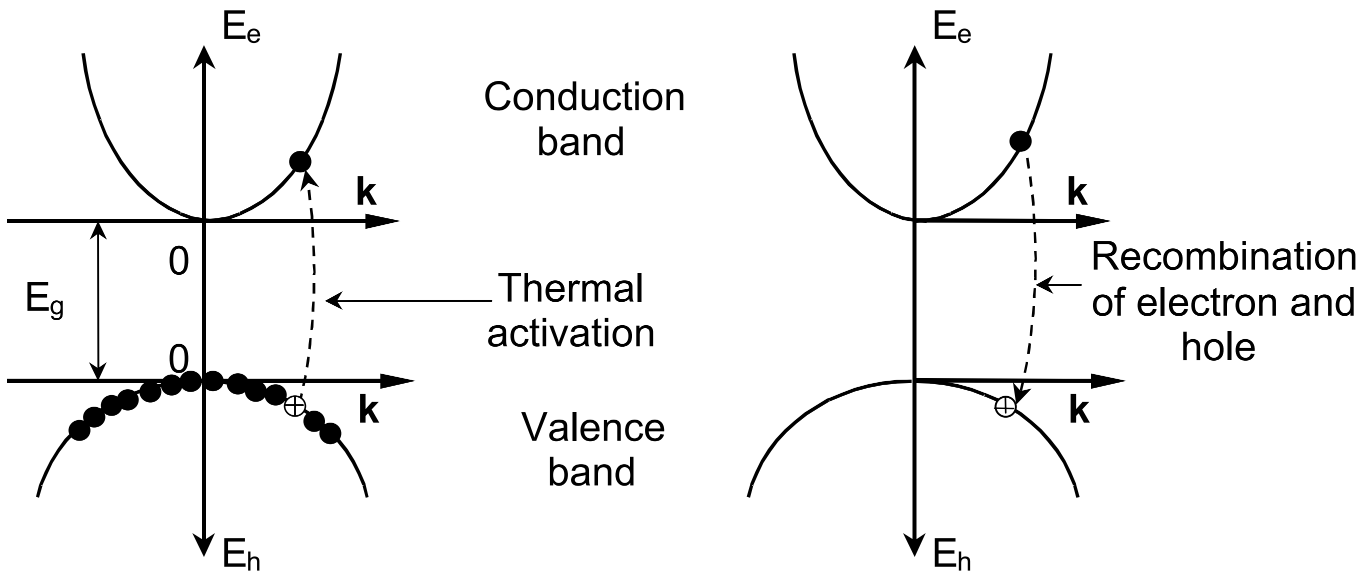
Intrinsic semiconductors. Thermal activation of carriers.



Probability of thermal activation of e-h pairs
$w_a \propto exp(-E_g/k_bT).$

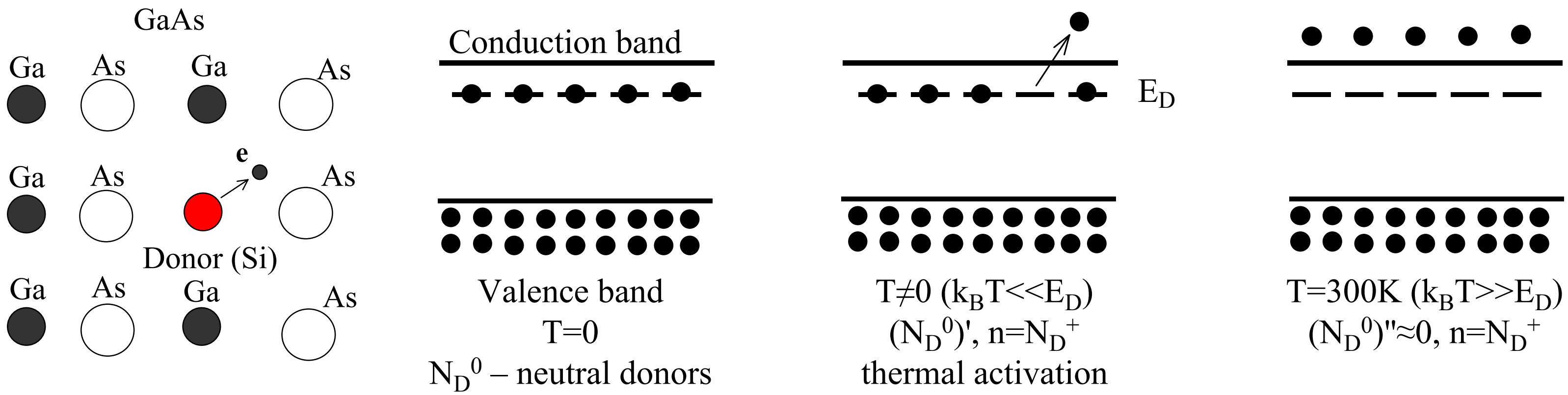
Probability of recombination
$w_r \propto np$

In thermal equilibrium: $w_a = w_r$ and $n = p = n_i$, $n_i^2 \propto exp(-E_g/k_BT).$

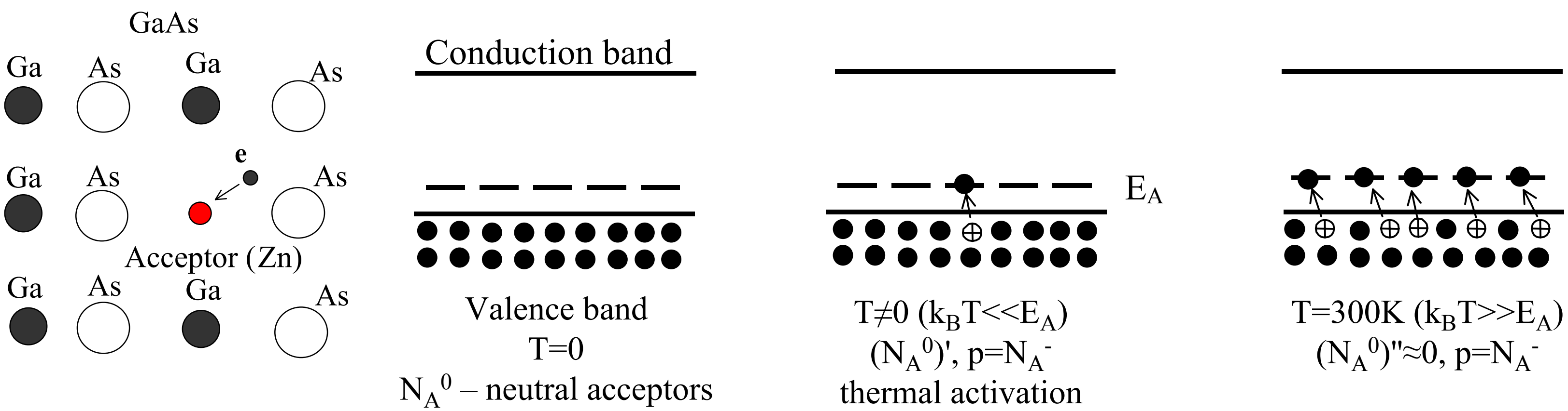
At room temperature: $n_i = 2{\cdot}10^6\ cm^{-3}$ *for GaAs*
$n_i = 1{\cdot}10^{10}\ cm^{-3}$ *for Si*

Doping of semiconductors

Donors

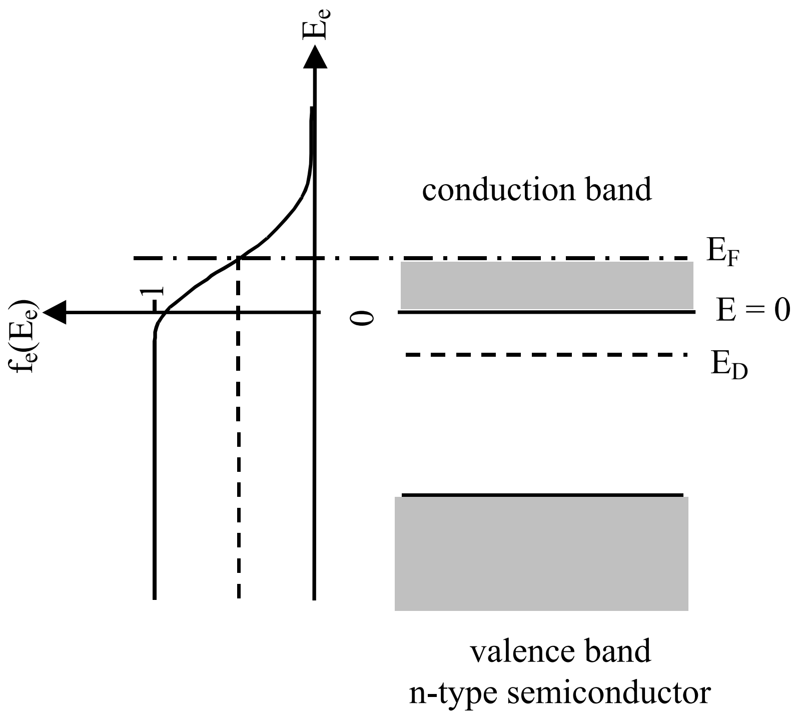


Acceptors



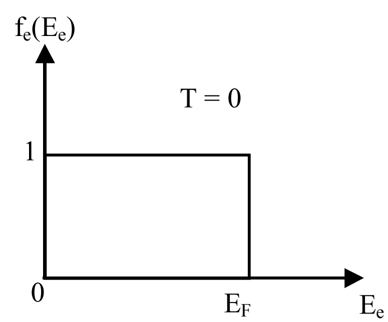
Distribution function of electrons f_e (E_e)

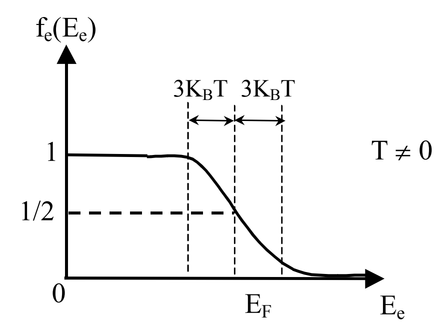
Specifies the probability, that an available state at energy E_e is occupied by an electron.



Fermi-Dirac distribution

$$f_e(E_e) = \frac{1}{1+\exp\left(\frac{E_e - E_F}{k_B T}\right)}$$

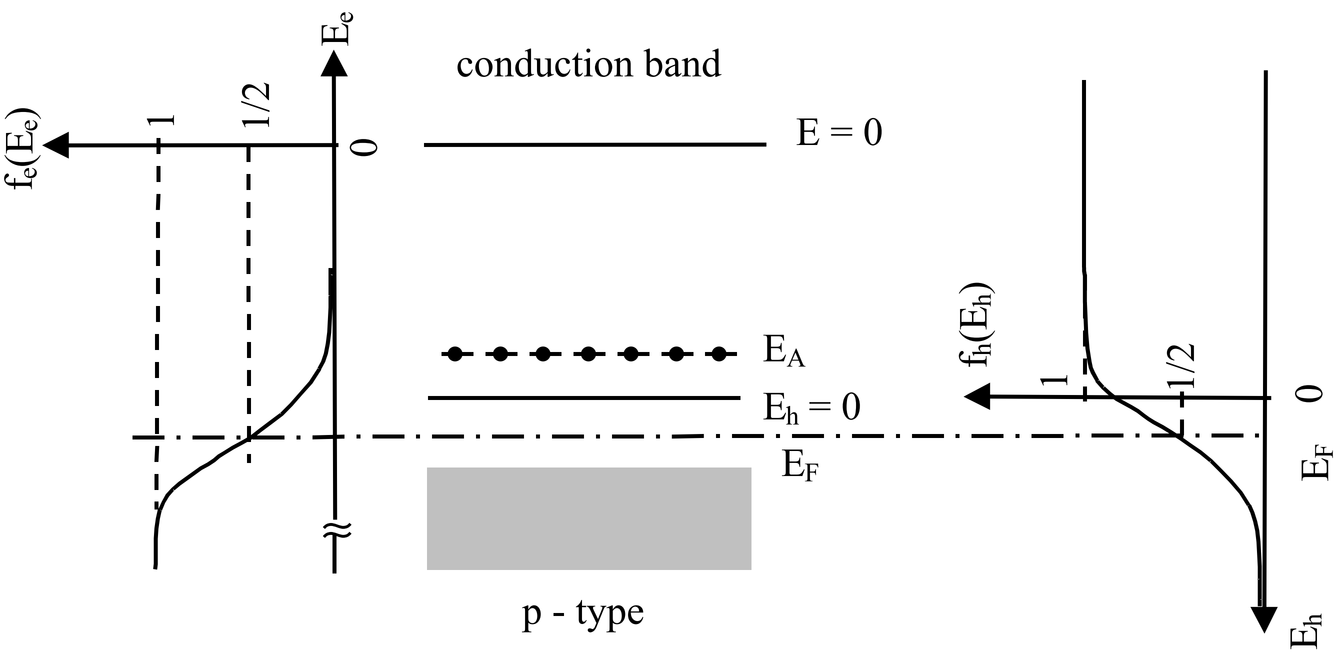




Distribution function of holes f_h (E_h)

The probability, that available state is not occupied by electron (or is occupied by hole)

$$f_h(E_h) = 1 - f_e(E_e) = 1 - \frac{1}{1+e^{\frac{E_e - E_F}{K_B T}}} = \frac{1}{1+e^{\frac{-(E_e - E_F)}{K_B T}}} = \frac{1}{1+e^{\frac{E_h - E_F}{K_B T}}}$$

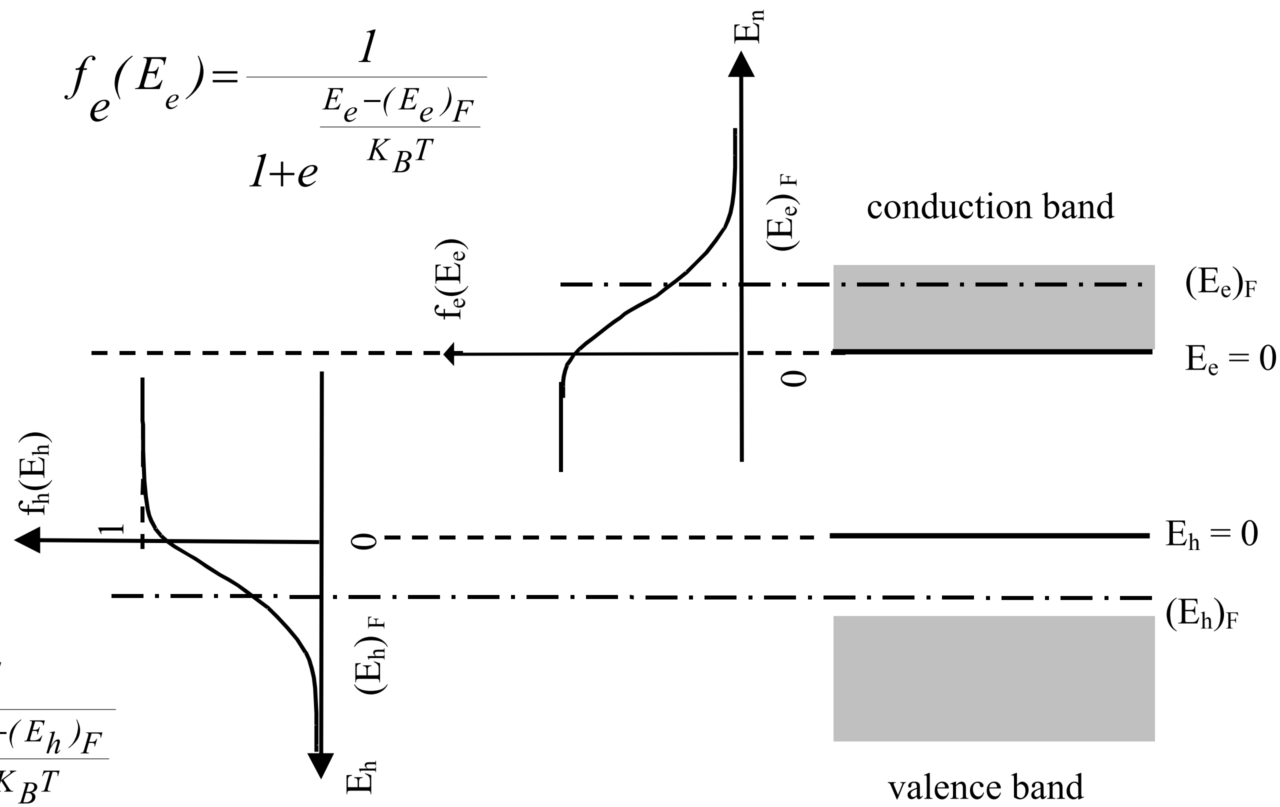


In thermal equilibrium the Fermi level is the same for electrons and holes.

Quasi levels of Fermi in semiconductors

For the nonequilibrium case (the electrons and holes have been created by electrical injection or optical exitation) it is convinient to introduce two Fermi levels for electrons $(E_e)_F$ and holes $(E_h)_F$

$$f_e(E_e) = \frac{1}{1+e^{\frac{E_e-(E_e)_F}{K_B T}}}$$



$$f_h(E_h) = \frac{1}{1+e^{\frac{E_h-(E_h)_F}{K_B T}}}$$

Density of states

$dn(E_e)$ $\left[\frac{1}{\text{cm}^3}\right]$ - Number of electrons in energy interval from E_e to E_e+dE_e

equal to the probability, that an available state with energy E_e is occupied by an electron ($f_e(E_e)$) multiplied by number of states (dN_s) within energy interval from E_e to E_e+dE_e

$$dn(E_e) = f_e(E_e)dN_S$$
$$dN_s = \rho_e(E_e)dE_e$$

in 3D case

$$\rho_e(E_e) = \frac{\sqrt{2}\cdot m^{*3/2}}{\pi^2\hbar^3}\cdot\sqrt{E_e}, \frac{1}{cm^3\cdot eV}$$

$$n(E_e < E_0) = \int_0^{E_0} f_e(E_e)\rho_e(E_e)dE_e$$

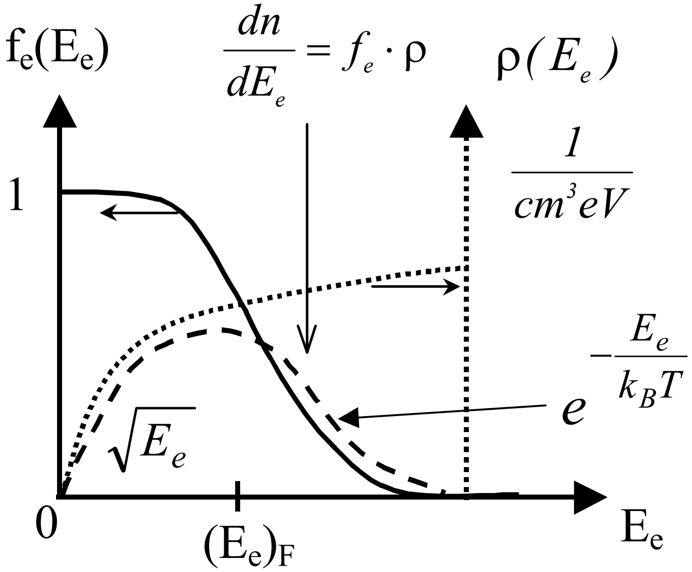
The equation for the electron quasi-fermi energy level determination

$$n = \int_0^{\infty} f_e(E_e,(E_e)_F)\rho_e(E_e)dE_e$$

electron quasi-Fermi level in nonequilibrium case (external field and injection)

Electron energy distribution in 3D case

$$n(E_e < E_0) = \int_0^{E_0} f_e(E_e)\rho_e(E_e)dE_e, \quad \rho(E_e) \propto \sqrt{E_e}$$



Density of states versus electron energy E_e