Compensation and spache charge neutrality

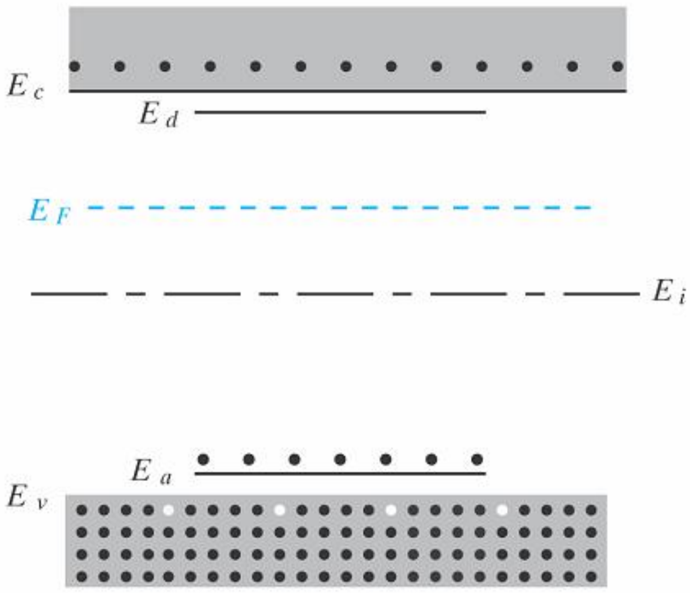


Figure 3.19
Compensation in an n-type semiconductor ($N_d > N_a$).

If both donor & acceptor impurities are present at the same time the Fermi level must adjust itself to preserve charge neutrality,

$$n + N_A^- = p + N_D^+$$

Thus in Fig. 3.19 the net electron concentration in the conduction band is

$$n = p + N_D^+ - N_A^-$$

Bandas de energía y portadores de carga en semiconductores

How many charges, fixed and free
Appear in the material

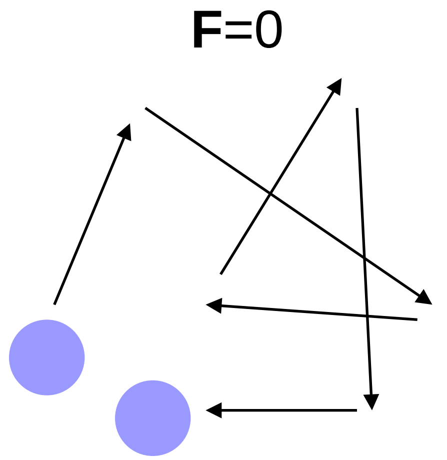
How the transport of the free charges
through the semiconductor is carried out

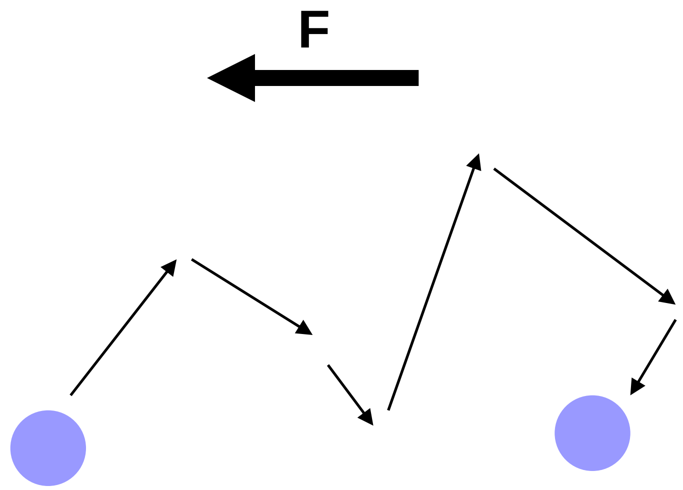
Carrier transport phenomena

Drift of Carriers in Electric Fields

Conductivity and Mobility

(under the influence of a small electric field, F)





- Random thermal motion, v_{th}
- Electrons are scattered off by atoms
- No net displacement over long time
- Average time between collisions,

$$\bar{t} \sim 10^{-12} s$$ **_mean free time_**

Electrons accelerated in the opposite direction of the applied field between collisions so a net displacement and an additional *drift velocity* component,

$$\langle v_x \rangle$$

Carrier transport phenomena

If all momentum gained between collisions is lost in the collision event then the momentum *applied* to the electron during its free flight is equal to the momentum *gained*,

Net drift of an average electron in response to the electric field.

$$-qF\bar{t} = m_e^* \langle v_x \rangle$$

$$\frac{cm^2}{V \cdot s} = \frac{cm}{V} \cdot \frac{cm}{s} = \frac{v_{carrier}}{F}$$

$$\langle v_x \rangle = -\left(\frac{e\tau_c}{m_e^*} \right) F$$

electron mobility ($cm^2 \cdot V^{-1} \cdot s^{-1}$)

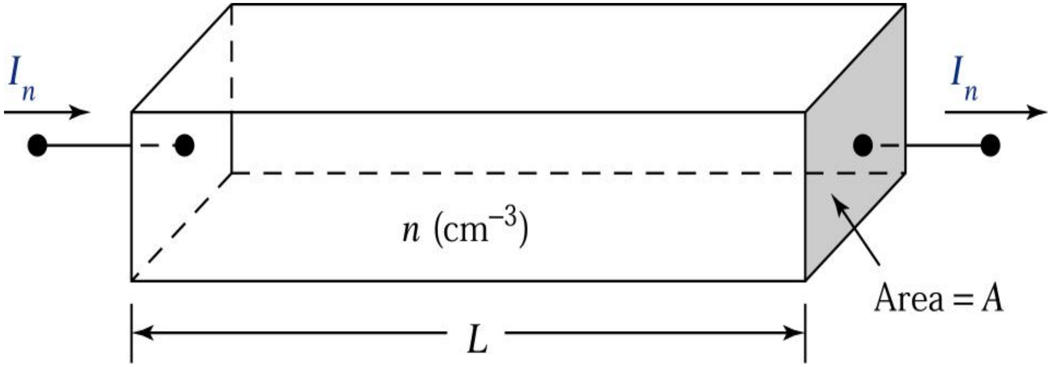
Similarly for holes in the valence band moving in the direction of the applied field:

$$\langle v_x \rangle = -\mu_n F$$

$$\langle v_p \rangle = \mu_p F$$

Carrier transport phenomena

Drift current density



The electron current density can be found by summing the product of charge and velocity for all electrons per unit volume,

$$J_n = \frac{I_n}{A} = -qn\langle v_x \rangle = qn\mu_n F$$

Similarly for holes, $$J_p = \langle qp v_x \rangle = qp\mu_p F$$

Carrier transport phenomena

CONDUCTIVITY

The total drift current density is simply the sum of both electron and hole current densities,

$$J = J_n + J_p$$

$$J = \left(qn\mu_n + qp\mu_p\right)F$$

↓

$$\sigma = q\left(n\mu_n + p\mu_p\right)$$

conductivity

Carrier transport phenomena

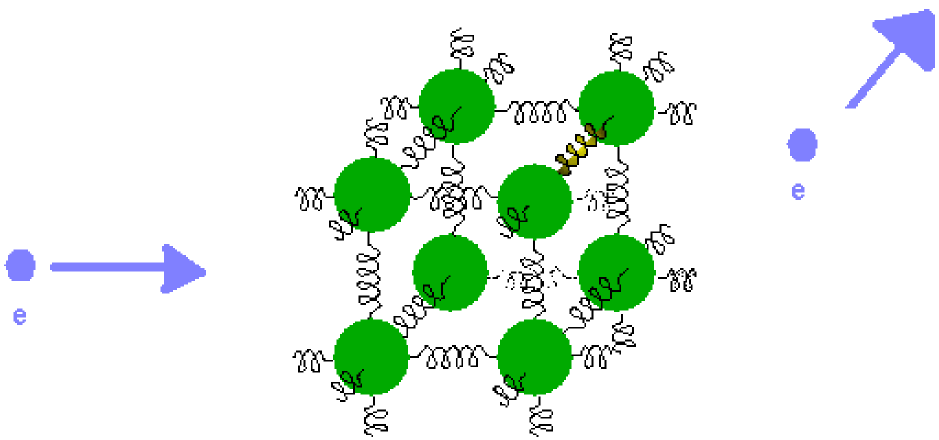
MOBILITY

As it can be seen, the mobility of free carries is related directly to the mean free time between collisions ($\bar{t}$), which in turn is determined by the various scattering mechanisms. The most important are:

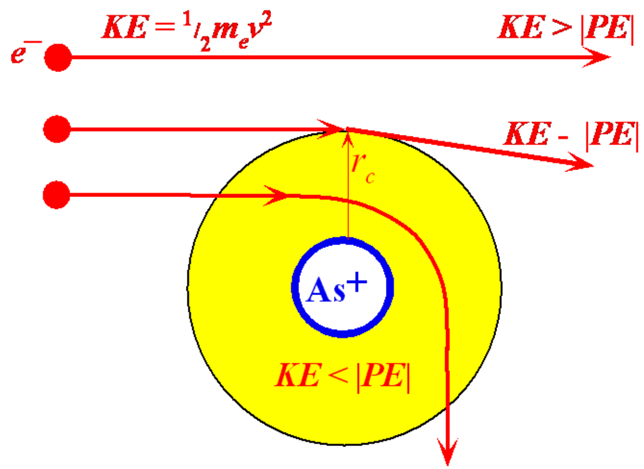
a) ***Lattice scattering*** results from the thermal vibrations of the lattice at any temperature above absolute zero.

b) ***Impurity scattering*** results when a charge carrier travels past an ionized dopant impurity. The charge carrier path will be deflected due to Coulomb force interaction.

Carrier transport phenomena



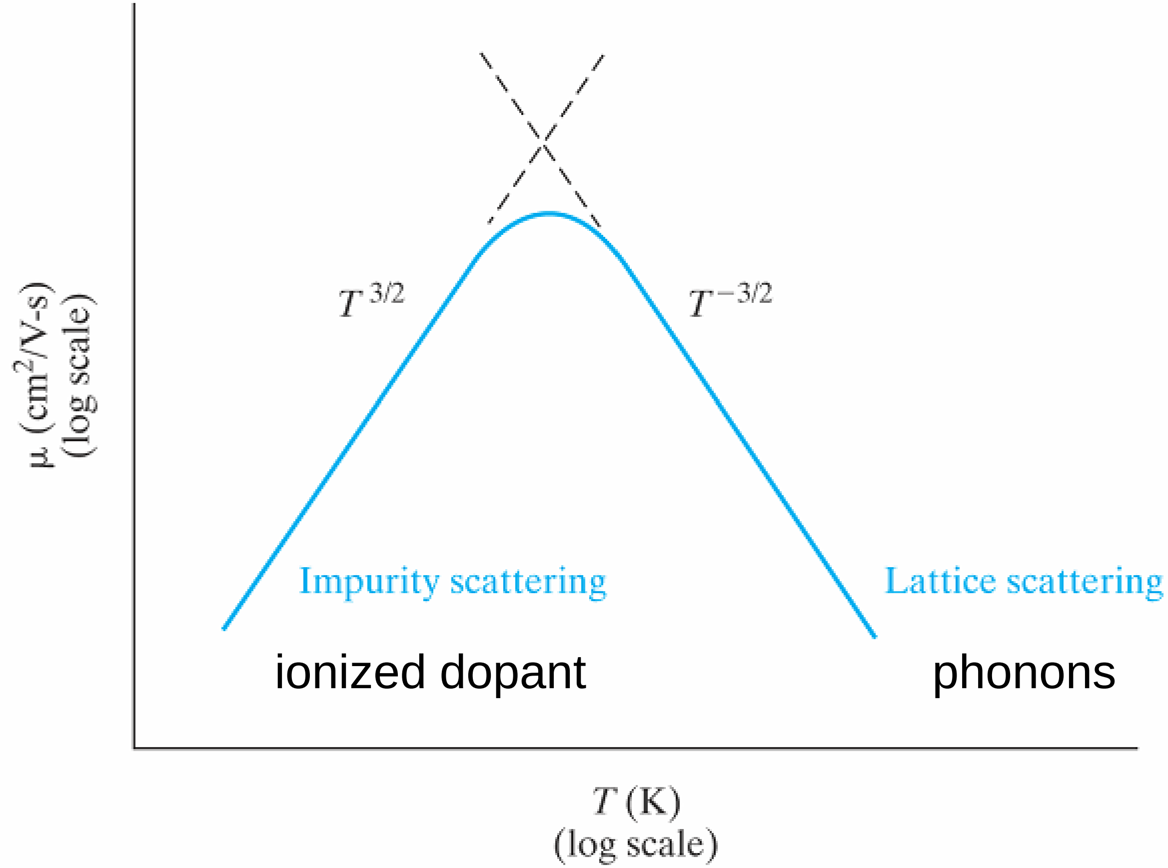
Scattering of electrons by phonons

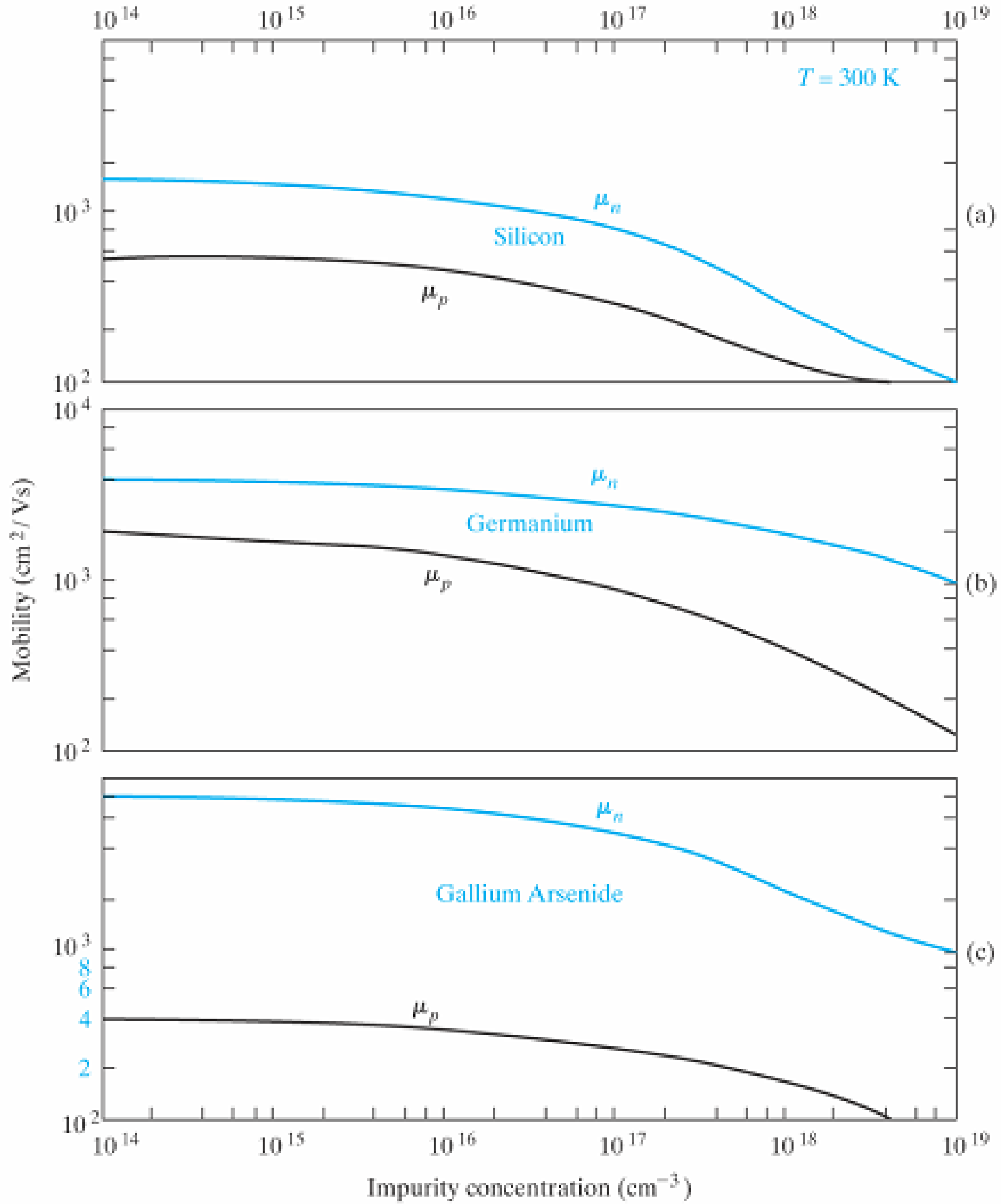


Scattering of electrons by an ionized impurity

Carrier transport phenomena

Approximate temperature dependence of mobility with both lattice and impurity scattering.





Variation of mobility with the total doping impurity concentration for Si, Ge and GaAs at 300 K.

The mobility due to two or more scattering mechanism add inversely (Mathiesen´s rule):

$$\frac{1}{\mu} = \frac{1}{\mu_1} + \frac{1}{\mu_2} + \ldots$$

Carrier transport phenomena

HIGH-FIELD EFFECTS

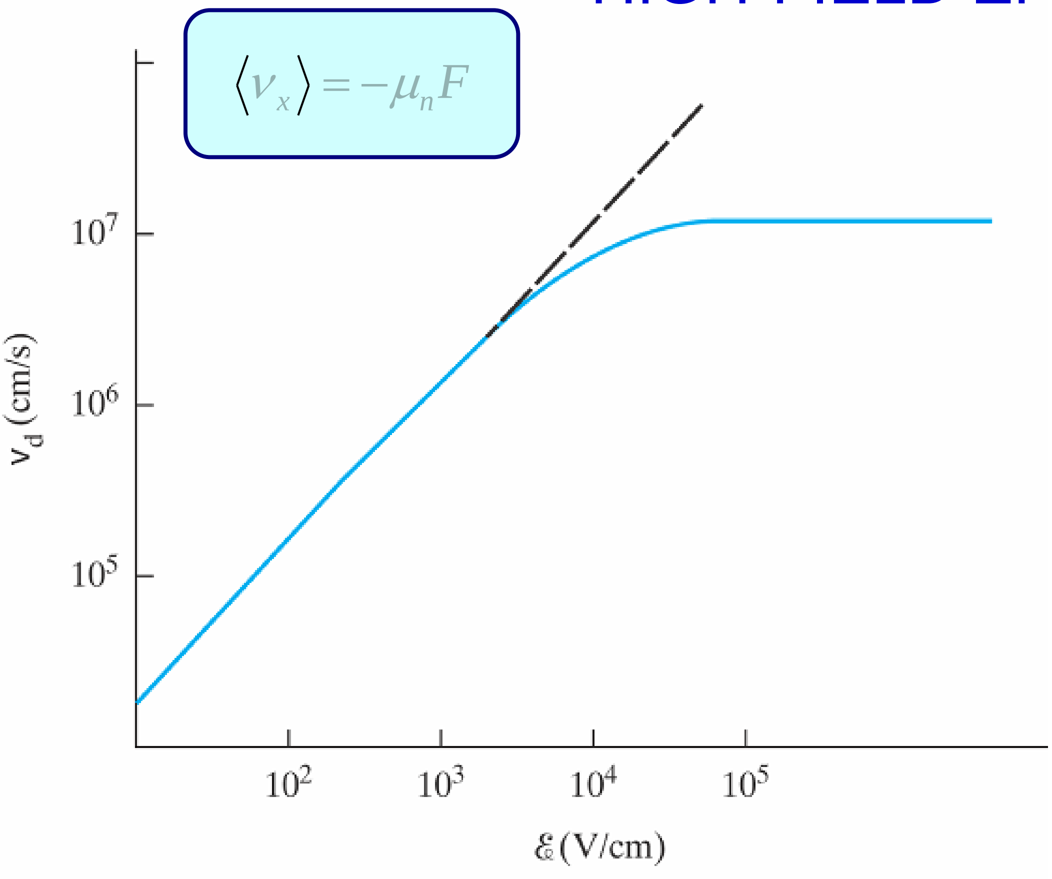


Figure 3.24

Saturation of electron drift velocity at high electric fields for Si.

In many cases an upper limit is reached for the carrier drift velocity in a high field. This limit occurs near v_{th} ($1\text{x}10^7$ cm/s), and represents the ***point at which added energy imparted by the electric field is transferred to the lattice rather than increasing the carrier velocity***.

Please, read 3.4.5 and 3.5 sections