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**:

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

provided that $v_D \gg 25\, mV$.

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

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

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

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

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

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:

$$
\begin{aligned}
\Delta v &= v_2 - v_1 \\
&= nV_T \ln\left(\frac{i_2}{\mathcal{I}_S}\right) - nV_T \ln\left(\frac{i_1}{\mathcal{I}_S}\right) \\
&= nV_T \ln\left(\frac{i_2}{\mathcal{I}_S}\frac{\mathcal{I}_S}{i_1}\right)
\end{aligned}
$$

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

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 $\mathcal{I}_s$.

We can likewise **invert** the above equation and express the ratio of the two currents in terms of the difference of the two voltages:

$$n V_T \, ln\left[\frac{i_2}{i_1}\right] = v_2 - v_1$$

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

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

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=2mA when v_D=0.6 V. Thus, we can use this information to solve for **scale current** I_S:

$$
\begin{aligned}
I_S\, e^{\frac{v_D}{nV_T}} &= i_D \\
I_S\, e^{\frac{0.6}{0.025}} &= 2 \\
I_S &= 2\, e^{\frac{-0.6}{0.025}} \\
I_S &= 7.55 \times 10^{-11}\, mA
\end{aligned}
$$

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:

$$
\begin{aligned}
i_D &= I_S\, e^{\frac{v_D}{nV_T}} \\
&= \left(7.55 \times 10^{-11}\right) e^{\frac{0.7}{0.025}} \\
&= 109.2\ mA
\end{aligned}
$$

Option 2

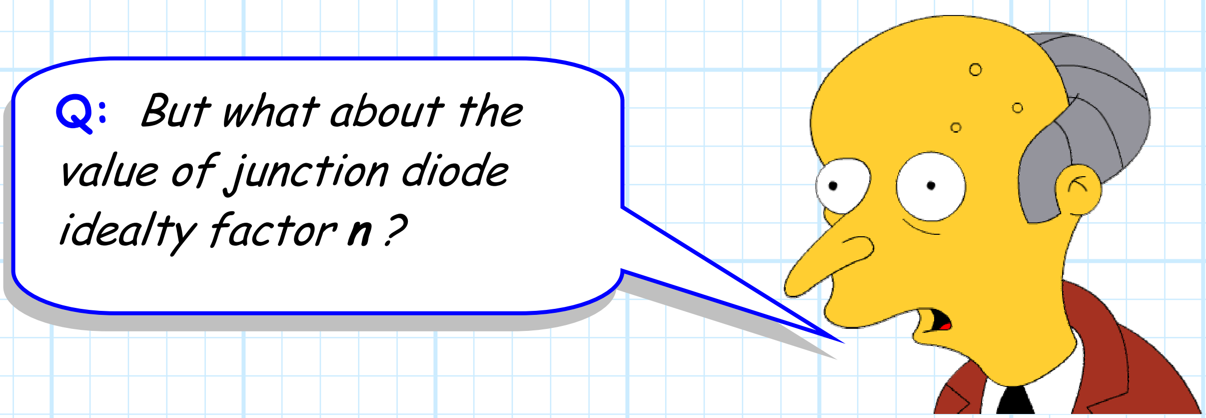
Here, we directly determine the current at $v_D = 0.7$ using one of the expressions derived earlier in **this** handout! Using i_1=2 mA, v_1 =0.6, and v_2 =0.7 V we can find current i_2 as:

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

$$\begin{aligned} i_2 &= i_1\, exp\left[\frac{(v_2 - v_1)}{nV_T}\right] \\ &= 2\, exp\left[\frac{(0.7 - 0.6)}{0.025}\right] \\ &= 109.2\ mA \end{aligned}$$

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 7.55×10^{-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 statement **implicitly** provide the diode current at the **standard** diode test voltage of $\mathbf{v_D}$**=0.7 V**.



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 =100mA, and i_2 =2 mA, we can determine the value of v_2:

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

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

$$\begin{aligned} v_2 &= 0.7 - 0.10 \\ &= 0.60 \, V \end{aligned}$$