The Junction Diode
Forward Bias Equation

In forward bias, we have learned that the diode current $i_D$ can be related to the diode voltage $v_D$ using the following approximation:

$$i_D = I_S \left( e^{v_D/nV_T} - 1 \right) \approx I_S \frac{v_D}{nV_T},$$

provided that $v_D \gg 25 \text{ mV}$.

We can invert this approximation to alternatively express $v_D$ in terms of diode current $i_D$:

$$I_S e^{v_D/nV_T} = i_D,$$

$$\frac{v_D}{e^{v_D/nV_T}} = \frac{i_D}{I_S},$$

$$\frac{v_D}{nV_T} = \ln \left( \frac{i_D}{I_S} \right),$$

$$v_D = nV_T \ln \left( \frac{i_D}{I_S} \right)$$
Now, say a voltage $v_1$ across some junction diode results in a current $i_1$. Likewise, different voltage $v_2$ across this same diode a diode of course results in a different current $i_2$. We can define the difference between these two voltages as $\Delta v = v_2 - v_1$, and then using the above equation can express this voltage difference as:

$$\Delta v = nV_T \ln \left( \frac{i_2}{I_s} \right) - nV_T \ln \left( \frac{i_1}{I_s} \right)$$

$$\Delta v = nV_T \ln \left( \frac{i_2}{I_s} \cdot \frac{I_s}{i_1} \right)$$

$$\Delta v = nV_T \ln \left( \frac{i_2}{i_1} \right)$$

Yikes! Look at what this equation says:

* The difference in the two voltages is dependent on the ratio of the two currents.

* This voltage difference is independent of scale current $I_s$.

We can likewise invert the above equation and express the ratio of the two currents in terms of the difference of the two voltages:
\[ nV_T \ln \left( \frac{i_2}{i_1} \right) = v_2 - v_1 \]

\[ \ln \left( \frac{i_2}{i_1} \right) = \frac{(v_2 - v_1)}{nV_T} \]

\[ \frac{i_2}{i_1} = \exp \left( \frac{(v_2 - v_1)}{nV_T} \right) \]

Again, we find that this expression is independent of scale current \( I_s \).

**Q:** Stop wasting my time with these pointless derivations! Are these expressions even remotely useful!?!?

**A:** These expressions are often very useful! Frequently, instead of explicitly providing device parameters \( n \) and \( I_s \), a junction diode is specified by stating \( n \), and then a statement of the specific diode current resulting from a specific diode voltage.

For example, a junction diode might be specified as:

"A junction diode with \( n = 1 \) pulls 2mA of current at a voltage \( v_D = 0.6 \) V."
The above statement completely specifies the performance of this particular junction diode—we can now determine the current flowing through this diode for any other value of diode voltage $v_D$. Likewise, we can find the voltage across the diode for any other diode current value $i_D$.

For example, say we wish to find the current through the junction diode specified above when a potential difference of $v_D=0.7$ V is placed across it. We have two options for finding this current:

**Option 1:**

We know that $n=1$ and that $i_D=2\,\text{mA}$ when $v_D=0.6$ V. Thus, we can use this information to solve for scale current $I_S$:

$$I_S e^{\frac{v_D}{nV_F}} = i_D$$

$$I_S e^{\frac{0.6}{0.025}} = 2$$

$$I_S = 2 e^{\frac{-0.6}{0.025}}$$

$$I_S = 7.55 \times 10^{-11} \, \text{mA}$$

Now, we use the forward-biased junction diode equation to determine the current through this device at the new voltage of $v_D=0.7$ V:

$$i_D = I_S e^{\frac{v_D}{nV_F}}$$

$$= (7.55 \times 10^{-11}) e^{\frac{0.7}{0.025}}$$

$$= 109.2 \, \text{mA}$$
**Option 2**

Here, we directly determine the current at $v_D = 0.7$ using one of the expressions derived earlier in this handout! Using $i_1=2 \text{ mA}$, $v_1=0.6$, and $v_2=0.7 \text{ V}$ we can find current $i_2$ as:

$$
\frac{i_2}{i_1} = \exp \left[ \frac{(v_2 - v_1)}{nV_T} \right]
$$

$$
i_2 = i_1 \exp \left[ \frac{(v_2 - v_1)}{nV_T} \right]
$$

$$
= 2 \exp \left[ \frac{(0.7 - 0.6)}{0.025} \right]
$$

$$
= 109.2 \text{ mA}
$$

Option 2 (using the equations we derived in this handout) is obviously quicker and easier (note in option 2 we did not have to deal with annoying numbers like $7.55 \times 10^{-11}$!).

Finally, we should also note that junction diodes are often specified simply as “a 2mA diode” or “a 10 mA diode” or “a 100 mA diode”. These statements implicitly provide the diode current at the standard diode test voltage of $v_D=0.7 \text{ V}$.

**Q:** But what about the value of junction diode ideality factor $n$?
A: If no value of $n$ is provided (and there is not sufficient information given to determine it), we typically just assume that $n = 1$.

For example, consider the following problem:

"Determine the voltage across a 100 mA junction diode when there is 2 mA of current flowing through it."

A “100 mA junction diode” simply means a junction diode that will have a current of 100 mA flowing through it ($i_D = 100$ mA) if the voltage across it is $v_D = 0.7$ V. We will assume that $n=1$, since no other information about that parameter was given.

Thus, using $v_1 = 0.7$, $i_1 = 100$ mA, and $i_2 = 2$ mA, we can determine the value of $v_2$:

$$v_2 - v_1 = nV_T \ln \left( \frac{i_2}{i_1} \right)$$

$$v_2 - 0.7 = (0.025) \ln \left( \frac{2}{100} \right)$$

$$v_2 = 0.7 - 0.10$$

$$v_2 = 0.60 \text{ V}$$

EXCELENT!