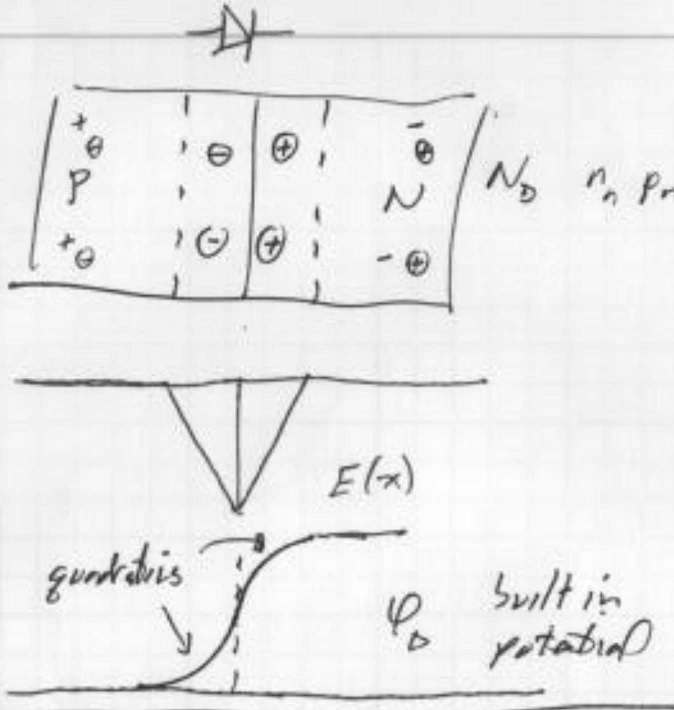
N_A p_p n_p



N_D n_n p_n

Gauss
$\int E \cdot ds = \frac{Q}{\epsilon}$

$V = -\int E\, dl$

φ_D

$\varphi_0 = V_{th} \ln \left(\frac{10^x n_i 10^y n_i}{n_i^2} \right)$

$= V_{th} \ln 10^{(x+y)} =$

$= \underbrace{V_{th} \ln(10)}_{60mV\ @\ R.T.} (x+y)$

memorize!

Drift = Diffusion + Einstein Relation $\Big\}$ $\varphi_0 = V_{TH} \ln \frac{N_A N_D}{n_i^2}$

$V_{th} = \frac{k_B T}{q} \simeq 25\text{-}26mV$ @ R.T., 300K

$n_i \simeq 10^{10} \frac{esp}{cc}$ @ R.T. (varies by 10^5 from -40 to $+85$)

write N_A, N_D as $10^x n_i$, $10^y n_i$

$N_A = 10^x n_i = 10^x 10^{10} = 10^{10+x}$

$N_D = 10^{10+y}$

Reverse bias

linear increase in depletion width gives

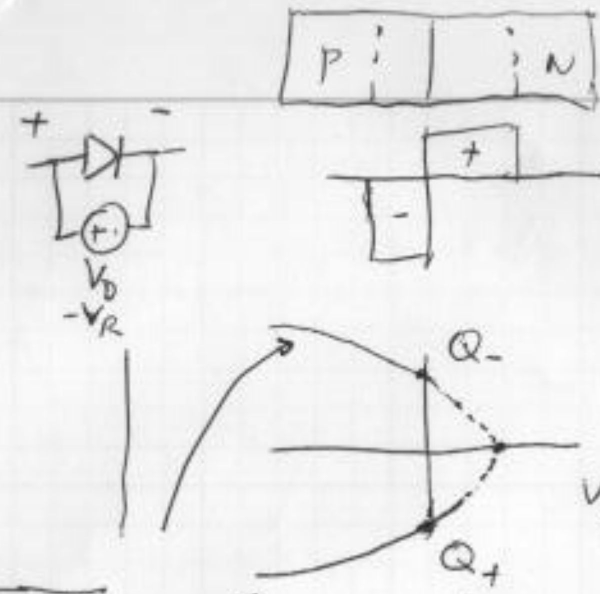
" " in charge

" " in peak field $\Rightarrow$

quadratic increase in potential

$(\varphi_0 + V_R)^2 \sim$ field, charge, width

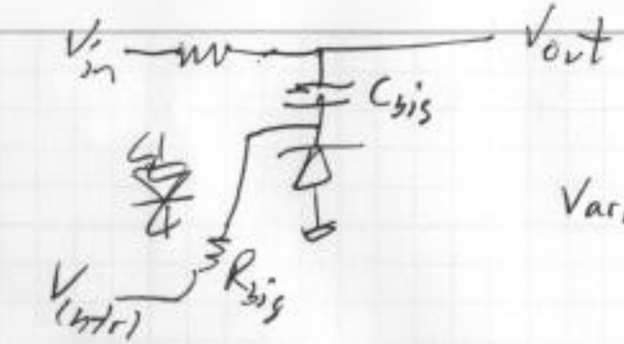
$\Rightarrow$ field, charge, width $\sim \sqrt{\varphi_0 + V_R} = \sqrt{\varphi_0 - V_D}$



$Q \sim \sqrt{\varphi_0 + V_R}$

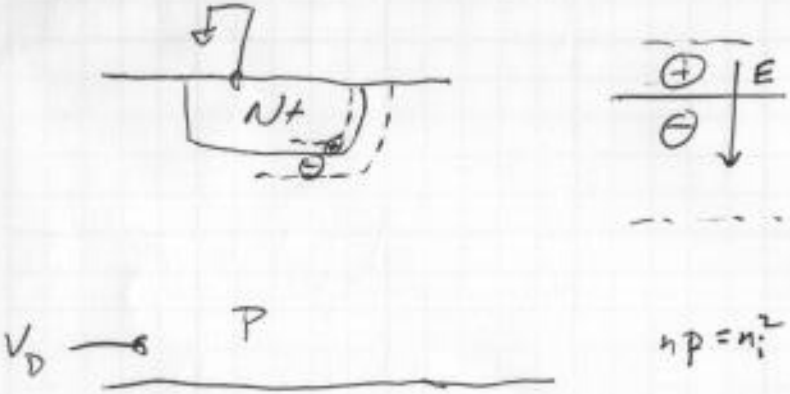
$C_j = \frac{dQ}{dV_R} = \frac{C_{j0}}{\sqrt{1 + V_R/\varphi_0}}$

OK in fwd bias to $\approx \frac{\varphi_0}{2}$



Varactor

If $V_R \sim 10 \times \varphi_0 \Rightarrow 3\times$ variation in C



$np = n_i^2$

when $V_D < 0$, current is due to minority carriers on the lightly doped side hitting the E-field and falling down the potential well

(current ≑ indep of reverse bias (until breakdown) = I

when $V_D = 0$ diffusion = drift

huge conc. gradient

I_s

held back by E-field

Just the highest energy particles get across

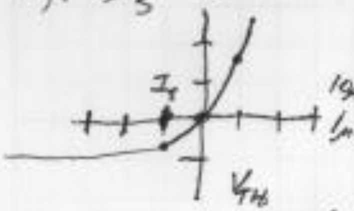
FWD bias, $V_D > 0$ lowers energy barrier

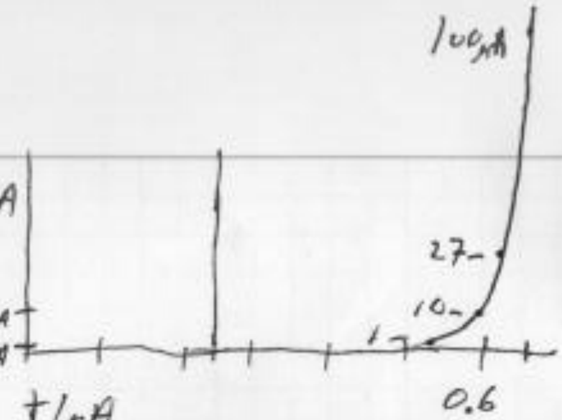
Fermi-Dirac distribution of energy

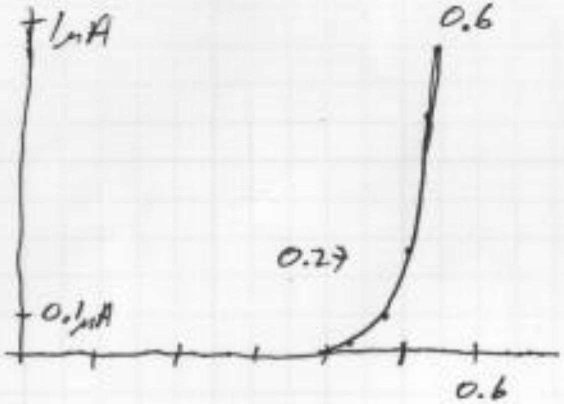
conc w/ energy greater than X: $\sim e^{-X/kT}$

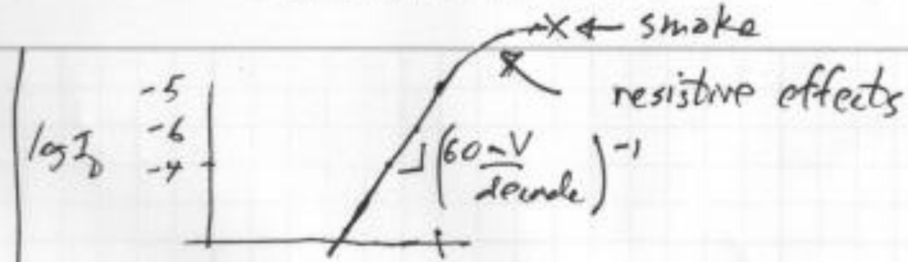
Result: $I_D = I_s\left(e^{V_D/V_{th}} - 1\right)$

r.s. $I_s = 10^{-15} A = 1 fA$







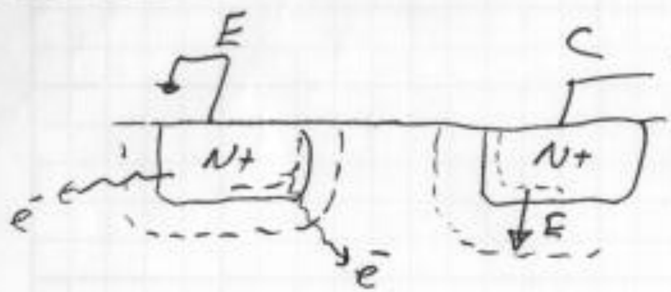


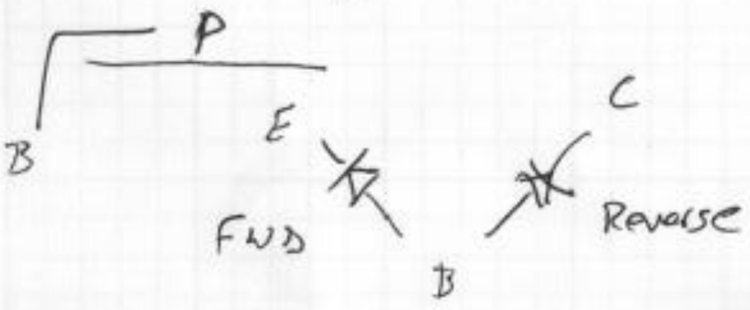
$$I_D = \begin{cases} -I_s & V_D << -V_{th} \\ 0 & V_D = 0 \\ I_s e^{V_D/V_{th}} & V_D >> V_{th} \end{cases}$$

$$I_{D0} = I_s e^{V_{D0}/V_{th}}$$

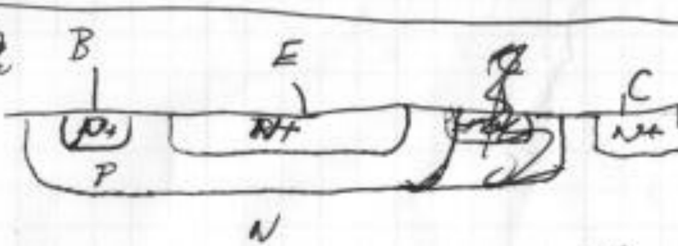
$$e^{(V_{D0}+V_{th})/V_{th}} = e \cdot e^{V_{D0}/V_{th}}$$

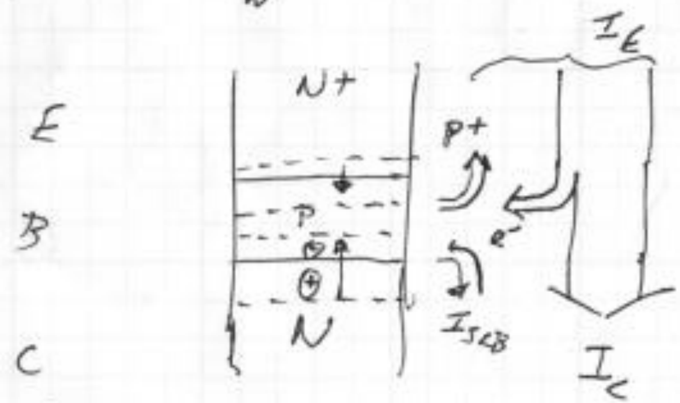
$$e^{(V_{D0}+\ln 10\, V_{th})} = 10\, e^{V_{D0}/V_{th}}$$





typically

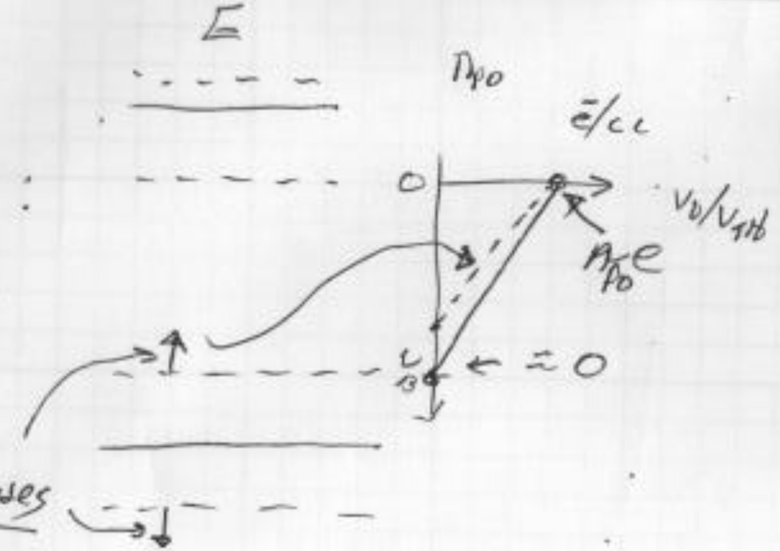




$I_c = \beta I_B$

$I = I_s e^{V_{BE}/V_{th}}$

what is $V_{BE\,ON}$?



V_C increases

W_B decreases

$J_n = q D_n \dfrac{dn_p}{dx}$ $\qquad I_C = A_E J_{no}$

$\uparrow$

$$\frac{n_{po} e^{V_D/V_{TH}} - 0}{W_B}$$

$$W_B \sim \sqrt{\varphi_0 + V_{CB}}$$

$$g_o = \frac{\partial I_C}{\partial V_{CE}} \doteq \frac{I_C}{V_A} \quad \leftarrow \text{Early voltage}$$

$r_o \doteq \frac{1}{g_o} = V_A/I_C$

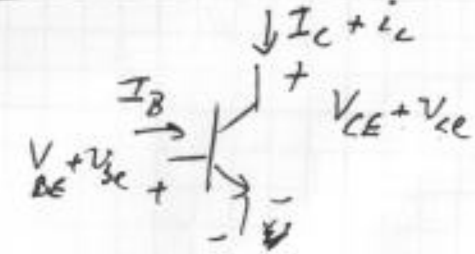
$$I_C = I_S e^{V_{BE}/V_{TH}}\left(1 + \frac{V_{CE}}{V_A}\right) \qquad I_C = \beta I_B$$

$$g_m = \frac{\partial I_C}{\partial V_{BE}} = \frac{I_C}{V_{TH}}$$

$$r_\pi = \frac{1}{g_\pi}$$

$$g_\pi = \frac{\partial I_B}{\partial V_{BE}} = \frac{\partial}{\partial V_{BE}}\left(\frac{I_C}{\beta}\right) = \frac{g_m}{\beta}$$

$$r_\pi = \frac{\beta}{g_m}$$



V_{BE}, V_{CE}, I_C, I_B satisfy nonlinear eqn.

v_{be}, v_{ce}, i_c are local linearization (tangent plane

$i_c = g_m v_{be} + \frac{1}{r_o} v_{ce}$

$i_b = \frac{1}{r_\pi} v_{be}$