

Chapter 3-2. Diffusion and band bending

We will learn two new topics in this lecture:

Diffusion – a process whereby particles tend to spread out or redistribute as a result of their random thermal motion, migrating on a macroscopic scale from regions of high particle concentration to region of low particle concentration.

Examples of diffusion:

Perfume in a room

Ink drop in a bottle of water

Hot point probe measurements

Band bending – resulting from the presence of electric field inside a semiconductor. No band bending means the electric field is zero.

Hot-point probe measurement

This is a commonly used technique for determining whether a semiconductor is p-type or n-type.

Carriers diffuse more rapidly near the *hot* probe. This leads to a *particle* current away from the hot probe and an *electrical* current away (p-type) or towards (n-type) the hot probe.

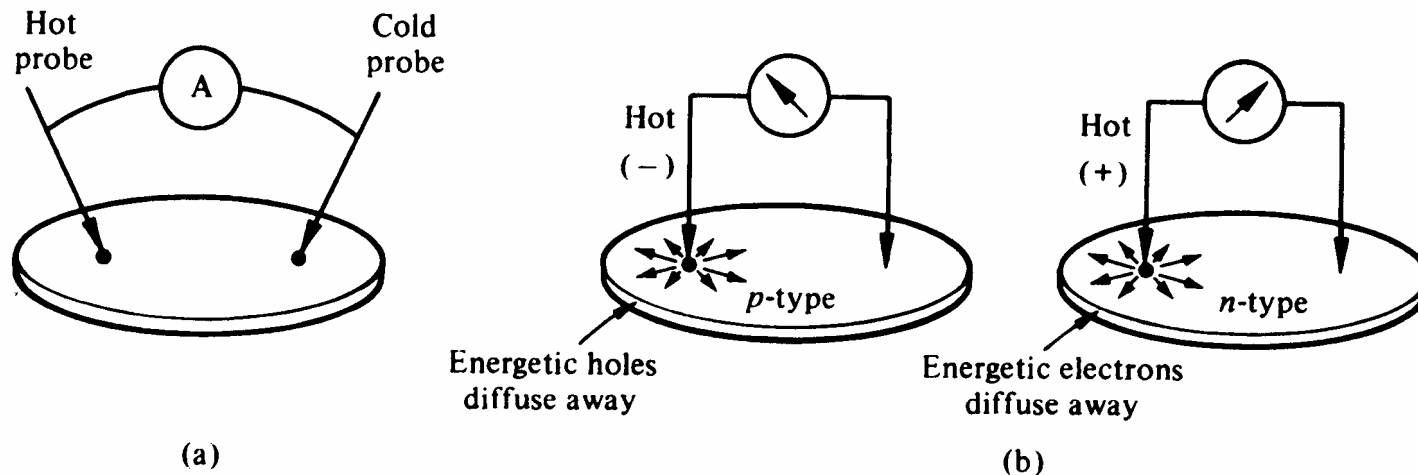


Figure 3.13

Diffusion current

- For diffusion to occur, there must be a **concentration gradient**.
- Logically, greater the concentration gradient, greater the **flux of particles** diffusing from higher concentration region to lower concentration region.

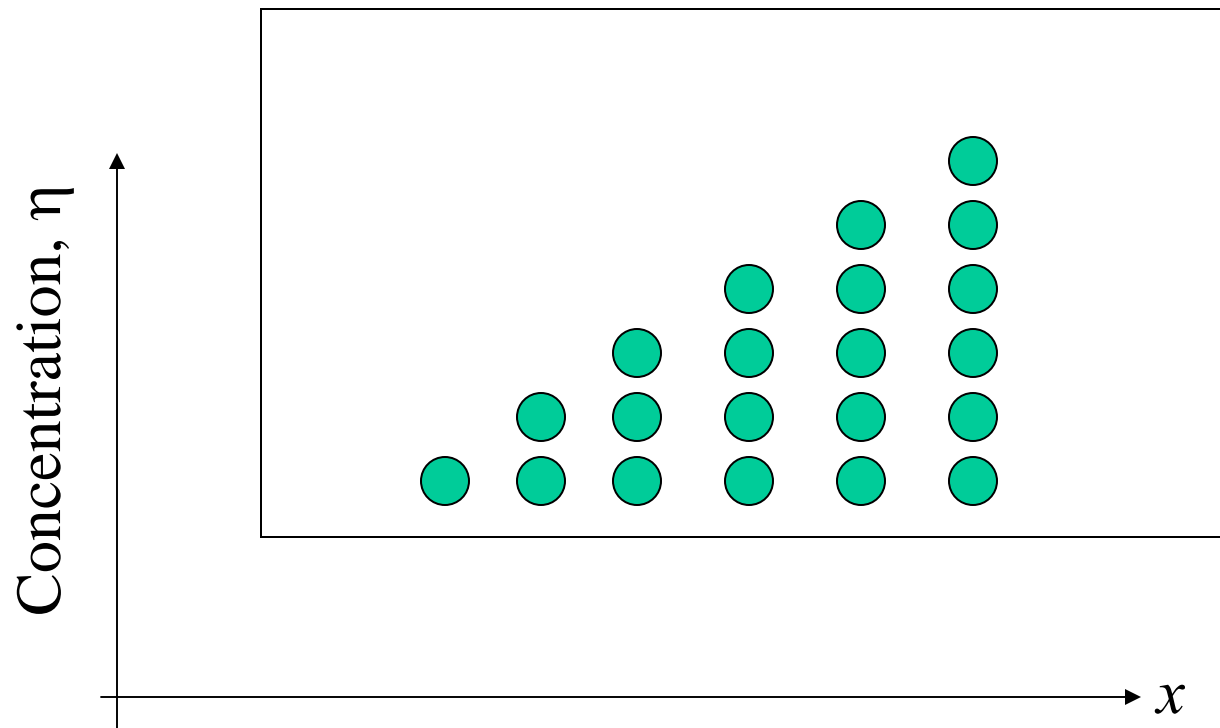
If F is the flux (i.e. the # of particles / (cm² s) crossing a plane perpendicular to the particle flow, then,

$$F = -D \frac{d\eta}{dx}$$

where D is called the diffusion coefficient. The **(-)** sign appears because for **positive** concentration gradient, $d\eta/dx$, the particles diffuse along the **negative** x direction.

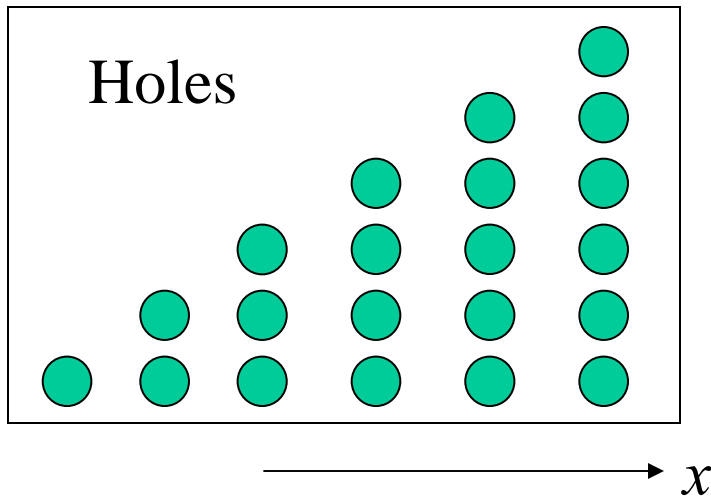
Particle diffusion

Concentration gradient, $d\eta/dx = \text{positive}$



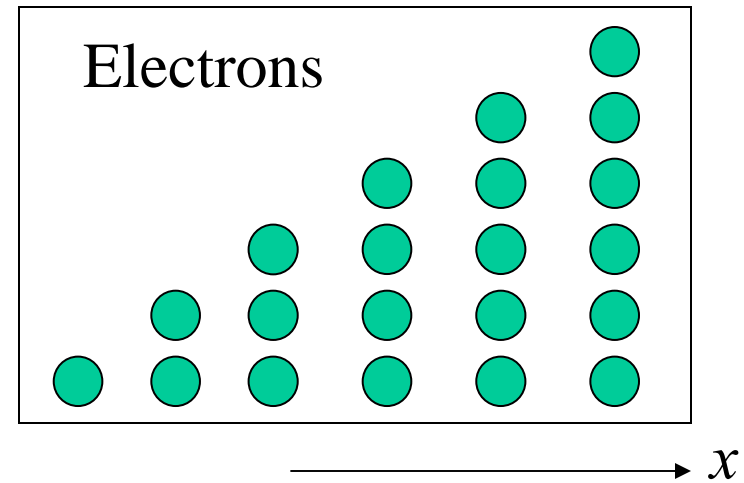
Particles flow along $-x$ direction

Diffusion current



hole flux \leftarrow
hole diffusion current \leftarrow

$$J_{p|diff} = -q D_p (dp / dx)$$



electron flux \leftarrow
electron diffusion current \rightarrow

$$J_{n|diff} = +q D_n (dn / dx)$$

What is the unit of diffusion coefficient, D ?

Total currents

$$J_p = J_{p|drift} + J_{p|diff} = [q\mu_p p E] + \left[-qD_p \frac{dp}{dx}\right]$$

↑ drift ↑ diffusion

$$J_n = J_{n|drift} + J_{n|diff} = [q\mu_n n E] + \left[qD_n \frac{dn}{dx}\right]$$

The total current flowing in semiconductor is given by:

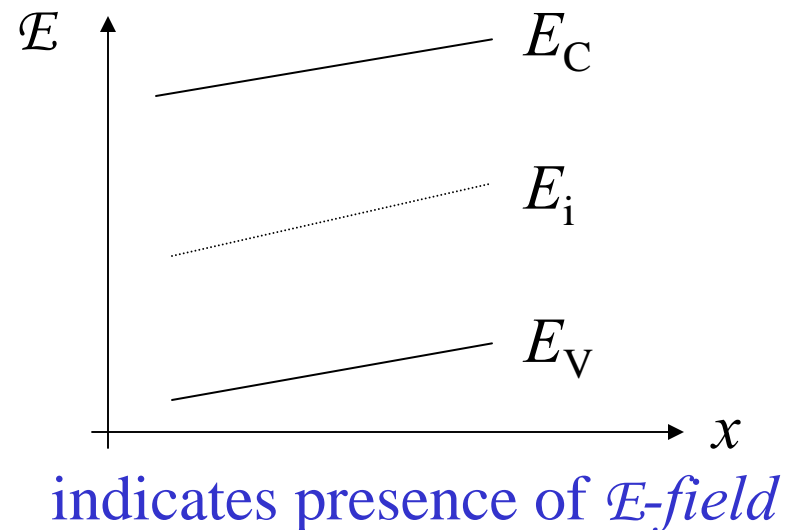
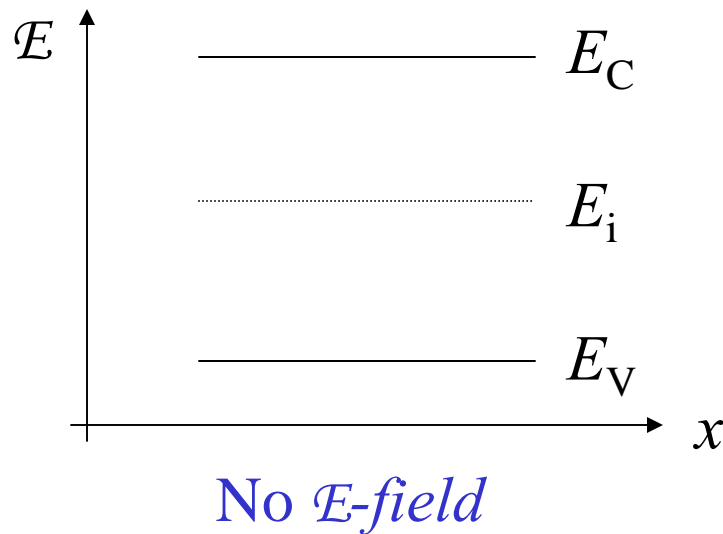
$$J = J_n + J_p$$

Band bending

Band diagram represents energies of electrons – so far we have drawn it as independent of position.

When *E-field* is present, E_C and E_V change with position - called “band-bending”.

This is a way to represent that an *E-field* is present.



Band bending and electrostatic variables

Diagram represents total energy of electrons with x

$$\text{K.E.} = E - E_C \text{ for electrons}$$

$$\text{P.E.} = E_C - E_{\text{ref}} \text{ for electrons}$$

From elementary physics

$$\text{P.E.} = -qV \text{ for electrons}$$

$$V = -(1/q)(E_C - E_{\text{ref}})$$

$$\mathcal{E} = - (dV / dx) = (1/q) (dE_C / dx)$$

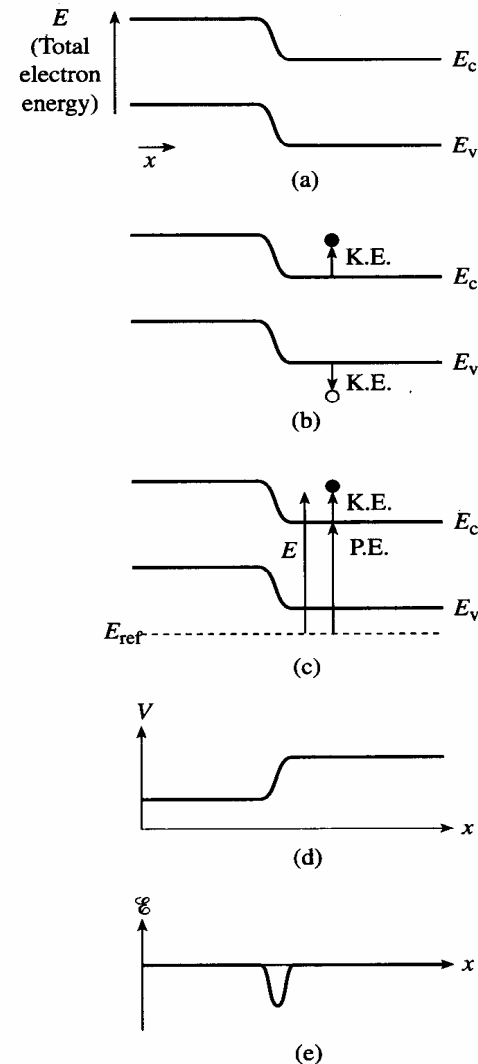


Figure 3.10

Band bending

Crudely, inverting E_C (in eV) versus x diagram results in electrostatic potential V (in Volts) versus x diagram. Similar to potential energy, V is relative with respect to some arbitrary reference.

$$V = -\frac{1}{q} (E_C - E_{\text{ref}})$$

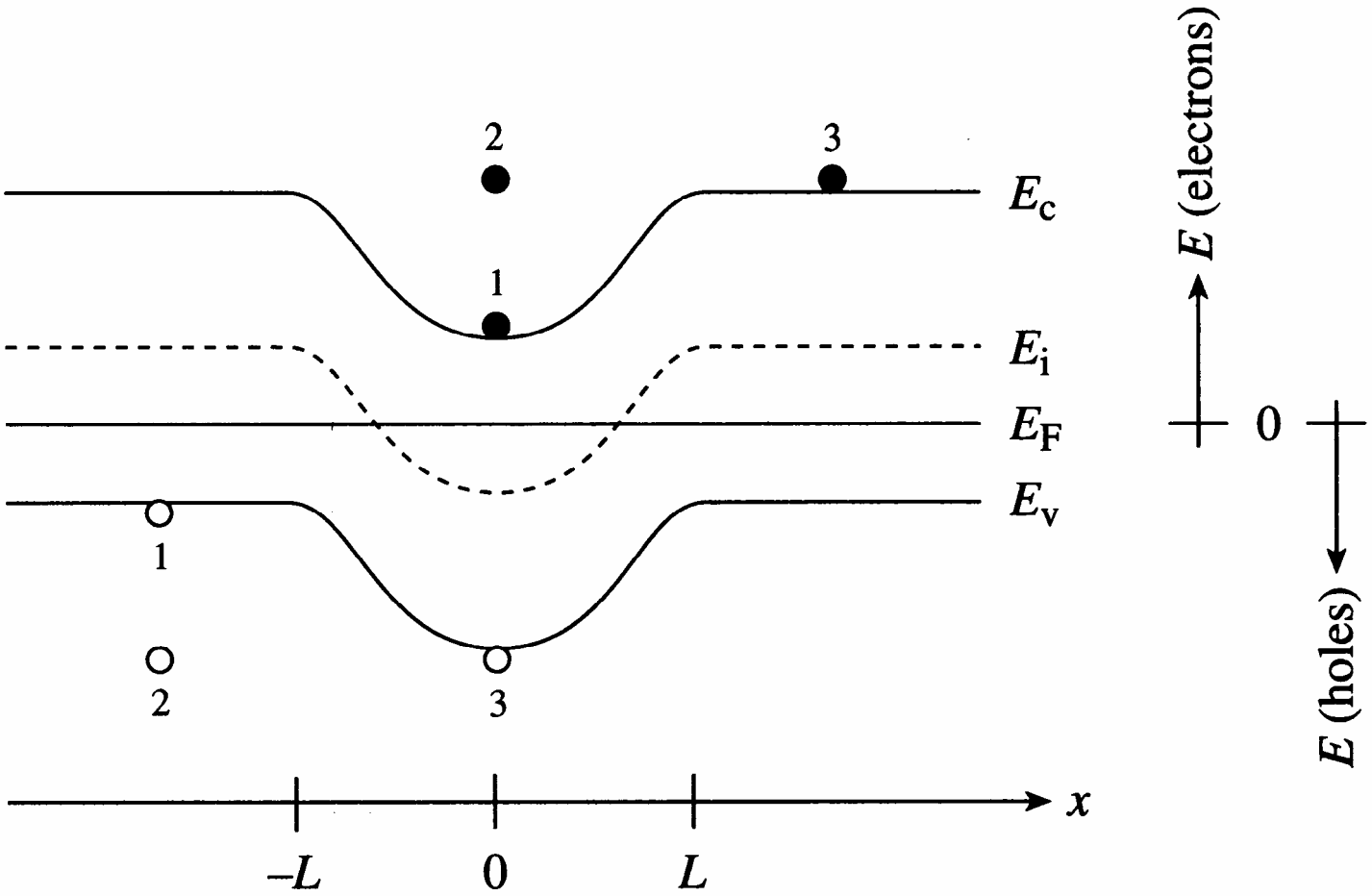
If $E_C - E_{\text{ref}}$ is given in eV, we use $e = 1.6 \times 10^{-19}$ C to convert from eV to Joules. Thus, values of V in Volts are numerically equal to $E_C - E_{\text{ref}}$ expressed in eV.

The slope of E_C (energy in eV) versus x diagram gives the \mathcal{E} -field versus x plot.

$$\mathcal{E} = \frac{1}{q} \frac{dE_C}{dx} = \frac{1}{q} \frac{dE_V}{dx} = \frac{1}{q} \frac{dE_i}{dx}$$

\mathcal{E} -field expressed in V/cm will be numerically equal to dE_i / dx if E_i is in eV and x in cm

Example 1: (Exercise 3.2) Plot electrostatic potential, V , and \mathcal{E} -field, \mathcal{E} , versus x for the case shown below.



Review

$$\rho = \frac{1}{qp\mu_p + qn\mu_n}$$

Resistivity formula

$$J_{\text{drift}} = J_{n|\text{drift}} + J_{p|\text{drift}} = q(\mu_n n + \mu_p p)\mathcal{E}$$

Drift current density

$$J_{n|\text{diff}} = qD_n \frac{dn}{dx} \quad \text{and} \quad J_{p|\text{diff}} = -qD_p \frac{dp}{dx}$$

Diffusion current density

$$J_p = J_{p|\text{drift}} + J_{p|\text{diff}} = qp\mathcal{E} + (-)qD_p \frac{dp}{dx}$$

$$J_n = J_{n|\text{drift}} + J_{n|\text{diff}} = qn\mathcal{E} + qD_n \frac{dn}{dx}$$

*Total hole and
electron current
density*

$$J = J_n + J_p$$

Total current density