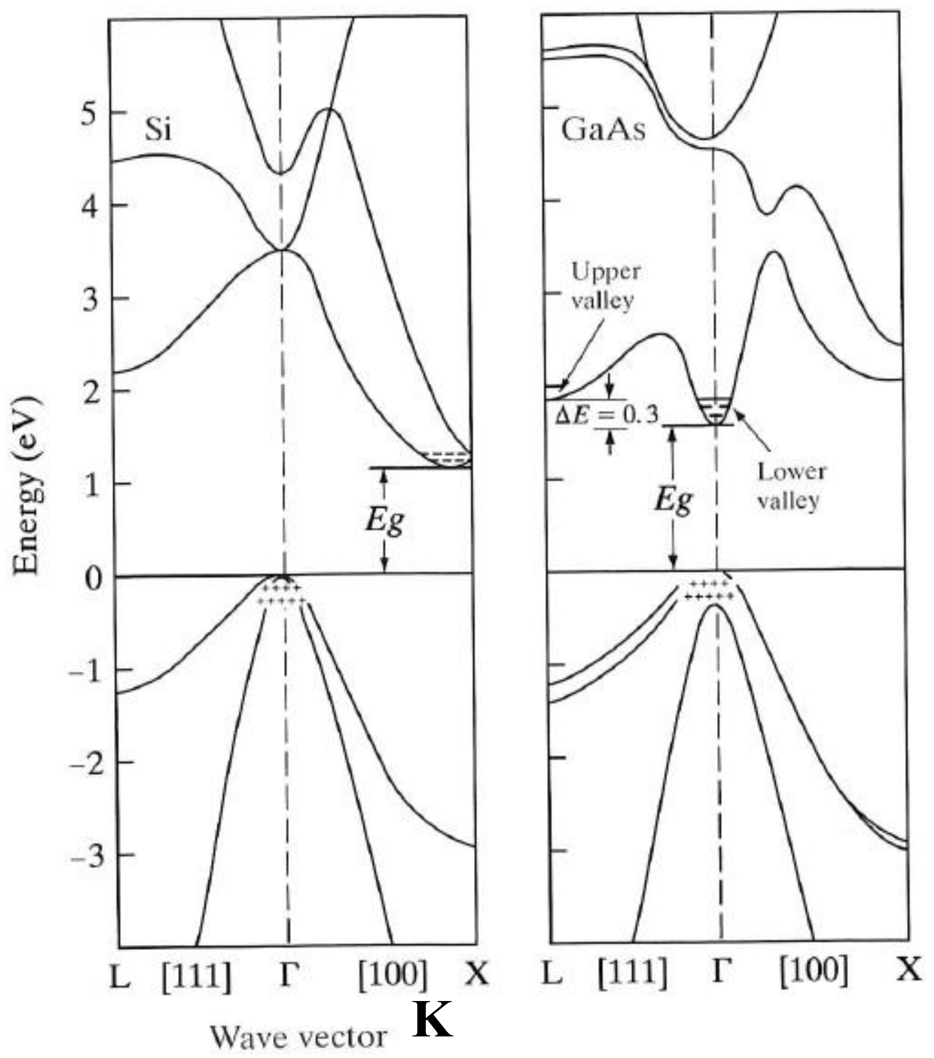


Fig. 4.8. Energibanden för diamant (C), germanium (Ge) och kisel (Si).

Real band structures for Si and GaAs



Silicon has indirect bandgap Eg=1.12 eV

GaAs has direct bandgap Eg=1.43 eV

Energy band in solid material

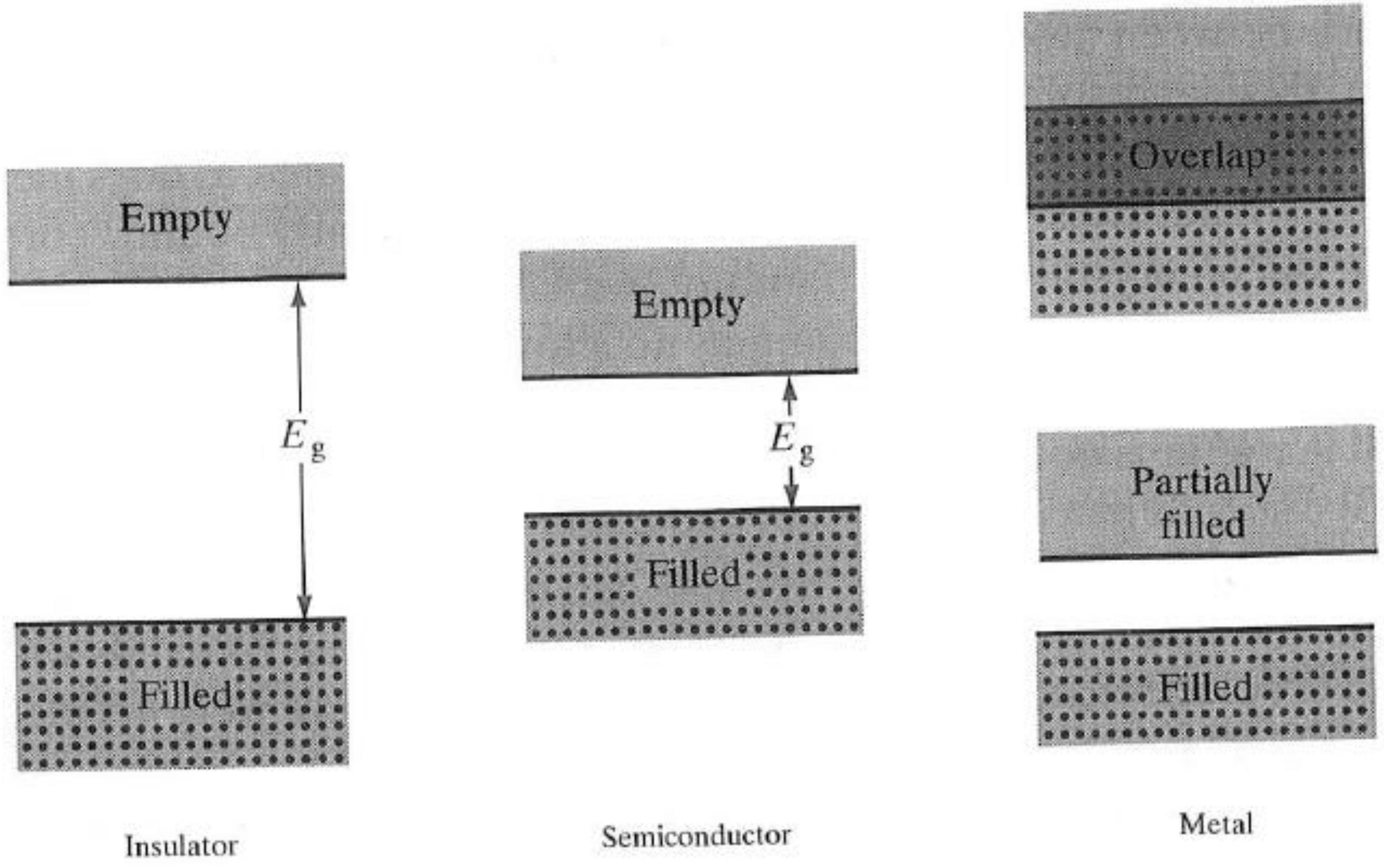
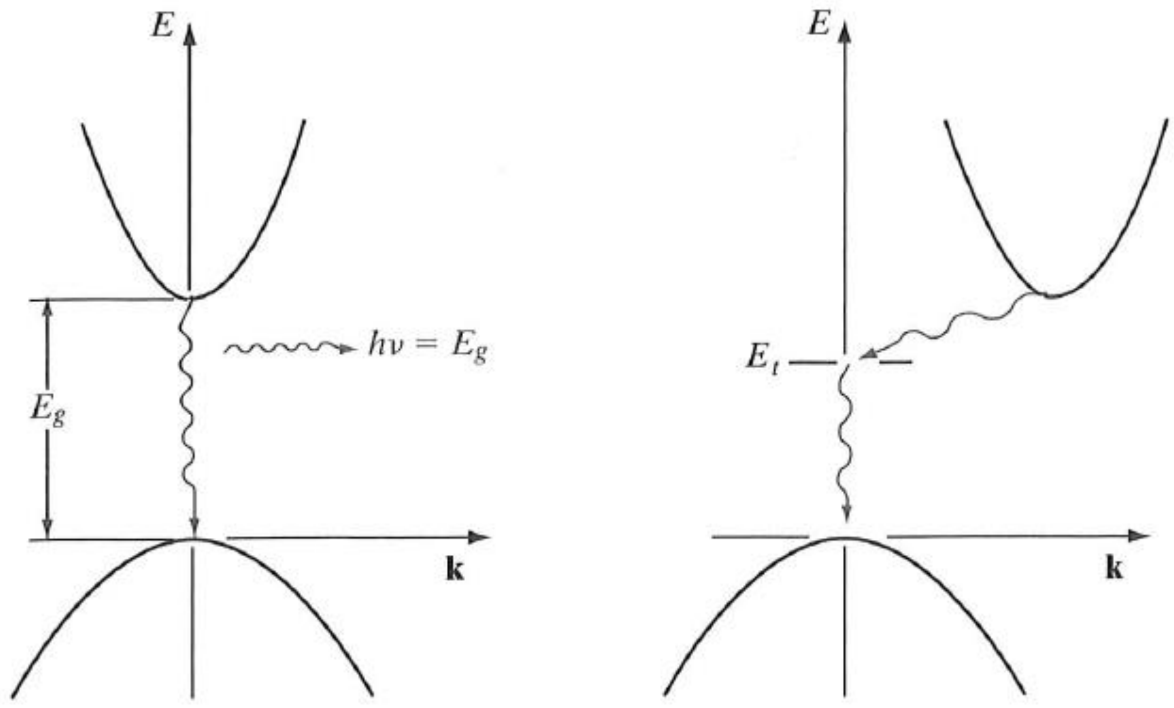


Figure 3–4
Typical band structures at 0 K.

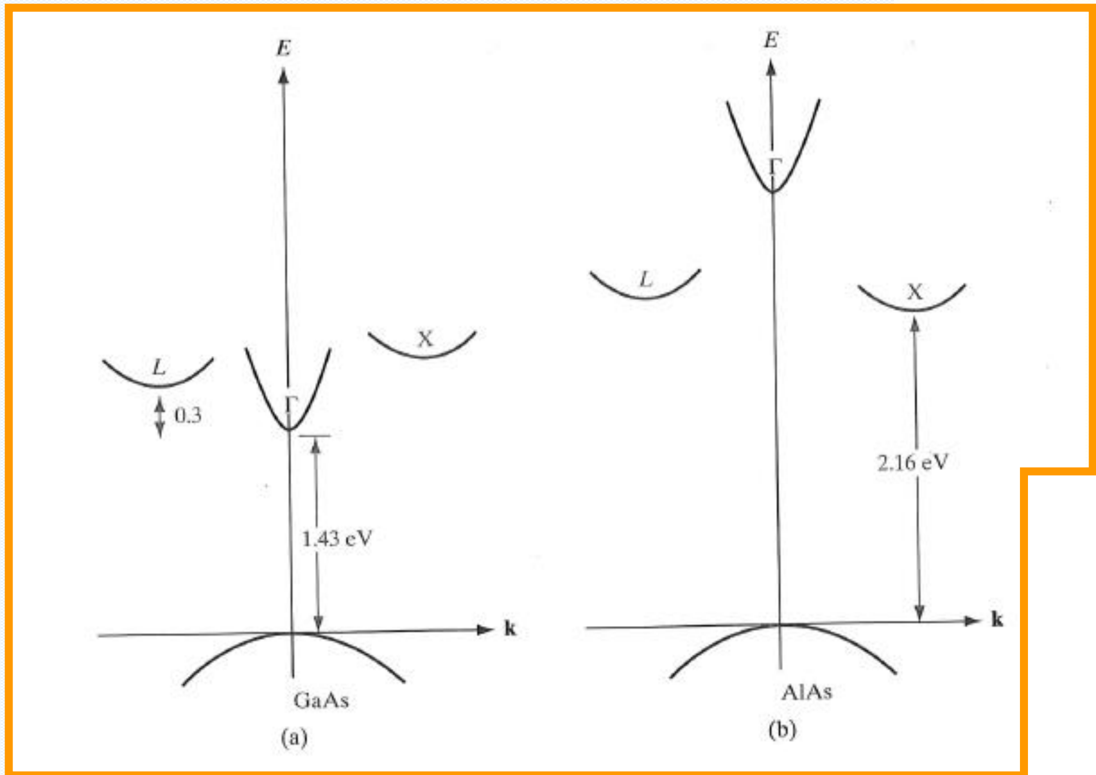
Direct and indirect bandgap

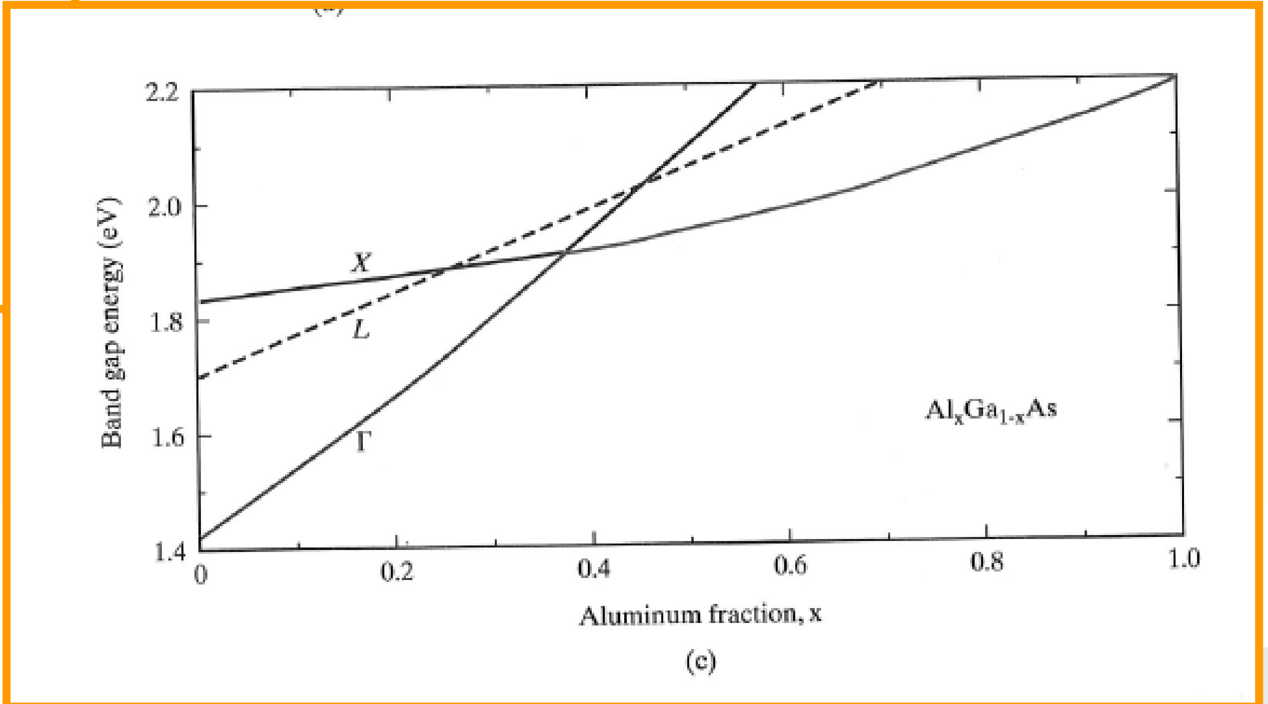


(a) Direct
(b) Indirect

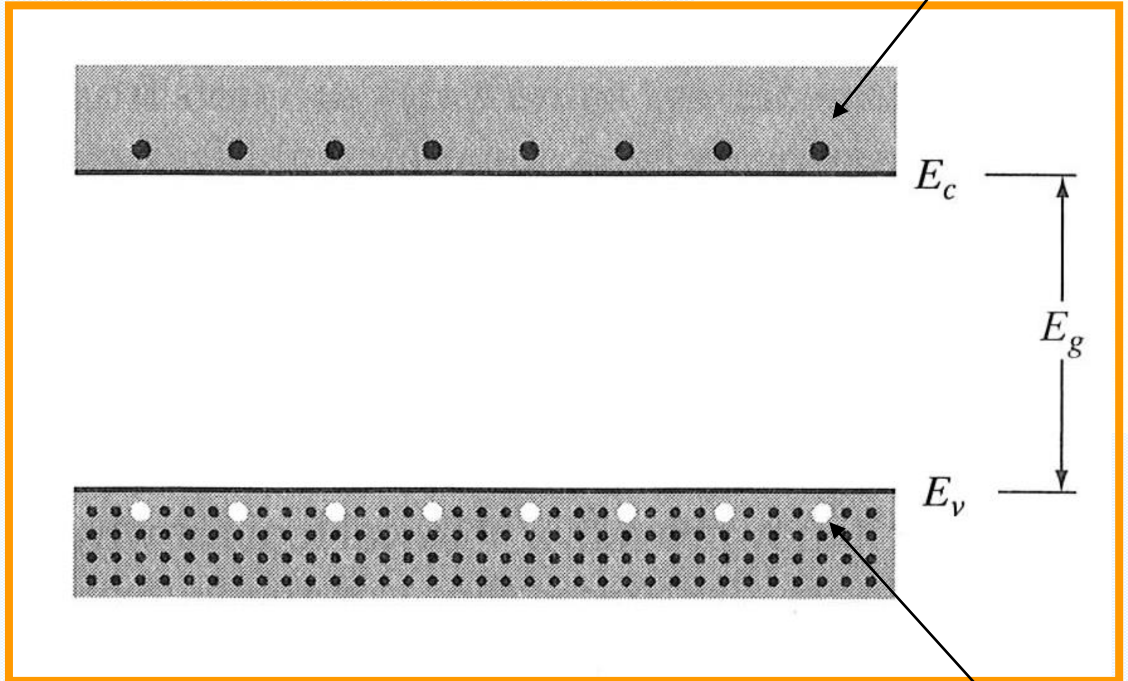
- Semiconductors with a direct band gap can emit photons
- Semiconductors indirect bandgap can emit photons through a defect level in the band gap
- In general, the indirect semiconductors does not emit photons, instead the energy is transferred into heat

Tailor the bandgap for GaAs and AlAs

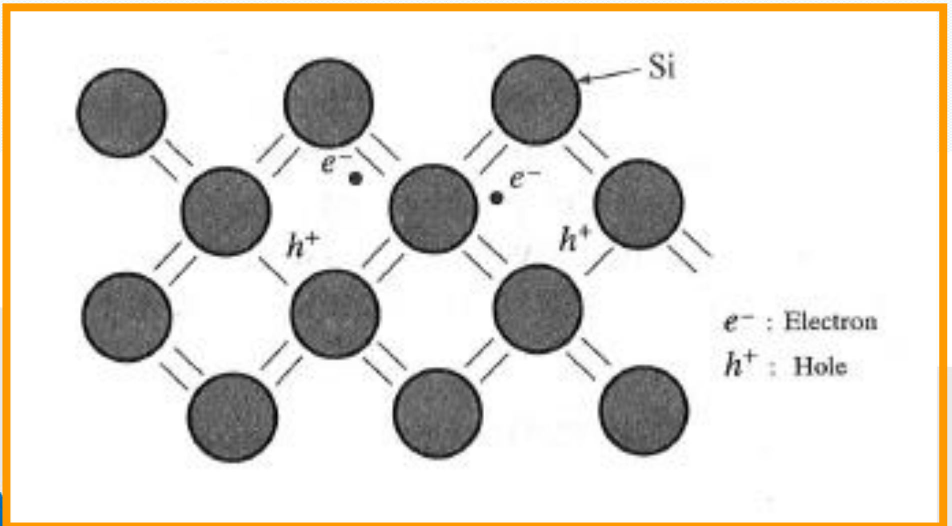




Electrons and holes (intrinsic material, undoped without defects)

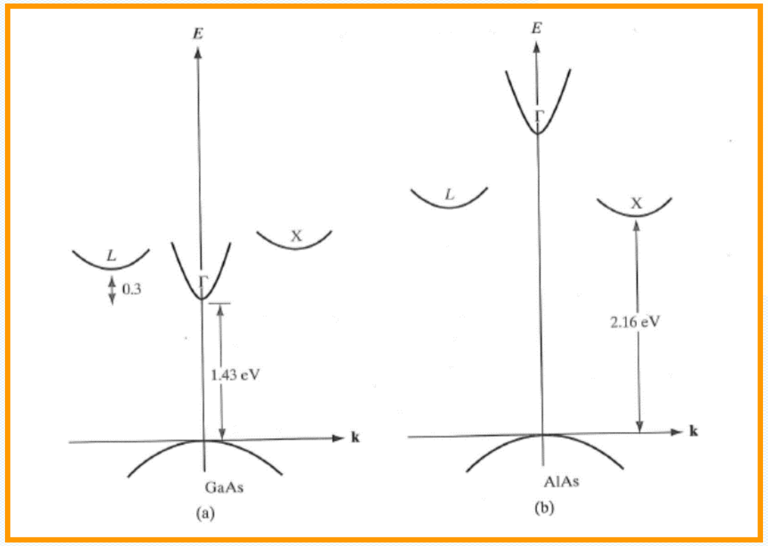


- At T = 0K there are no electrons in the conduction band and the semiconductor is as an insulator
- When T> To there is a number of electrons in the conduction band and the semiconductor can conduct an electrical current



Effective mass

•Do not describe the particle's actual mass, but its apparent mass in the crystal lattice



$$E = \frac{1}{2}mv^2 = \frac{1}{2}\frac{p^2}{m} = \frac{\hbar^2}{2m}\vec{k}^2$$

$$p = mv = \hbar\vec{k}$$

$\hbar = h/2\pi$

GaAs $m_n/m_0=0.067$
AlAs $m_n/m_0=0.38$

$$\frac{d^2E}{d\vec{k}^2} = \frac{\hbar^2}{m} \quad eller \quad m^* = \frac{\hbar^2}{d^2E/d\vec{k}^2}$$

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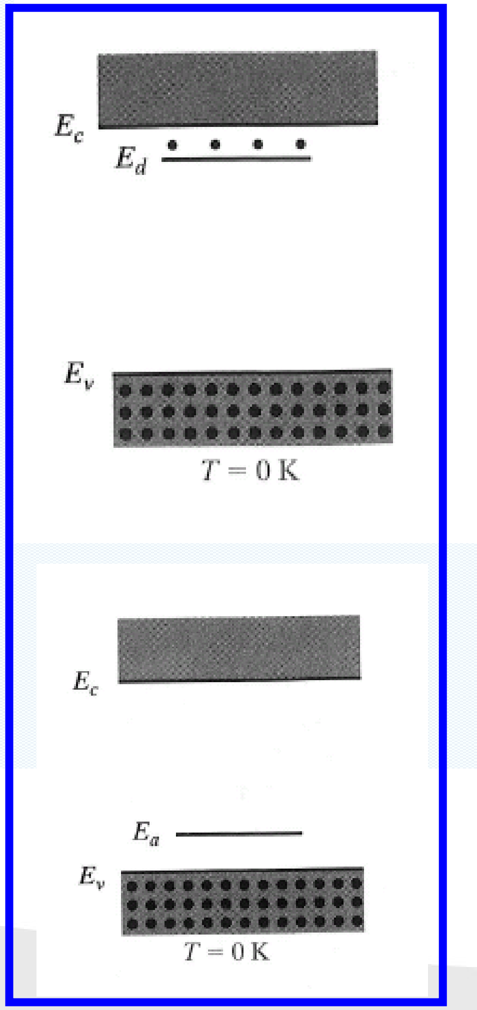
Intrinsic semiconductors

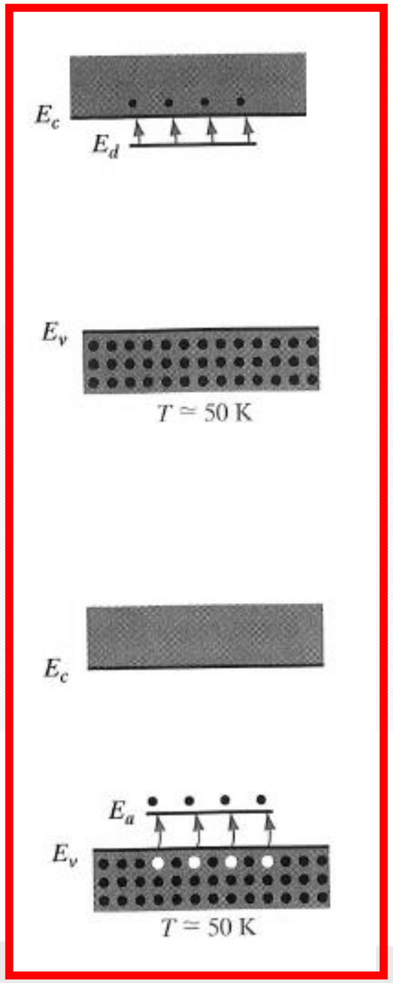
- An ideal semiconductor crystal without impurities and lattice defects called a intrinsic semiconductors. No free charges are at T = 0K
- Electrons and holes are generated in pairs $n=p=n_i$
- The Generations velocity of electron-hole pairs are equal as the recombination velocity $r_i=g_i$ (equilibrium)

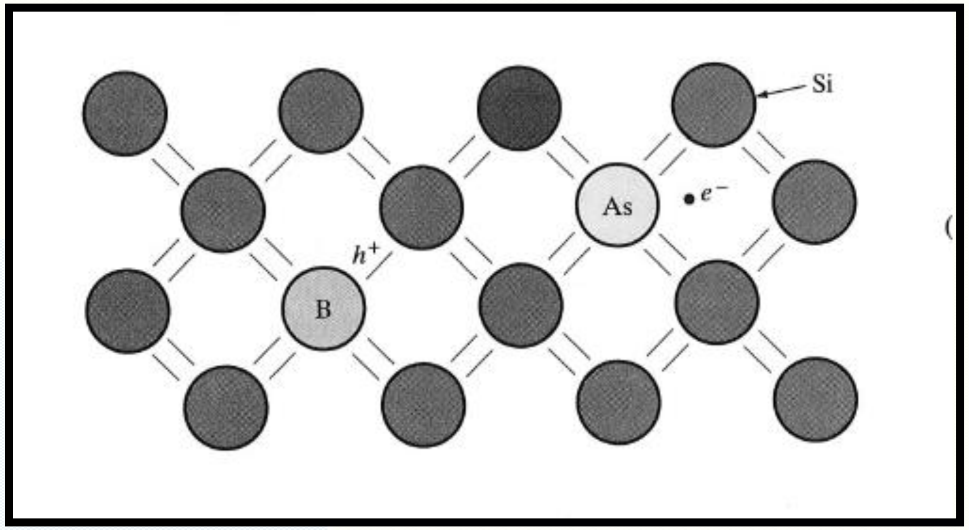
Extrinsic semiconductor

T=0K



T=~50K





Extrinsic semiconductor

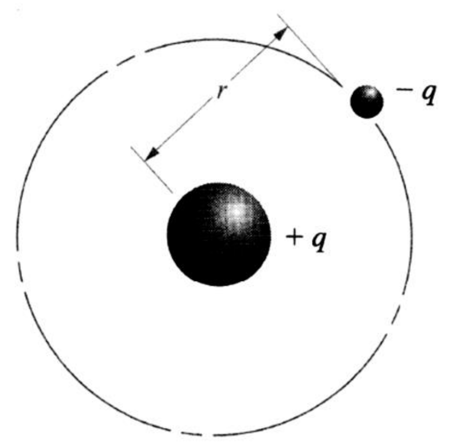
Bohrs model for an atom applied on a doped semiconductor!

The energy for an electron in its ground state

$m^*_n=0.26m_o$ för kisel

n=integer
"quantified"

$$r_n = \frac{K\ \mathbf{n}^2\hbar^2}{mq^2}$$



$$-\frac{q^2}{Kr^2} = -\frac{mv^2}{r}$$

The electrostatic force is balanced by the centripetal force

$$K = 4\pi\epsilon_0\,\epsilon_r$$

$$r = \frac{4\pi\,\epsilon_r\epsilon_0\hbar^2}{m_n^* q^2} = \frac{11.8(8.85\times10^{-12})(6.63\times10^{-34})^2}{\pi(0.26)(9.11\times10^{-31})(1.6\times10^{-19})^2}$$

n=1 $\quad r = 2.41\times10^{-9}m = 24.1$ Å.

Note that this is more than four lattice spacings $a = 5.43$ Å.

Relative dielectrical constant ~ 12 for Silicon

Charge Carrier Concentration

Fermi-Dirac statistics (only one particle in each energy State) the likelihood that an available energy level shall be filled with an electron. E_F is called Fermi level or chemical potential

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

k is Boltzmann's constant ($k = 8.62 \times 10^{-5}$ eV/K $= 1.38 \times 10^{-23}$ J/K)

$$\boxed{f(E_F) = [1 + e^{(E_F - E_F)/kT}]^{-1} = \frac{1}{1+1} = \frac{1}{2}}$$

$E = E_F$

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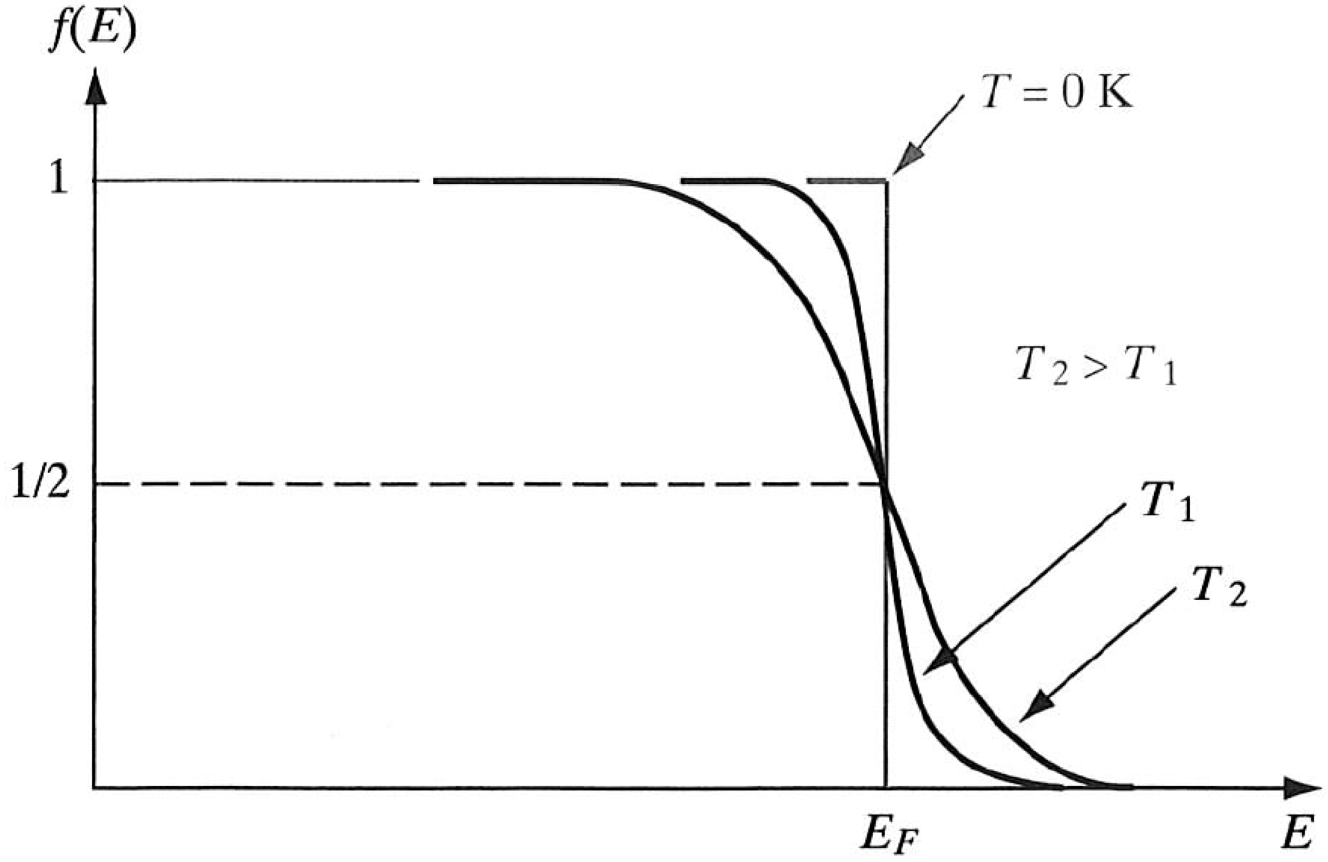
Charge Carrier Concentration

Temperature dependence



Charge Carrier Concentration

The probability to find a hole in the valence band is provided by $[1 - f(E)]$