FoP 3B Part II

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Room 151

Lecture 5: pn junction (part I)

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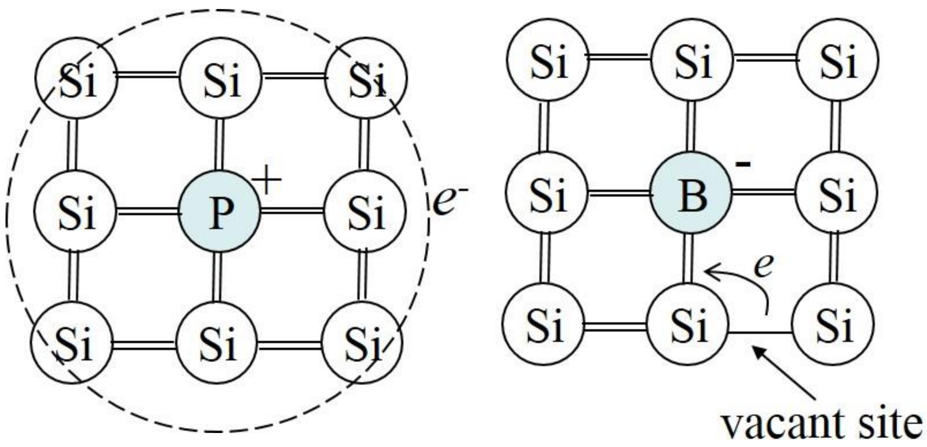
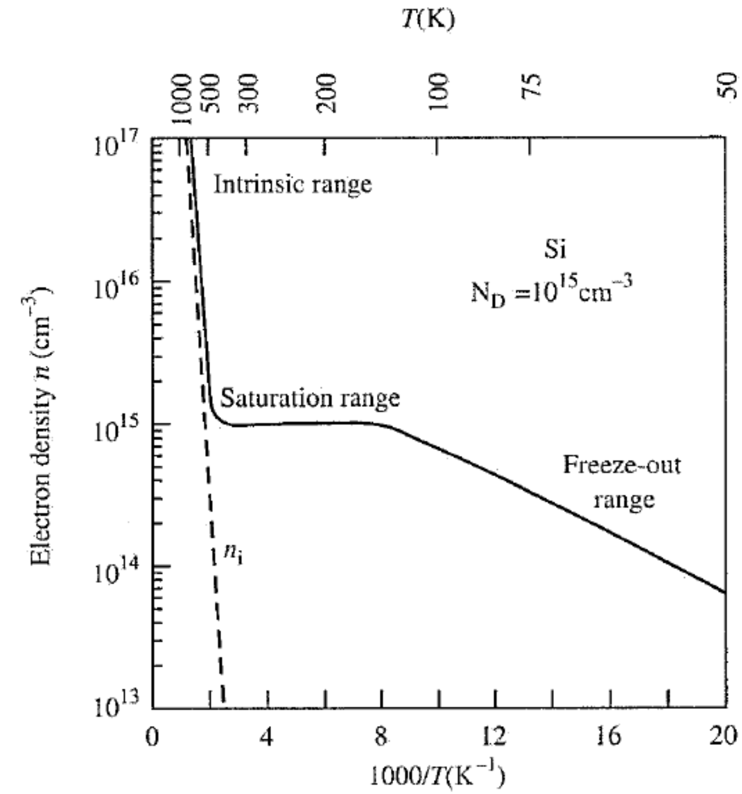
Summary of Lecture 4



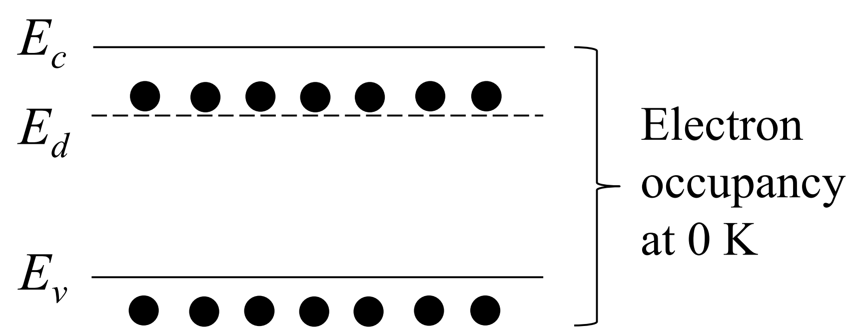
Donor and acceptor 'impurities'



Temp dependence of doping

Carrier concentrations and Fermi level (e.g. *n*-type semiconductor):

$$n \sim N_D$$
$$p \sim n_i^2/N_D$$
$$\mu = E_c - kT\ln\left(\frac{N_c}{N_D}\right)$$



Aim of today's lecture

► To describe the *equilibrium** properties of a pn-junction

Key concepts:

-Depletion approximation

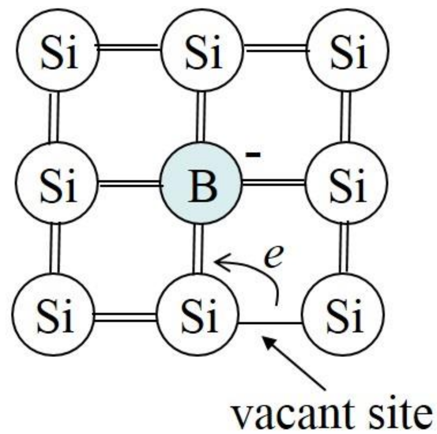
-derive electric field and potential for pn-junction

* Assumes no light or electrical biasing.

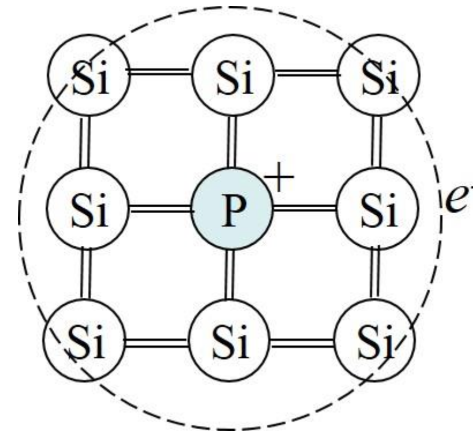
What happens when we bring p- and n-doped regions together?

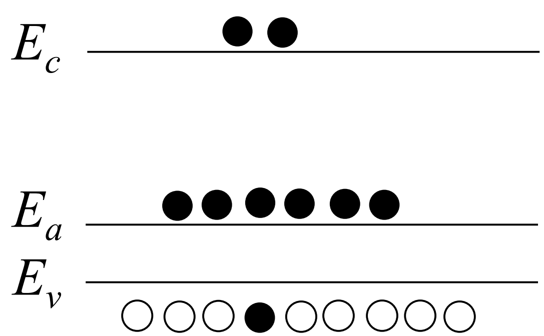
p-type Si	*n*-type Si

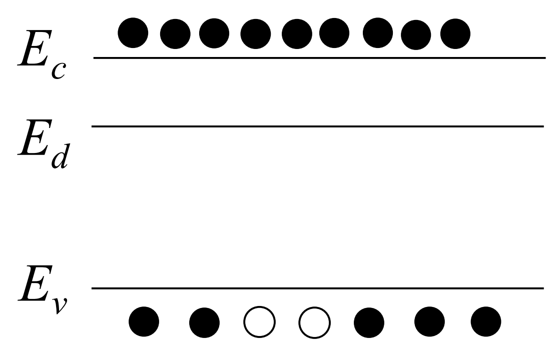
p-region



n-region

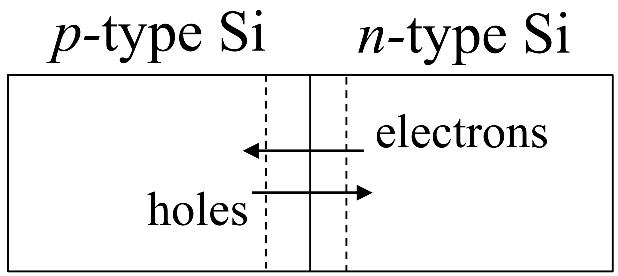


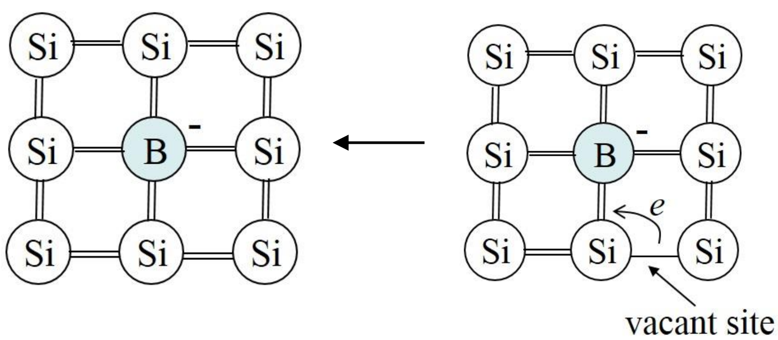




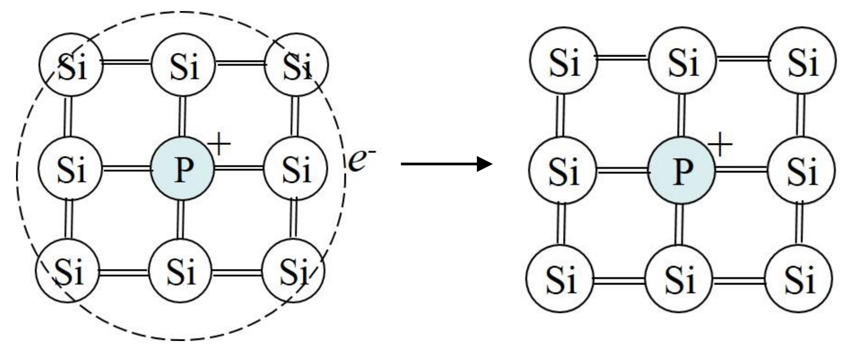
- Concentration gradient for electrons and holes.
- Electrons diffuse to the p-region and holes diffuse to the n-region.

Carrier diffusion and built-in electric field

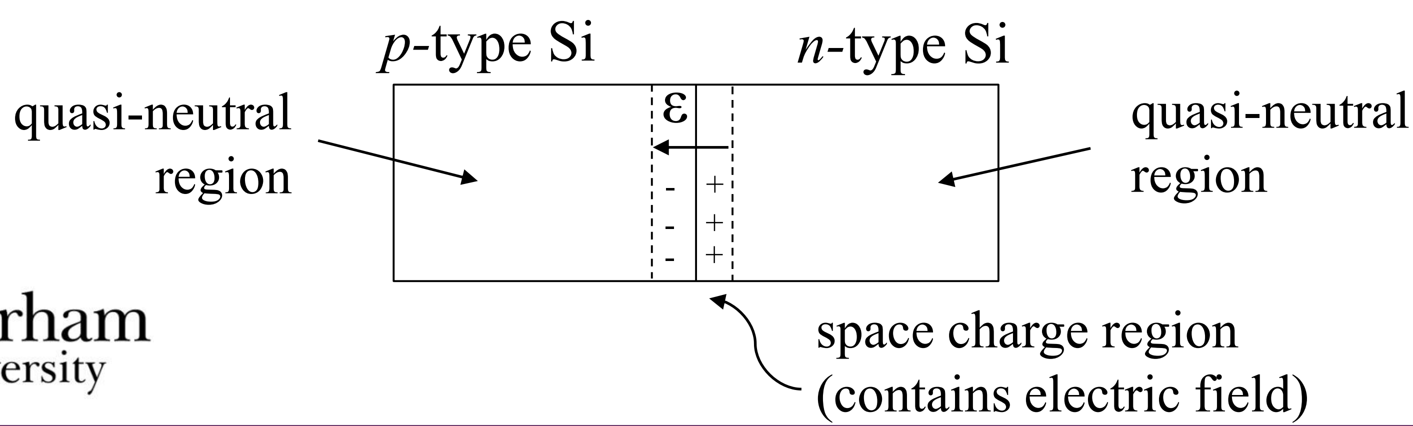




Net negative charge from *ionised* acceptors



Net positive charge from *ionised* donors



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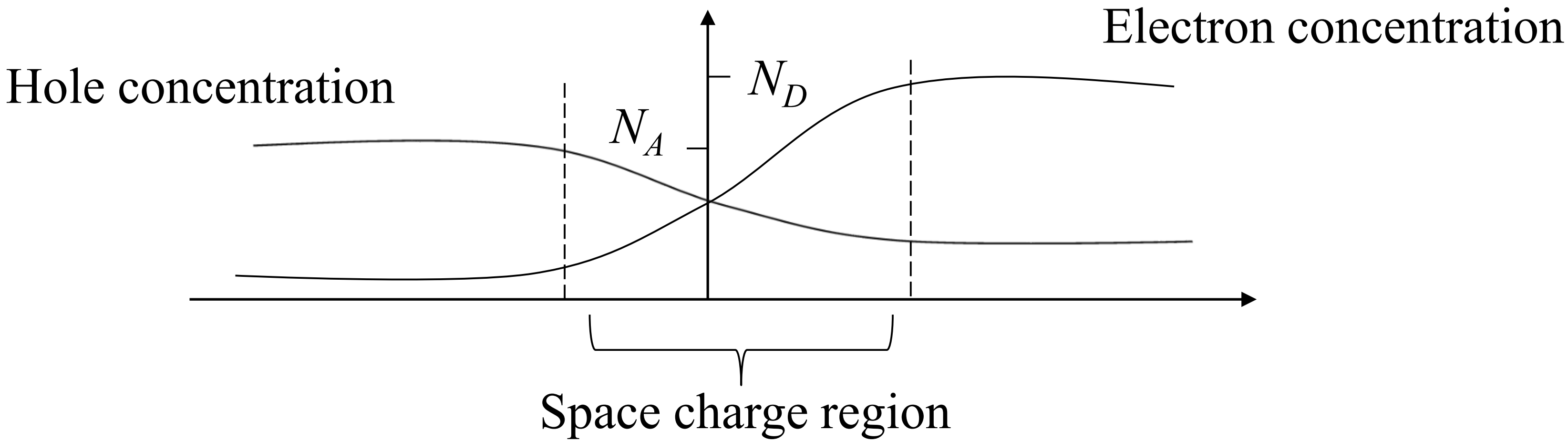
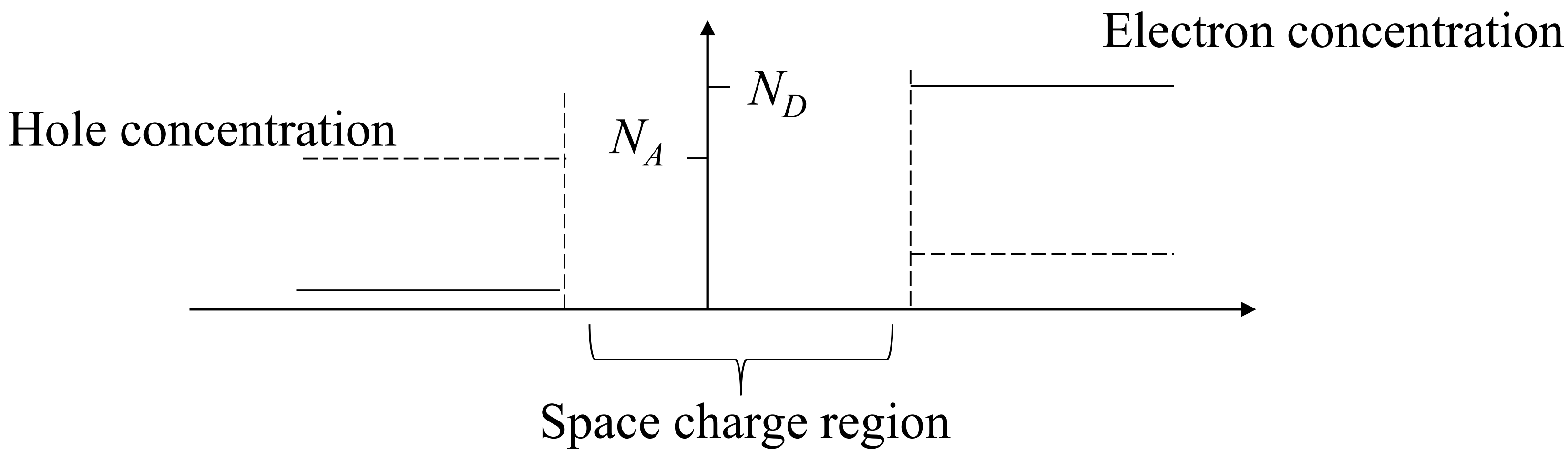
The depletion approximation

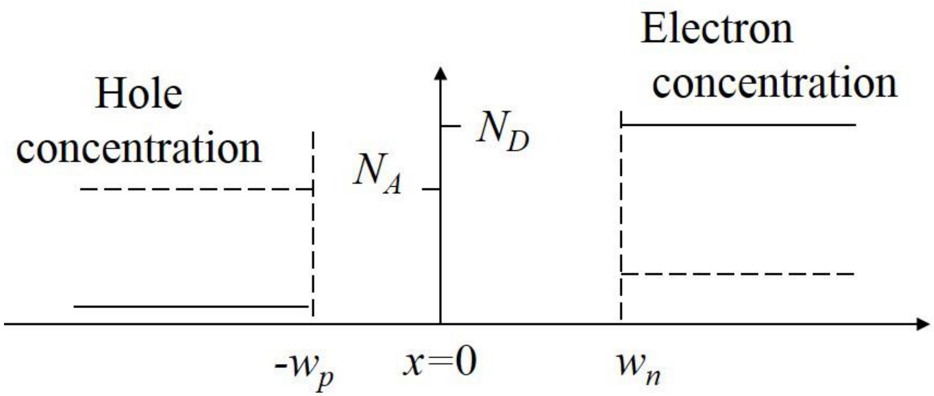
Expected carrier diffusion profile:



Depletion approximation (no carriers within space charge region):



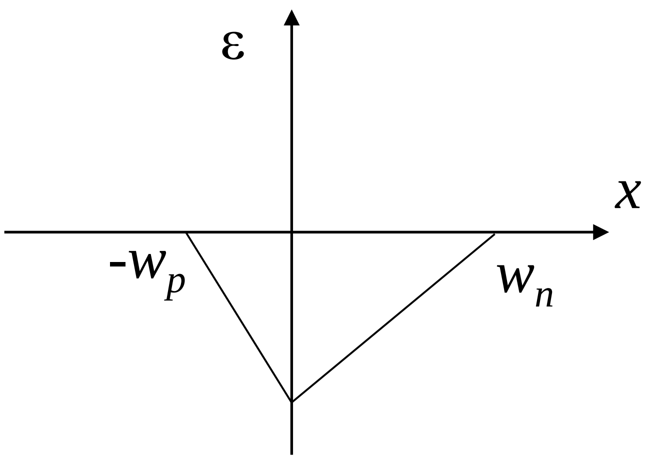
Built-in electric field



Gauss' law:

$$\vec{\nabla}\cdot\vec{\mathcal{E}} = \frac{d\mathcal{E}}{dx} = \frac{\rho(x)}{\epsilon_r\epsilon_0}$$

$$\rho(x) = \begin{cases} -eN_A & -w_p < x < 0 \\ eN_D & 0 < x < w_n \\ 0 & \text{elsewhere} \end{cases}$$



$$\Rightarrow \mathcal{E}(x) = \begin{cases} -\dfrac{eN_A}{\epsilon_r\epsilon_0}(x+w_p) & -w_p < x < 0 \\ \dfrac{eN_D}{\epsilon_r\epsilon_0}(x-w_n) & 0 < x < w_n \end{cases}$$

Continuity of electric field at the boundary $x = 0$ gives:

$$N_A w_p = N_D w_n$$

(charge neutrality condition)

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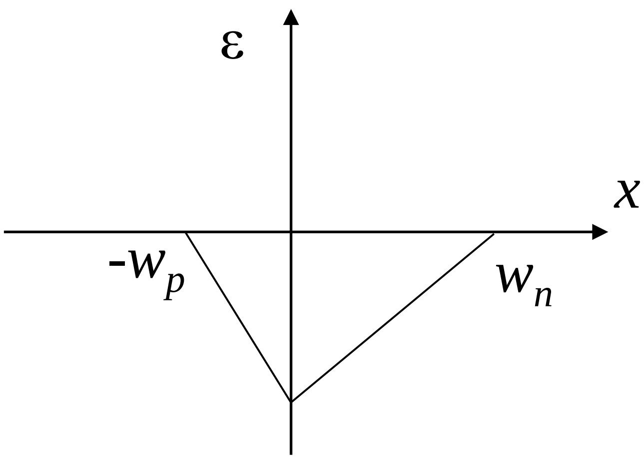
Electric potential

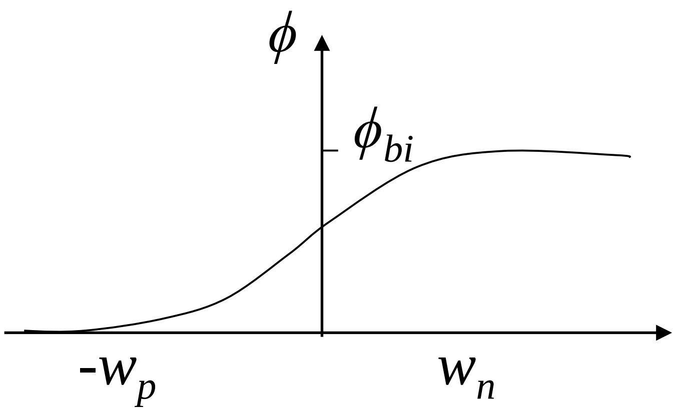
From $\vec{\mathcal{E}} = -\vec{\nabla}\phi$ (ϕ = electrostatic potential)



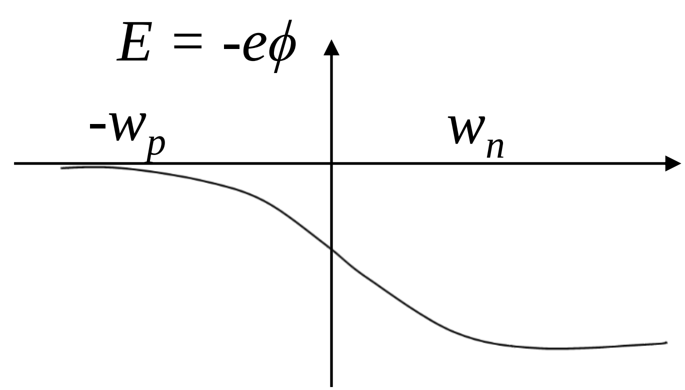
$$\varepsilon(x) = \begin{Bmatrix} -eN_A(x+w_p)/\epsilon_r\epsilon_0 \\ eN_D(x-w_n)/\epsilon_r\epsilon_0 \\ 0 \end{Bmatrix} \qquad \begin{matrix} -w_p < x < 0 \\ 0 < x < w_n \\ \text{elsewhere} \end{matrix}$$

$$\phi(x) = \begin{matrix} \dfrac{eN_A}{2\epsilon_r\epsilon_0}(x+w_p)^2 & -w_p < x < 0 \\ \phi_{bi} - \dfrac{eN_D}{2\epsilon_r\epsilon_0}(x-w_n)^2 & 0 < x < w_n \end{matrix}$$

(ϕ_{bi} = built-in potential)

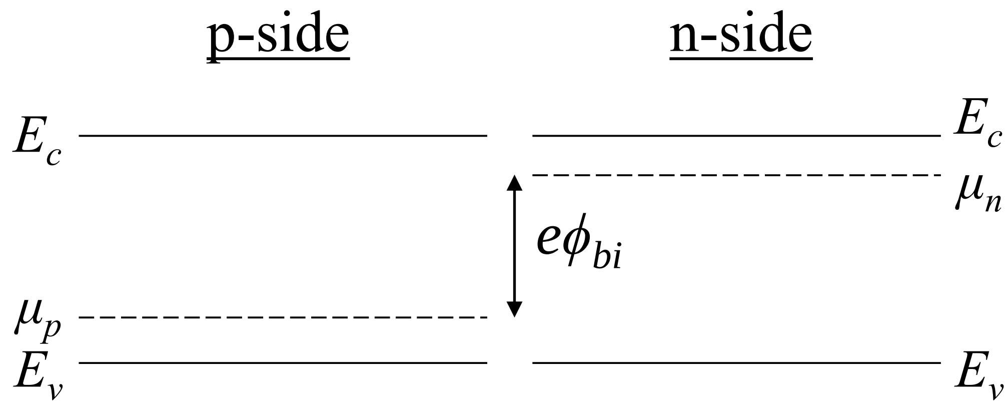


Potential

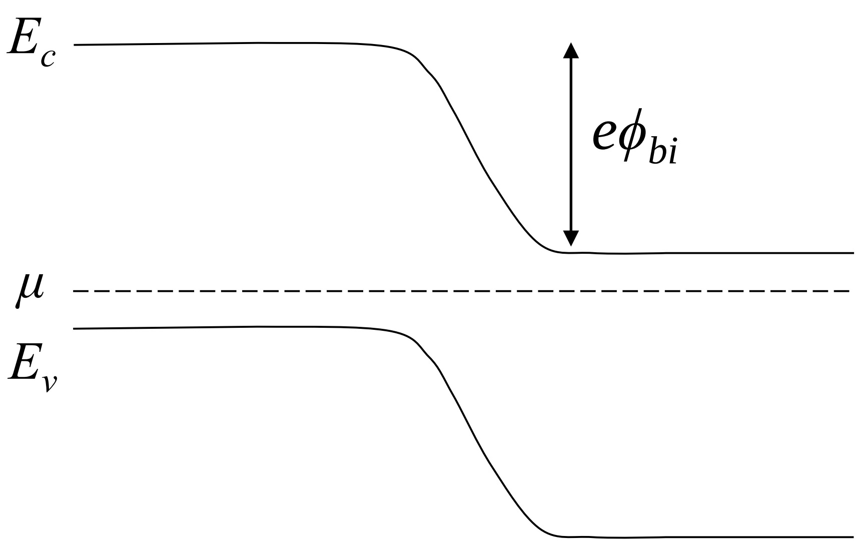


Electron energy

Energy level diagram for pn-junction



Before contact (unequal chemical potential $\mu = \frac{\partial G}{\partial n}$)



After contact

Note constant chemical potential after contact.