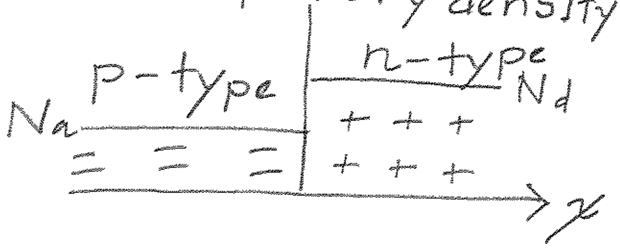
PN junction

$$N_d = \begin{cases} N_d & x > 0 \\ 0 & x < 0 \end{cases}$$

Impurity density

$$N_a = \begin{cases} 0 & x > 0 \\ N_a & x < 0 \end{cases}$$



Energies are shifted by $-e\phi(x)$.

For now take equilibrium ($\mu = \text{const.}$).

ϕ slowly varying on atomic scale.

$$n_c(x) = N_c(T)\, e^{-(\varepsilon_c - e\phi(x) - \mu)/k_B T}$$

$$p_v(x) = P_v(T)\, e^{-(\mu - \varepsilon_v + e\phi(x))/k_B T}$$

Far away from junction

$$N_d = n_c(\infty) = N_c(T)\, e^{-(\varepsilon_c - e\phi(\infty) - \mu)/k_B T}$$

$$N_a = p_v(-\infty) = P_v(T)\, e^{-(\mu - \varepsilon_v + e\phi(-\infty))/k_B T}$$

$$\rightarrow \quad e\phi(\infty) - e\phi(-\infty) = \varepsilon_c - \varepsilon_v + k_B T \ln\left[\frac{N_d N_a}{N_c P_v}\right]$$

and $$e\Delta\phi = E_g + k_B T \ln\left[\frac{N_d N_a}{N_c P_v}\right].$$

$$n_c(x) = N_c(T)\, e^{-\beta(\varepsilon_c - e\phi(x) - \mu)} \qquad x > 0$$

$$N_d = n_c(\infty) = N_c(T)\, e^{-\beta(\varepsilon_c - e\phi(\infty) - \mu)}$$

$$n_c(x) = N_d\, e^{-\beta(e\phi(\infty) - e\phi(x))}$$

$$p_v(x) = P_v(T)\, e^{-\beta(\mu - \varepsilon_v + e\phi(x))} \qquad x < 0$$

$$N_a = P_v(-\infty) = P_v(T)\, e^{-\beta(\mu - \varepsilon_v + e\phi(-\infty))}$$

$$p_v(x) = N_a\, e^{-\beta(e\phi(x) - e\phi(-\infty))}$$

$$\rho(x) = +e\, p_v(x) - eN_a \qquad x < 0$$

$$= +eN_d - e n_c(x) \qquad x > 0$$

$$|\xleftarrow{\quad d_p \quad}\!\!|\!\!\xrightarrow{\quad d_n \quad}|$$

$$-\phi''(x) = -\frac{eN_a}{\varepsilon} \qquad -d_p < x < 0$$

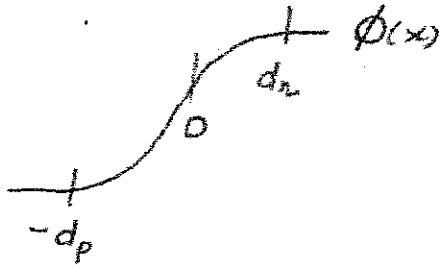
$$-\phi''(x) = \frac{eN_d}{\varepsilon} \qquad 0 < x < d_n$$

$$\phi(x) = \phi(-\infty) + \frac{1}{2}\frac{eN_a}{\varepsilon}(x + d_p)^2 \qquad -d_p < x < 0$$

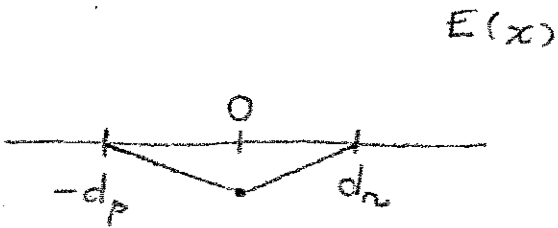
$$\phi(x) = \phi(\infty) - \frac{1}{2}\frac{eN_d}{\varepsilon}(x - d_n)^2 \qquad 0 < x < d_n$$

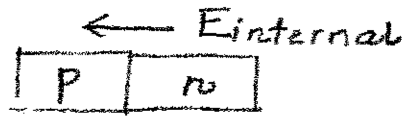
(i) $\phi'(0) = \dfrac{eN_a}{\varepsilon} d_p = \dfrac{eN_d}{\varepsilon} d_n$ $\qquad d_n, d_p \sim 10^2$ to $10^4\,\text{Å}$

(ii) $\phi(0) = \phi(-\infty) + \dfrac{1}{2}\dfrac{eN_a}{\varepsilon} d_p^2 = \phi(\infty) - \dfrac{1}{2}\dfrac{eN_d}{\varepsilon} d_n^2$



$$E(x) = -\phi'(x) = -\frac{eN_a}{\varepsilon}(x + d_p) \qquad x<0$$
$$= +\frac{eN_d}{\varepsilon}(x - d_n) \qquad x>0$$





$h \longrightarrow$ recomb. (against E)

$\longleftarrow h$ generation (not many)

$V_{high} \xrightarrow[E_{applied}]{} V_{low}$

$$J_h^{rec} \propto e^{-e[\Delta\phi_0 - V]/k_BT}$$

$$J_h^{rec} = J_h^{gen} \big|_{V=0}$$

$$J_h = J_h^{rec} - J_h^{gen} = J_h^{gen}\left(e^{eV/k_BT} - 1\right)$$

$$j = e\left(J_h^{gen} + J_e^{gen}\right)\left(e^{eV/k_BT} - 1\right)$$