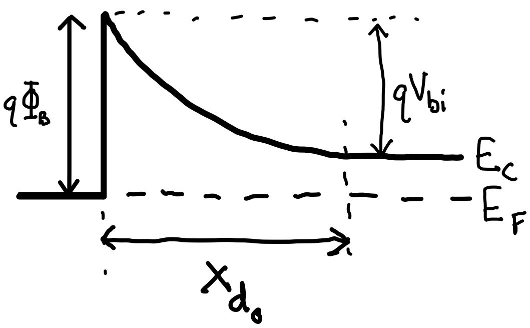
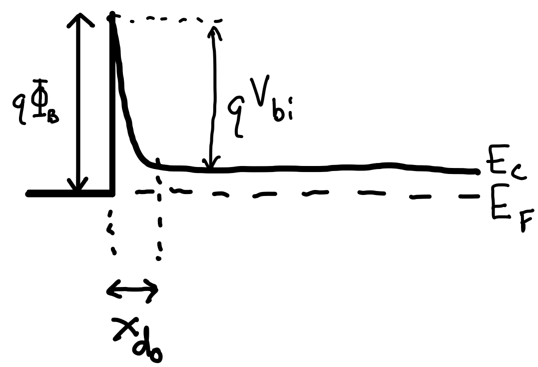
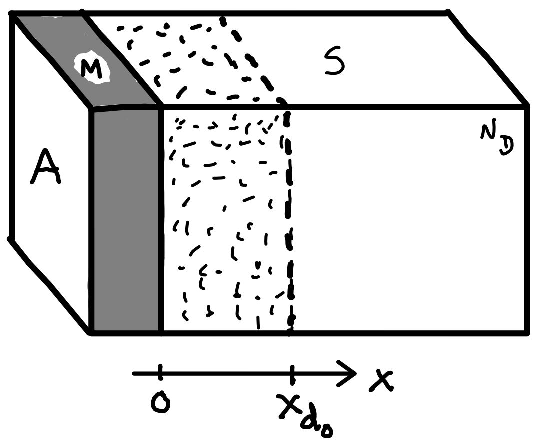
Metal - Semiconductor Junctions

Small N_D (Schottky):



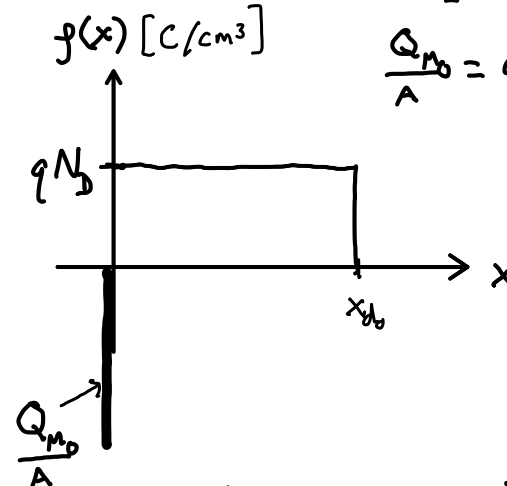
Large N_D (ohmic):



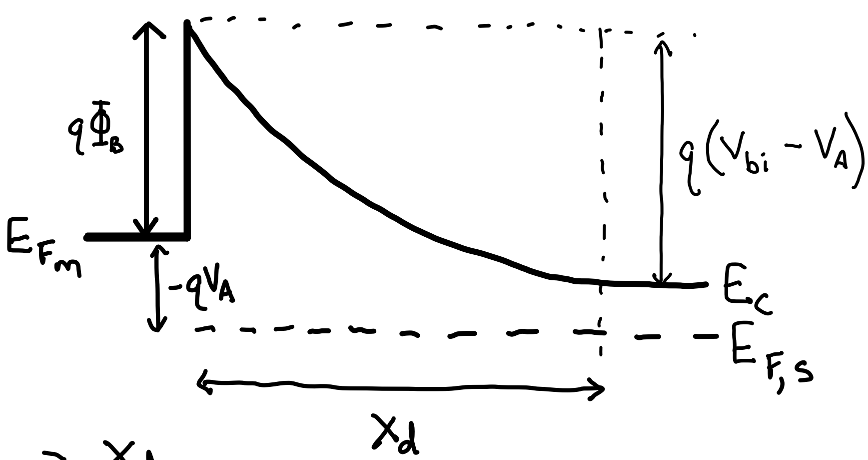


$[Q_{M_0}]$ = coulombs

$$\frac{Q_{M_0}}{A} = qN_D x_{d_0}$$



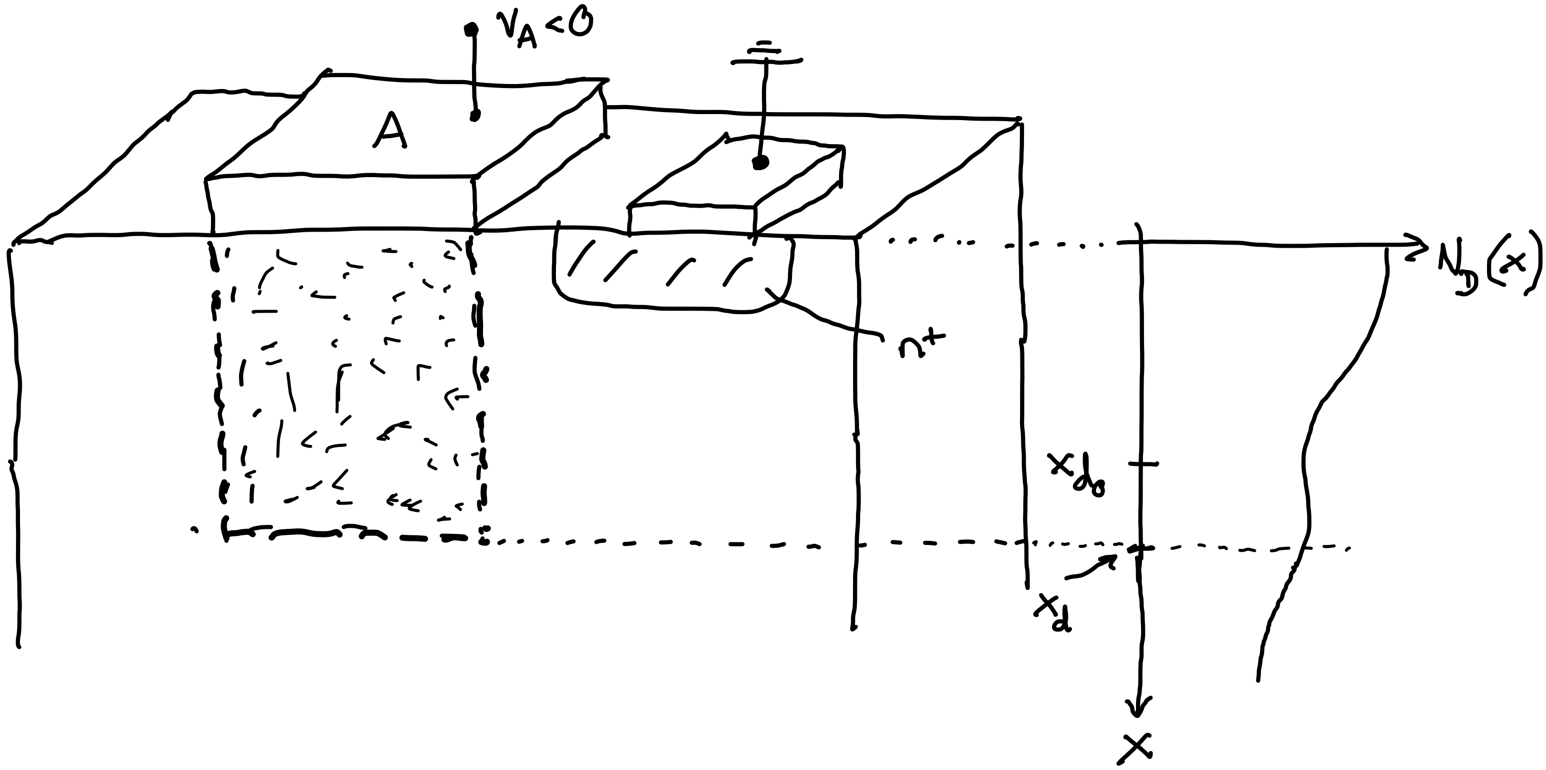
Schottky contact under reverse bias ($V_A < 0$):

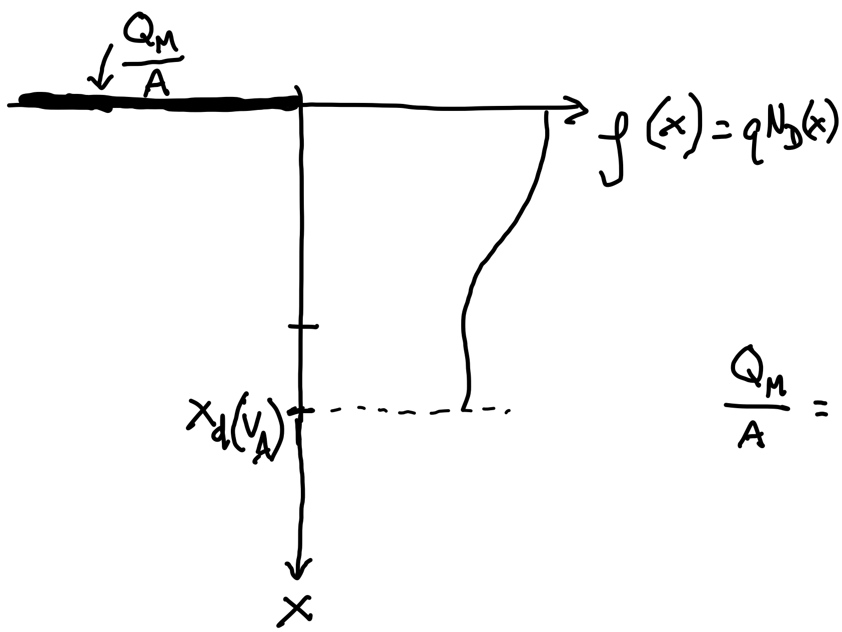


$x_d > x_{d_0}$

Use of Schottky contact to characterize doping density in moderately doped semiconductor:

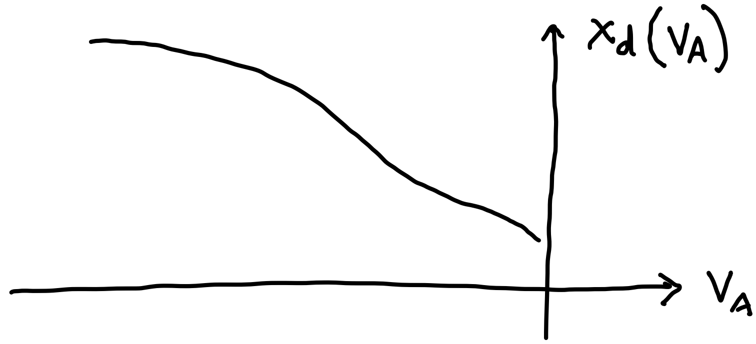
- Consider arbitrary doping profile in (vertical) x-direction:

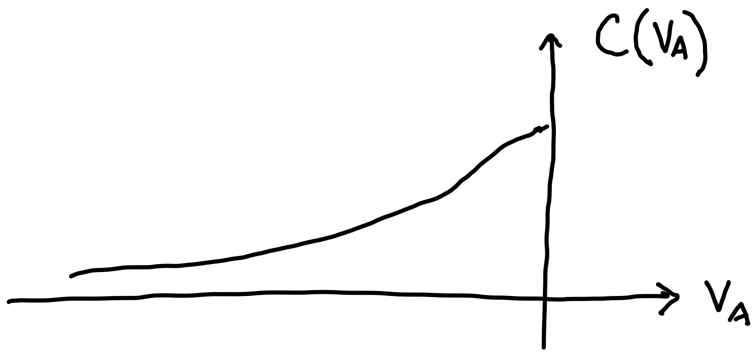




$$\frac{Q_M}{A} = \int_0^{x_d} \rho(x)\,dx$$

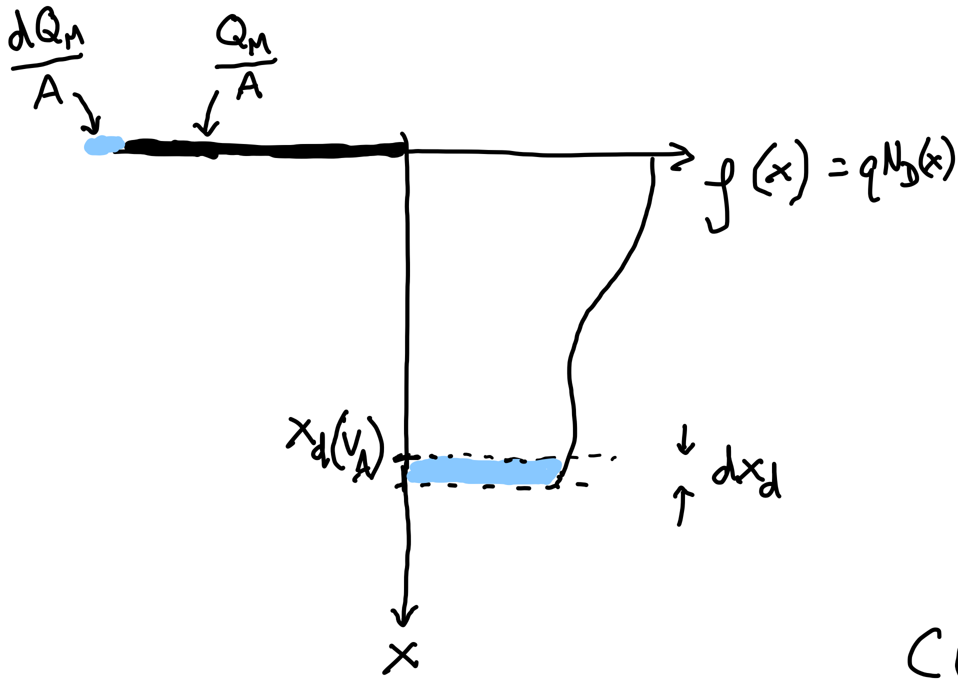
Apply DC bias V_A to contact and measure C:





$$C(V_A) = \frac{\epsilon_s A}{x_d(V_A)} \quad (1)$$

If $|V_A|$ is increased by $|dV_A|$:



$$\frac{dQ_M}{A} = \rho(x_d) \cdot dx_d \quad (3)$$

$$= qN_D(x_d) \cdot dx_d$$

$$C(V_A) = \frac{-dQ_M}{dV_A} \quad (2)$$

$$C(V_A) = \frac{\epsilon_s A}{x_d(V_A)} \qquad (1)$$

$$C(V_A) = \frac{-dQ_M}{dV_A} \qquad (2)$$

$$\frac{dQ_M}{A} = \rho(x_d)\cdot dx_d = q N_D(x_d)\cdot dx_d \qquad (3)$$

From (1):

$$\frac{1}{[C(V_A)]^2} = \frac{x_d^2}{\epsilon_s^2 A^2}$$

$$\frac{d}{dV_A}\left[\frac{1}{C^2}\right] = \frac{2x_d}{\epsilon_s^2 A^2}\cdot\frac{dx_d}{dV_A} \qquad (4)$$

From (2) and (3):

(3)

$$C = \frac{-dQ_M}{dV_A} = \frac{-A}{dV_A}\cdot\left(\frac{dQ_M}{A}\right) = -q N_D(x_d)\cdot A\cdot\frac{dx_d}{dV_A}$$

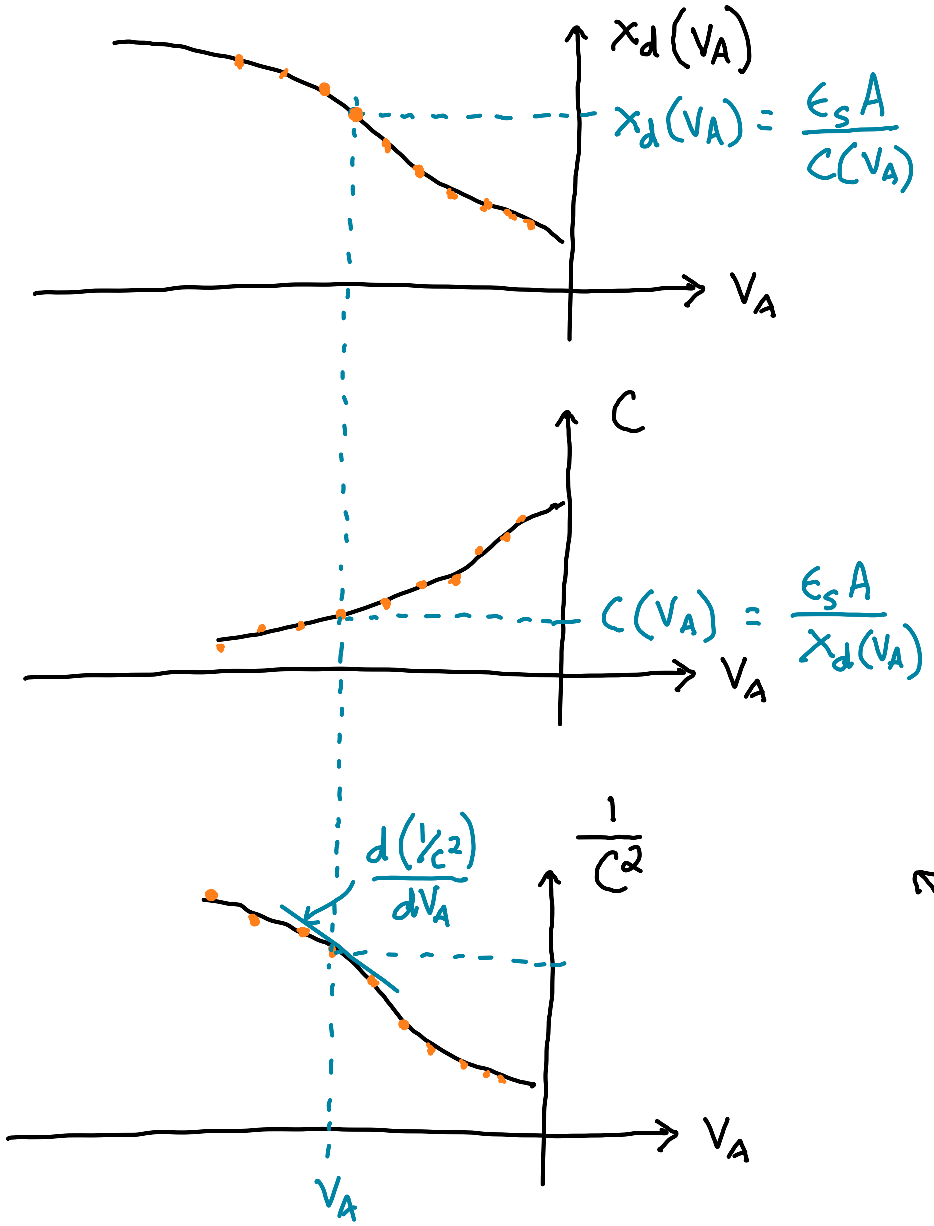
(1)

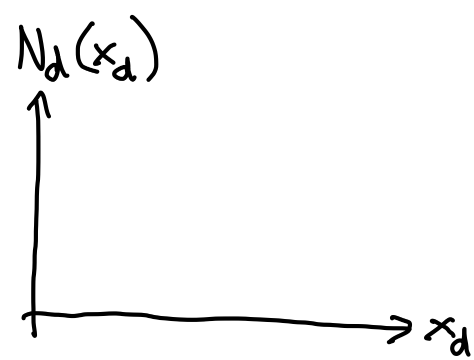
$$\frac{dx_d}{dV_A} = \frac{-C}{q\cdot N_D(x_d)\cdot A} = \frac{-\epsilon_s}{q\cdot N_D(x_d)\cdot x_d} \qquad (5)$$

Plug (5) into (4):

$$\frac{d\left[1/C^2\right]}{dV_A} = \frac{-2x_d}{\epsilon_s^2 A^2} \cdot \frac{\epsilon_s}{q \cdot N_D(x_d) \cdot x_d}$$

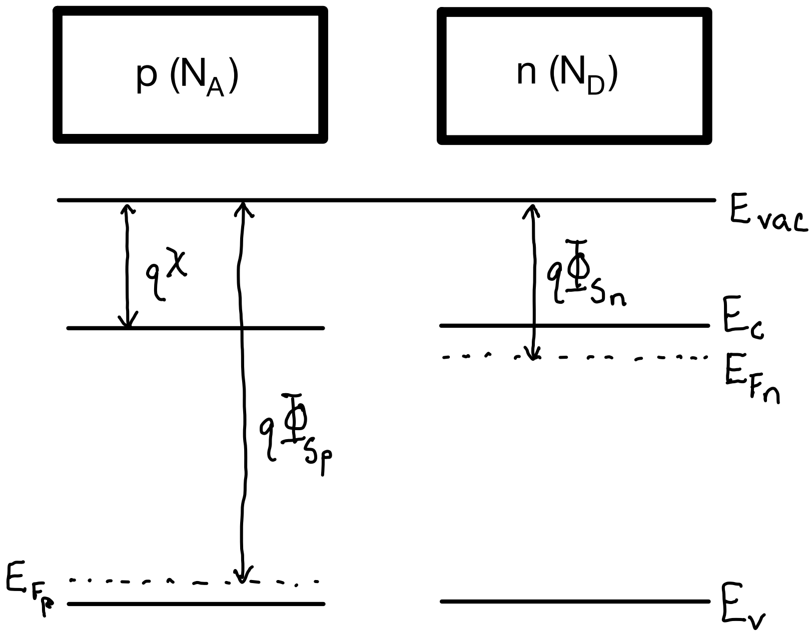
$$\boxed{N_D(x_d) = \frac{-2}{q\epsilon_s A^2\left[d(1/C^2)/dV_A\right]}}$$

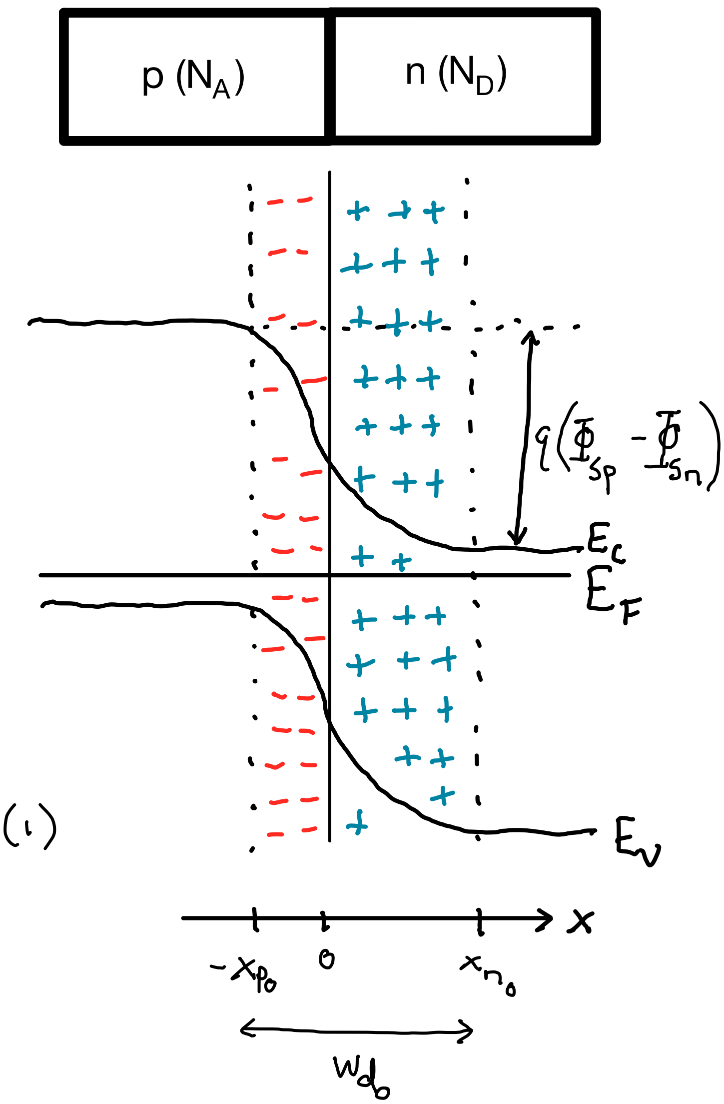




Can use this info to fill in this plot

p-n Junctions



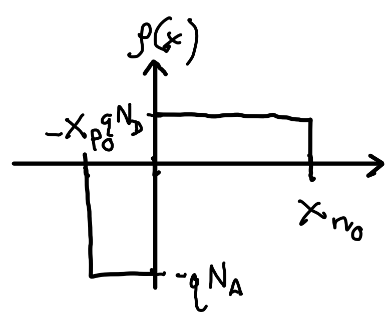


$$A_o = V_{bi} = \Phi_{Sp} - \Phi_{Sn} = \frac{kT}{q}\ln\left[\frac{N_A \cdot N_D}{n_i^2}\right] \quad (1)$$

$$\frac{d\mathcal{E}_x(x)}{dx} = \frac{qN}{\epsilon_s} \quad (2)$$

$$N_A x_{p_o} = N_D x_{n_o} \quad (3)$$

$$A_o = \frac{1}{2}\left(x_{n_o} + x_{p_o}\right)\mathcal{E}_{max_o} \quad (4)$$



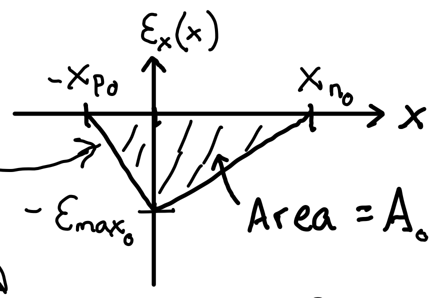
From (1) – (4):

$$x_{n_o} = \left\{\frac{2\epsilon_s V_{bi}}{q}\left[\frac{N_A}{N_D(N_A+N_D)}\right]\right\}^{1/2}$$

$$x_{p_o} = \left\{\frac{2\epsilon_s V_{bi}}{q}\left[\frac{N_D}{N_A(N_A+N_D)}\right]\right\}^{1/2}$$

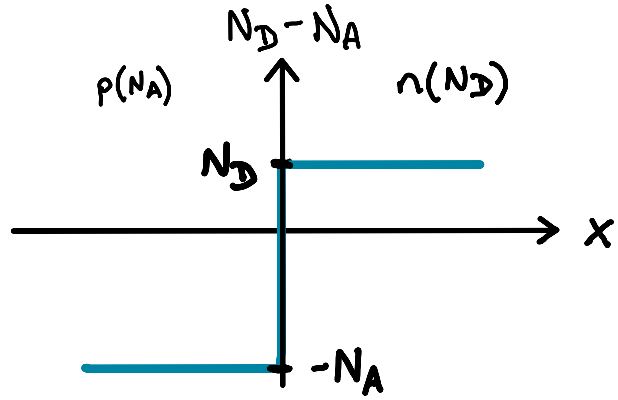
$$W_{d_o} = \left[\frac{2\epsilon_s V_{bi}}{q}\left(\frac{1}{N_A}+\frac{1}{N_D}\right)\right]^{1/2} = x_{p_o} + x_{n_o}$$

$$\mathcal{E}_{max_o} = \frac{2V_{bi}}{W_{d_o}}$$



$$\frac{\mathcal{E}_{max_o}}{x_{p_o}} = \frac{qN_A}{\epsilon_s} \qquad \frac{\mathcal{E}_{max_o}}{x_{n_o}} = \frac{qN_D}{\epsilon_s}$$

1. Abrupt junction (shown on previous page)

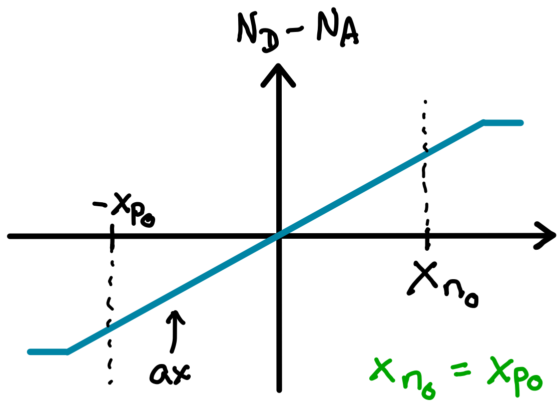


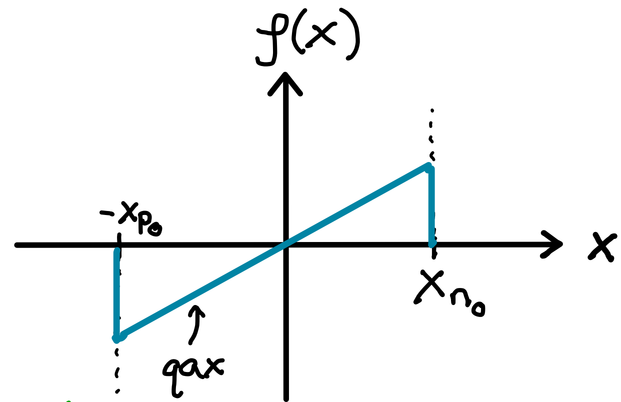
- Formed by epitaxial techniques (e.g., MOCVD, MBE)

- Not all pn junctions are abrupt (e.g., diffused junctions, implanted junctions)

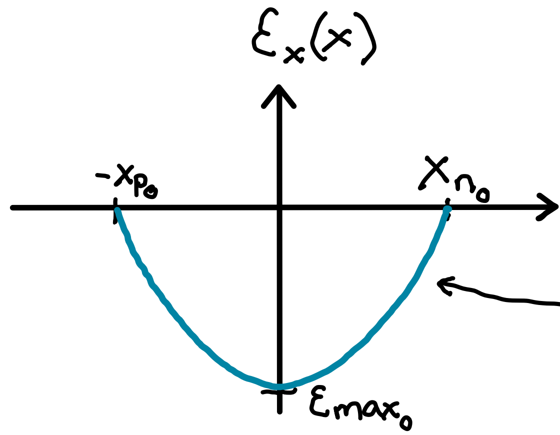
- Analytic solution can be obtained for linearly graded junction (many others can only be solved numerically)

2. Linearly Graded Junction: $N_D - N_A = ax$





$x_{n_0} = x_{p_0}$
(symmetric junction)

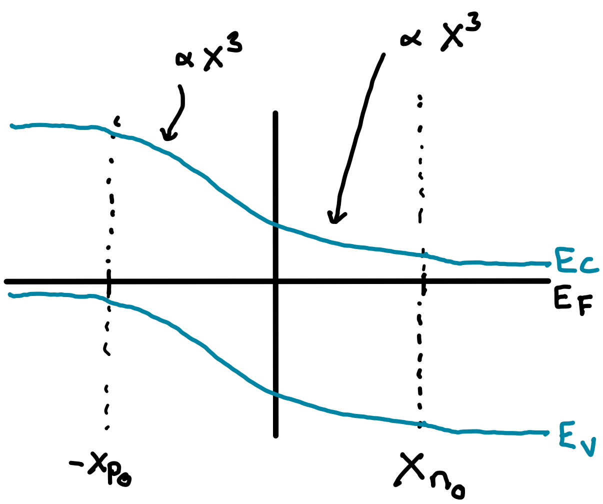


<u>Poisson's equation:</u>

$$\frac{d\mathcal{E}_x(x)}{dx} = \frac{\rho(x)}{\epsilon_s} = \frac{qa}{\epsilon_s}x$$

$$\mathcal{E}_x(x) = \frac{-qa}{2\epsilon_s}\left[x_{n_0}^2 - x^2\right]$$

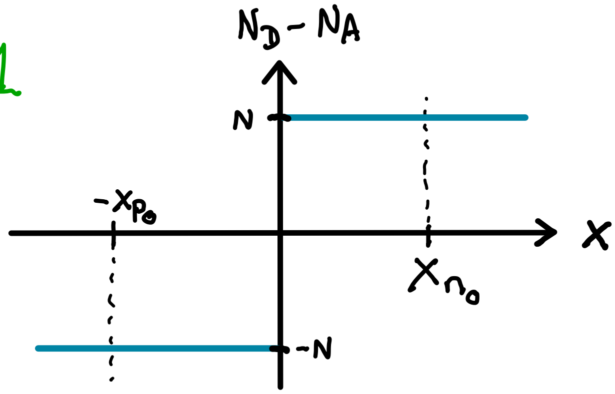
(paraballa)

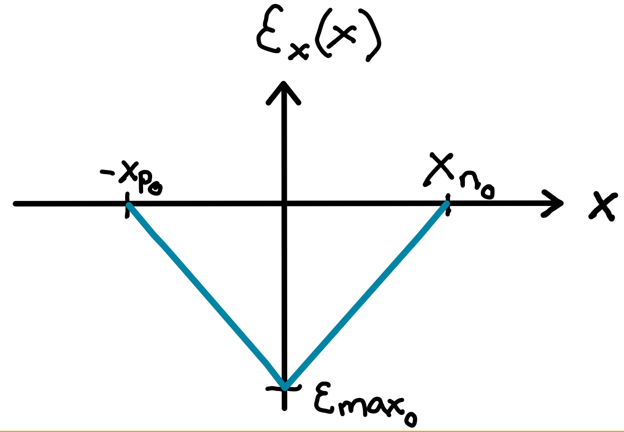


In depletion region, $\mathcal{E}_x \propto x^2$, so $E_c \propto x^3$ (and $E_v \propto x^3$)

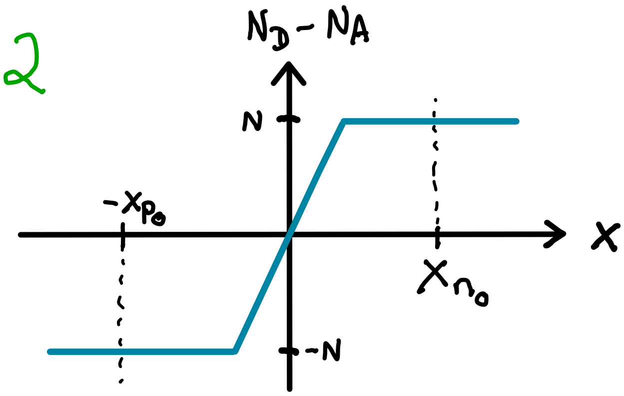
→ Some cases to consider (note: scale for $\mathcal{E}_x$ and x is different in each diagram):

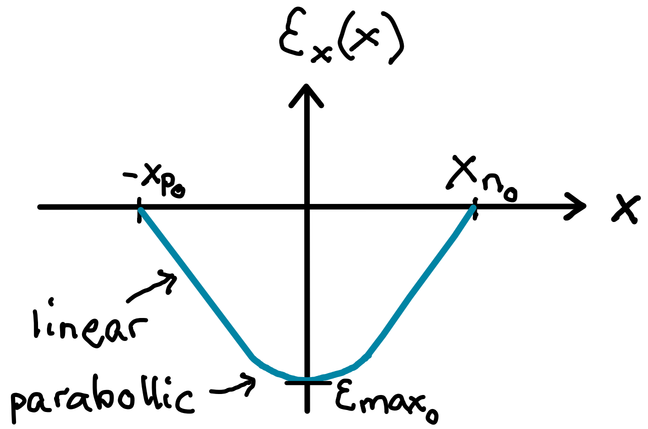
#1



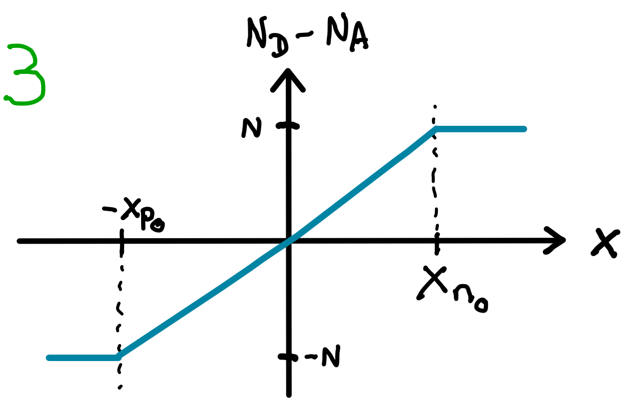


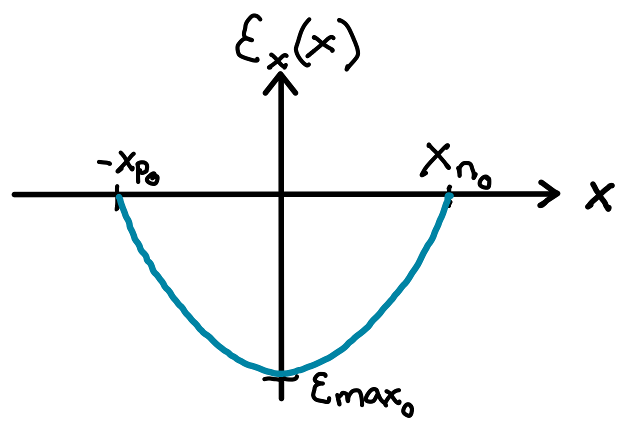
#2



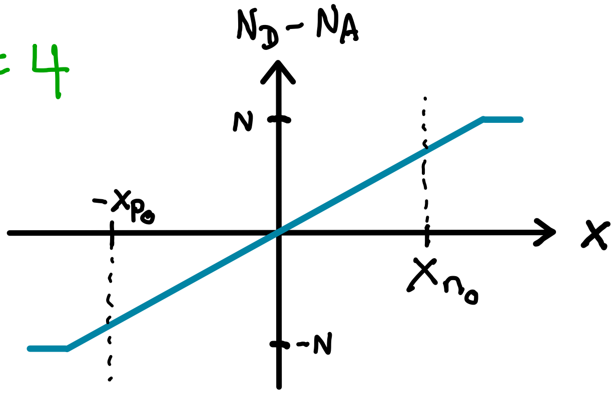


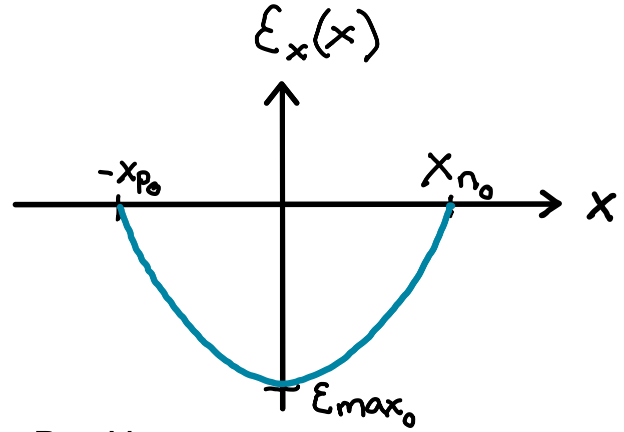
#3





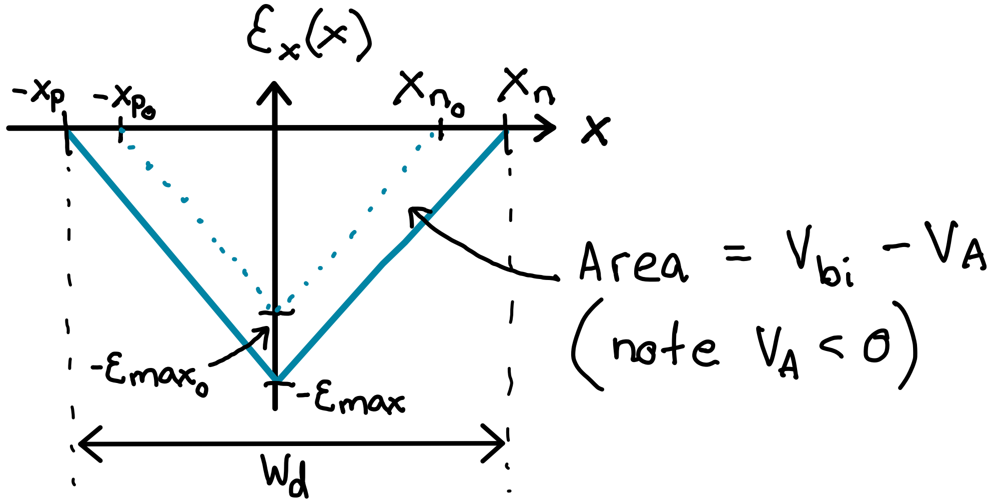
#4





Reverse Biased pn Junctions: E-field

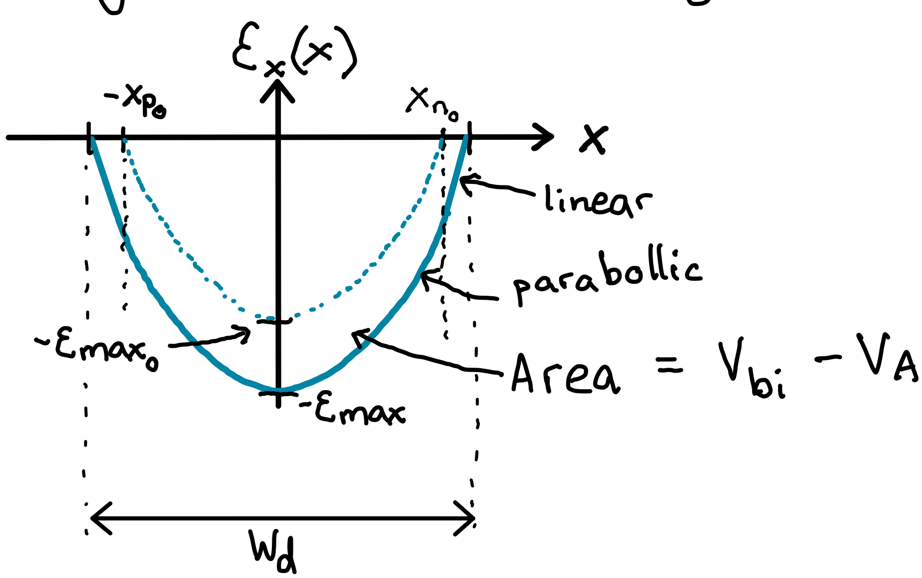
→ Abrupt junction (#1 from last page)



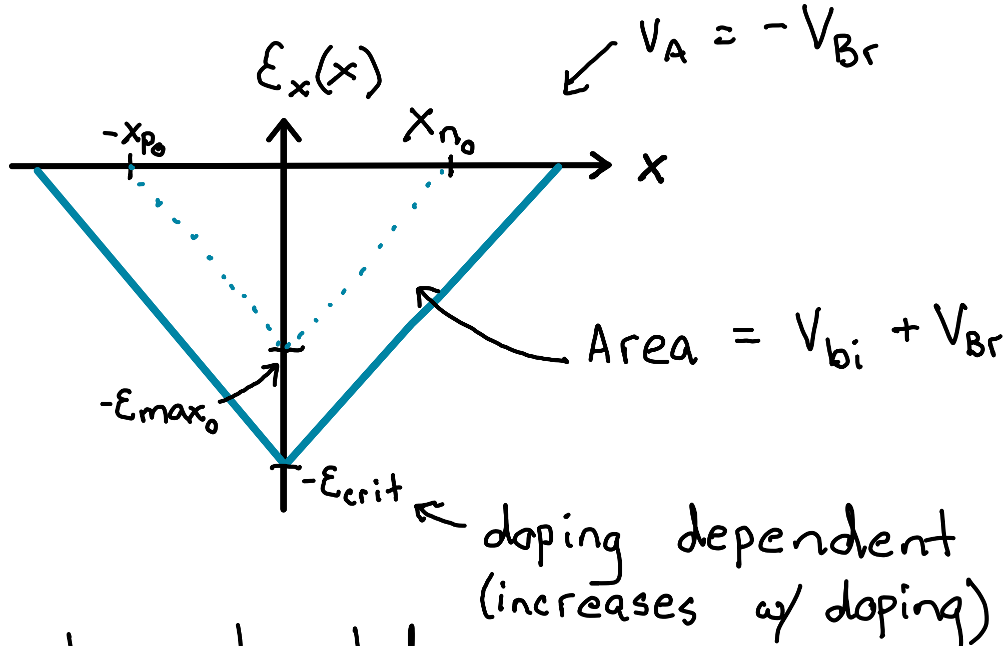
$$W_d = \left[\frac{2\epsilon_s}{q} \left(\frac{1}{N_A} + \frac{1}{N_D} \right) (V_{bi} - V_A) \right]^{1/2}$$

$$\mathcal{E}_{max} = \frac{2(V_{bi} - V_A)}{W_d}$$

→ Linear grade in depletion region (#3 from last page):



Breakdown:



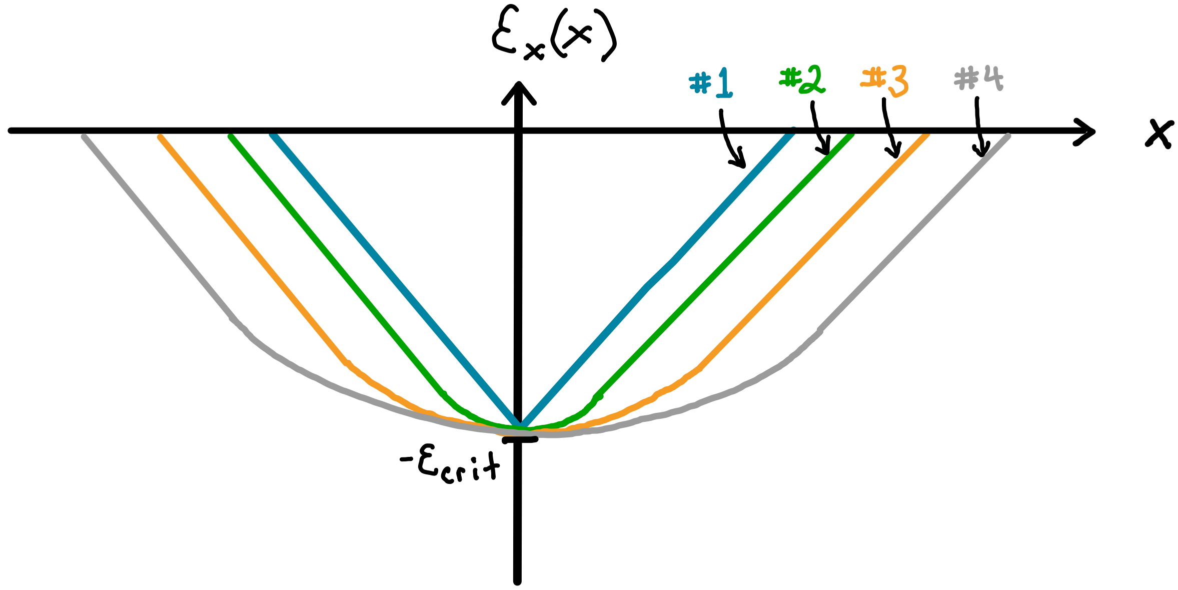
→ Avalanche breakdown

- Multiplication
- Occurs in light to moderately doped structures

→ Zener breakdown

- $\mathcal{E}$-field breaks covalent bonds
- Occurs in heavily doped structures ($\gtrsim 1e18$)

Breakdown of structures from p. 9:



- Area under each curve $= V_{bi} + V_{Br}$