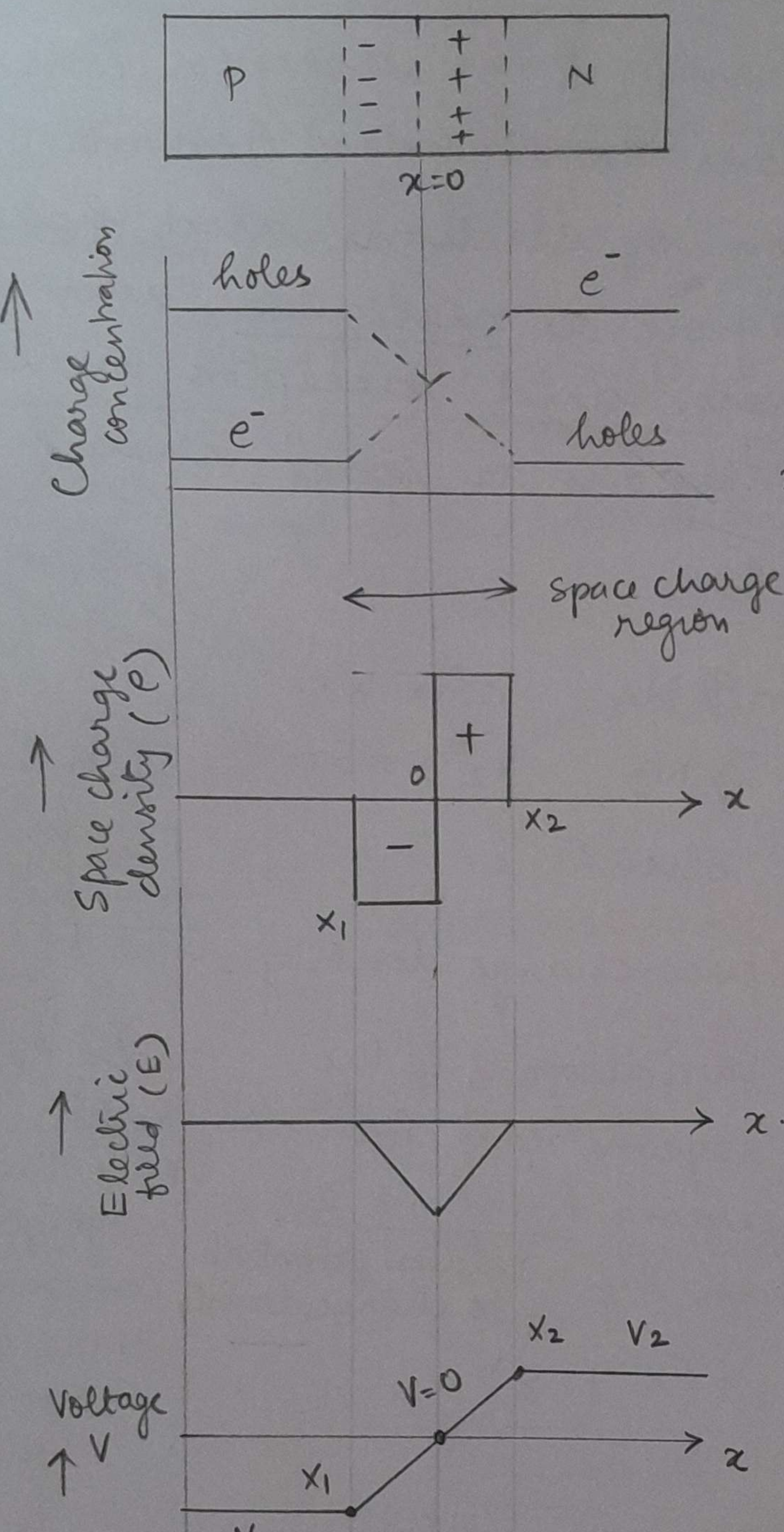
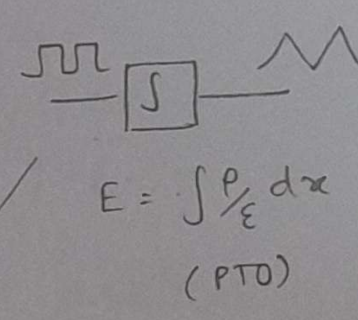
ormation of PN Junction :-





$E = \int \frac{\rho}{\varepsilon} \, dx$

(PTO)

$E = \frac{-\rho}{\varepsilon}$

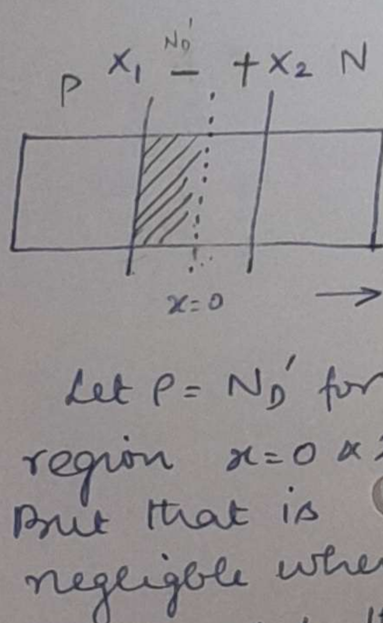
Derivation for Width of the Barrier (Depletion layer)

In this analysis, let us consider alloy junction in which there is an abrupt change from acceptor ions on p-side to donor ions on N-side. Assume that the concentration of electrons and holes in the depletion region is <u>negligible</u> and that all of the <u>donors. and acceptors are ionized.</u>

Hence, the regions of space charge may be described as

$\boxed{\frac{\text{charge}}{\text{unit Area}}}$

$$\rho = -qN_A, \quad 0 > x > x_1$$
$$\rho = +qN_D, \quad x_2 > x > 0$$
$$\rho = 0 \text{ elsewhere.}$$



where ρ = space charge density.

The potential variation in the space charge region can be calculated using <u>Poisson's eqn</u>, which is given by

relates potential to charge density

$$\nabla^2 V = \frac{-\rho(x, y, z)}{\varepsilon_0 \varepsilon_r}.$$

ε_r = relative permittivity

The relevant equation for the required

$$\frac{d^2 v}{dx^2} = \frac{-\rho}{\varepsilon_0 \varepsilon_r}.$$

Let $\rho = N_D'$ for region $x = 0$ & x_1

But that is negligible when compared to the total impurity concentration N_D

$N_D' <<< N_D$

So, $N_D' \simeq N_D$

$\nabla^2 V = -\rho/\varepsilon$

$E = -\nabla V$

$E = -\int \frac{\rho}{\varepsilon}$

$\int E \cdot dx = V$

an Applying the above equation to the P-side of the junction, we get

$$\frac{d^2V}{dx^2} = \frac{qN_A}{\varepsilon_0 \varepsilon_r} \Big/ \frac{-qN_D}{\varepsilon_0 \varepsilon_r} \quad \because \rho = -qN_A$$

Integrating twice,

$$E = -\left(\frac{qN_A x}{\varepsilon_0 \varepsilon_r}\right)$$

$$V = \frac{qN_A x^2}{2\varepsilon_0 \varepsilon_r} + Cx + D \qquad E = -\left(\frac{dV}{dx}\right)$$

where C and D are constants of integration

From the fig:

V = 0 at $\underline{x = 0}$ and hence $D = 0$

when $\underline{x < X_1}$ on the P-side, the potential is constant and so,

$$\left[\because 0 = \frac{qN_A(0)}{2\varepsilon_0 \varepsilon_r} + C(0) + D\right]$$

$$\Rightarrow D = 0$$

$$\frac{dV}{dx} = 0 \text{ at } x = X_1.$$

Hence,

$$0 = \frac{2qN_A X_1}{2\varepsilon_0 \varepsilon_r} + CX_1 \qquad \left[\because \frac{dV}{dx} = \frac{2qN_A x}{2\varepsilon_0 \varepsilon_r}\right]$$

$$\therefore C = -\frac{qN_A X_1}{\varepsilon_0 \varepsilon_r}.$$

$$\therefore V = \frac{qN_A x^2}{2\varepsilon_0 \varepsilon_r} - \frac{qN_A X_1}{\varepsilon_0 \varepsilon_r} \cdot x$$

$$x = X_2 \;\Big|\; V_2 = -\frac{qN_D X_2^2}{2\varepsilon_0 \varepsilon_r} + \frac{qN_D X_2}{\varepsilon_0 \varepsilon_r} \cdot x_2$$

As $V = V_1$ at $x = X_1$, we have

$$V_1 = + \frac{q N_A}{\epsilon_0 \epsilon_r} \left[\frac{x^2}{2} - X_1 x \right] \Bigg|_{\text{at } x = X_1}$$

$$= \frac{+ q N_A}{\epsilon_0 \epsilon_r} \left[\frac{X_1^2}{2} - X_1^2 \right]$$

$$= + \frac{q N_A}{\epsilon_0 \epsilon_r} \left[- \frac{X_1^2}{2} \right]$$

$$\therefore \quad V_1 = - \frac{q N_A X_1^2}{2 \epsilon_0 \epsilon_r}$$

$\rho = + q N_D$

$V = - \frac{q N_D}{2 \epsilon_0 \epsilon_r} x^2 + Cx + D$

$\frac{dv}{dx}\Big|_{x = x_2} = 0$

$C = - \frac{q N_D X_2}{\epsilon_0 \epsilon_r}$

Same procedure when applied to N-side,

$$V_2 = + \frac{q N_D X_2^2}{2 \epsilon_0 \epsilon_r}$$

$q = N_A$

$x_1 A \Rightarrow \boxed{x_1 A N_A}$

$\therefore$ The Total built in potential or contact potential is V_0, where

$$V_0 = V_2 - V_1 = \frac{q}{2 \epsilon_0 \epsilon_r} \left[N_A X_1^2 + N_D X_2^2 \right]$$

The +ve charge on the N-side must be equal in magnitude to the negative charge on the P-side for the neutral specimen.

Hence, $\boxed{N_A X_1 = - N_D X_2}$

charge neutrality condition → all charge in a volume adds to zero.

$N_A x_1 A = - N_D x_2 A$

& Substituting this relation in the above equation,

and using the fact that X_1 is a negative quantity, we get

$$X_1 = -\left[\frac{2\epsilon_0\epsilon_r V_0}{q N_A\left(1+\frac{N_A}{N_D}\right)}\right]^{1/2}$$

$\frac{q N_A N_D (N_D + N_A)}{N_D}$

Similarly,

$$X_2 = \left[\frac{2\epsilon_0\epsilon_r V_0}{q N_D\left(1+\frac{N_D}{N_A}\right)}\right]^{1/2}$$

The total depletion width $W = X_2 - X_1$ and hence,

$W^2 = X_1^2 + X_2^2 - 2X_1X_2$, and then

(we take this for easy simplification)

Substituting for X_1 and X_2 from the above equations, we find

$$W = \left[\frac{2\epsilon_0\epsilon_r V_0}{q}\left(\frac{N_A + N_D}{N_A N_D}\right)\right]^{1/2}$$ ✓

Inference:

The depletion width 'W' is proportional to $(V_0)^{1/2}$.

(1)

$$x_2 = -\frac{N_A}{N_D} \cdot x_1$$

$$\therefore V_0 = \frac{q}{2\epsilon_0 \epsilon_r}\left[N_A x_1^2 + N_D \frac{N_A^2}{N_D^2} \cdot x_1^2\right]$$

$$\frac{2V_0 \epsilon_0 \epsilon_r}{q} = N_A x_1^2 + \frac{N_A^2}{N_D} x_1^2$$

$$\frac{2V_0 \epsilon_0 \epsilon_r}{q} = x_1^2\left[N_A + \frac{N_A^2}{N_D}\right]$$

$$x_1 = \left[\frac{2V_0 \epsilon_0 \epsilon_r}{q N_A\left[1 + \frac{N_A}{N_D}\right]}\right]^{1/2}$$

As x_1 = a $-$ve quantity

$$x_1 = -\left\{\frac{2V_0 \epsilon_0 \epsilon_r}{q N_A\left[1 + \frac{N_A}{N_D}\right]}\right\}^{1/2}$$

(2)

$$2 \times \left[\frac{2\epsilon V_0}{q \frac{N_A}{N_D}(N_D + N_A)}\right]^{1/2} \times \left[\frac{2\epsilon V_0}{q \frac{N_D}{N_A}[N_D + N_A]}\right]^{1/2}$$

$$= \frac{4\epsilon V_0}{q}\left[\frac{1}{\sqrt{\frac{N_A}{N_D}}\sqrt{N_D + N_A}\sqrt{\frac{N_D}{N_A}}\sqrt{N_D + N_A}}\right]^{1/2}$$

$$= \frac{4\epsilon V_0}{q(N_A + N_D)}$$

$$N_A x_1 = -N_D x_2$$

$$x_2 = \frac{-N_A x_1}{N_D}$$

$$\frac{2\epsilon V_0 N_D}{q N_A (N_A+N_D)} + \frac{2\epsilon V_0 N_A}{q N_D (N_A+N_D)} + \frac{4\epsilon V_0}{q(N_A+N_D)}$$

$$\left(N_A x_1^2 + \cancel{N_D} \frac{N_A^2 x_1^2}{N_D^{\cancel{2}}}\right)$$

$$\frac{2\epsilon V_0}{q(N_A+N_D)}\left[\frac{N_D}{N_A} + \frac{N_A}{N_D} + 2\right]$$

$$x_1^2 \left(N_A + \frac{N_A^2}{N_D}\right) \frac{q}{2\varepsilon_0 \varepsilon_r} = V_0 \quad \frac{N_D^2 + N_A^2}{N_A N_D} + 2$$

$$N_A\left(1 + \frac{N_A}{N_D}\right)$$

$$\frac{N_D^2 + N_A^2 + 2N_A N_D}{N_A N_D}$$

$$\left(\left[\frac{2V_0 \varepsilon_0 \varepsilon_r}{q N_A \left(1 + \frac{N_A}{N_D}\right)}\right]^{\frac{1}{2}}\right)$$

$$-2 x_1 x_2 = + \frac{2\epsilon_0 \epsilon_r V_0}{q\left[(N_A N_D)\left(1+\frac{N_A}{N_D}\right)\left(1+\frac{N_D}{N_A}\right)\right]^{\frac{1}{2}}}$$

$$= -\frac{2\epsilon_0 \epsilon_r V_0}{q(N_A+N_D)}$$

$$N_A x_1^2 + N_D$$

$$\int dx = x$$

$$x_1^2 = \frac{2\epsilon_0 \epsilon_r V_0}{q N_A \left(1 + \frac{N_A}{N_D}\right)}$$

$$\int x\,dx \qquad \frac{x^2}{2}$$

$$\frac{(N_A+N_D)^{\cancel{2}}}{\cancel{(N_A+N_D)}(N_A N_D)}$$

$$x_2^2 = \frac{2\epsilon_0 \epsilon_r V_0}{q N_D \left(1 + \frac{N_D}{N_A}\right)}$$

$$\boxed{= \frac{2\epsilon V_0}{q N_A \left(1 + \frac{N_A}{N_D}\right)} + \frac{2\epsilon V_0}{q N_D \left(1 + \frac{N_D}{N_A}\right)} + \frac{4\epsilon V_0}{q(N_A+N_D)}}$$