The relationship between $N_N$ and $N_D$ is given by:

$$\frac{N_N}{N_D} = 10^{x+4} = 10^x \cdot 10^4 = 10^x \cdot 10^4$$

for $x, y \in [4, 10^3]$.

The exponential function $y = V_{TH} \ln(10)$ for $x+y$ equals 60 mV at R.T.

The depth of depletion doubles with an increase of $V_R$.

If $N_n = 10^{15}$, what is $y_o$? (in $n_p$)

If $N_D = 10^{20}$, what is the relative width of the depletion region?

The relative voltage drop in $n_p$?

The minority carrier is relevant at R.T.?

($y_o + V_R$) is linearly related to charge field depletion region width.

Charge field width $\sim \sqrt{y_o + V_R} = \sqrt{y_o - V_R}$ when $V_R < 0$.

Example: $W_D = 1 \mu m$ when $V_R = -3$, $y_o = 31 V$.

What is $W_D$ when $V_R = -15$?

A: $2 \mu m$.

What bias would give $10 \mu m$? $A = -400 V$.

Will diode support that? $A = \frac{400 \text{V}}{2 \text{mm}} > 200 \text{V/mm}$.

In reverse bias, will the current (parasitic) be greater for heavily doped junctions or lightly doped junctions?

What if I shine light on the junction?

What if I forward bias the junction?

Reduces barrier height. $e^{-V_R}$.

Every 25 mV at R.T. increases diffusion current by $e = 2.7$.

Every $(25 \text{ mV}) \ln(10) = 60 \text{ mV}$ increases diffusion current by 10.
\[ I_s = I_s (\frac{V_D}{V_{TH}} - 1) \]

-1 is only important if 
\[-3V_{TH} < V_D < 3V_{TH} \]

\[ I_s(e^{-1}) = 1.7I_s \]
\[ I_s(e^2 - 1) = 6.4I_s \]

\[ \begin{align*}
N & = 10^{25} \\
\frac{N}{N_d} & = 10^{20} \\
\frac{N}{N_A} & = 10^{15}
\end{align*} \]

**Depletion region primarily in? P region**

**Leakage current from? h^+ drift**

**Forward bias current primarily? e^- diffusion, 10^5**

**What happens to e^- in p region?** recombination, lifetime?

**Ex.:** \[ I_s = 10^{-11} \text{A} \]

**When \( V_D = 300 \text{mV} \)**
\[ I_D = 10^{-11} e^{\frac{200 \text{mV}}{V_{TH}}} \]
\[ = 10^{-11} e^{\frac{200 \text{mV}}{0.7 \text{V}}} = (10^{-11}) 10^5 = 1 \text{mA} \]

**E**

**B**

**5V**

\[ I_E = I_s e^{\frac{V_D}{V_{TH}}} \]

\[ I_B = \text{recombination} + h^+ \text{ of } I_E e \]

\[ I_C = \beta I_B \]
\[ I_C \text{ gets majority of } I_E \]
\[ I_E - \text{recombination} \]

\[ \beta = 10 - 1000 \]
Bipolar Junction Transistor (BJT) by Barden, Brattain, Shockley.

**Base**

Not symmetric.

Lateral bipolar in CMOS is similar.

\[ I_C = I_S e^{V_{BE} / V_T} \]

\[ g_m = \frac{dI_C}{V_{BE}} = \frac{1}{V_T} I_S e^{V_{BE} / V_T} = \frac{I_C}{V_T} \]

\[ r_0 = ? \]

\[ n^+ \]

\[ p^- \]

\[ n \]

\[ n^+ \]

Today:

\[ J_{n, sat} = B D_n \frac{d n}{d x} = B \frac{D_n}{W} n_0 e^{-V_{BE} / V_T} \]

\[ n \sim n_0 e \]

\[ dx = W_B \]

\[ W_B \text{ depends on reverse biased } C_B \]

Linearize the nonlinear physics \( (\sqrt{V_B} + V_{CB}) \)

\[ I_C = I_S e^{V_{BE} / V_T} \left( 1 + \frac{V_{BE}}{V_A} \right) \]