Forward and Reverse Bias Approximations

A: Actually, all three of the above statements are true (or, at least, approximately so)!

Let’s review what we know about the junction diode in forward and reversed bias:

1. First, we know that if the diode is not in breakdown, the relationship between current and voltage can be precisely described as:

Q: Man, am I ever befuddled! Is the behavior of a junction diode in the forward biased region described as this:

\[ i_D = I_s \left( e^{\frac{v_D}{eV_T}} - 1 \right) \]

or as this:

\[ i_D = I_s e^{\frac{v_D}{eV_T}} \]

or as this

\[ i_D > 0 \quad \text{and} \quad v_D = 0.7 \quad V \]

???
\[ i_D = I_s \left( e^{v_D/nV_T} - 1 \right) \quad \text{for} \quad v_D > -V_{ZK} \]

Q: Here's where I get confused. Is this equation valid for reverse bias, or is it valid for forward bias?

A: The above expression is valid for forward bias, and it is valid for reverse bias, and it is also valid for the transition region between forward and reverse bias!

In other words, the above equation is a very accurate description of the junction diode behavior—with the important exception of when the junction diode is in breakdown.

2. Now, let's simplify the previous expression further, separately examining the cases when the junction diode is in forward bias (i.e., \( v_D \gg nV_T \)), and reverse bias (i.e., \(-V_{ZK} < v_D \ll -nV_T \)).

For the forward bias case, we find that:

\[ e^{v_D/nV_T} \gg 1 \quad \text{if} \quad v_D \gg nV_T \]
Therefore, we can approximate the junction diode behavior in **forward bias** mode as:

\[ i_D \approx I_s e^{v_D/nV_T} \quad \text{for} \quad v_D \gg nV_T \quad (\text{i.e., forward biased}) \]

Likewise, for the **reverse bias** case, we find that:

\[ e^{v_D/nV_T} \ll 1 \quad \text{if} \quad v_D \ll -nV_T \]

Therefore, we can approximate the junction diode behavior in **reverse bias** mode as:

\[ i_D \approx -I_s \quad \text{for} \quad -V_{Zk} < v_D \ll -nV_T \quad (\text{i.e., reversed biased}) \]

Combining, we can approximate the expression at the top of the previous page as:

\[
\begin{cases} 
I_s e^{v_D/nV_T} & \text{for} \quad v_D \gg nV_T \quad (\text{i.e., forward biased}) \\
-I_s & \text{for} \quad -V_{Zk} < v_D \ll -nV_T \quad (\text{i.e., reversed biased}) 
\end{cases}
\]

3. **We can now simplify these expressions even further!** We rewrite the above approximation for forward bias so that the junction diode voltage is a function of junction diode current:
As a previous example demonstrated, as we vary the value of diode current $i_D$ from microamps to kiloamps, the diode voltage will vary only a few hundred millivolts, from about 0.5 V to 0.9 V.

Thus, we can assume that if any appreciable current is flowing from junction diode anode to junction diode cathode (i.e., forward bias condition), the junction diode voltage will be approximately (i.e., within a few hundred millivolts) $0.7 \text{ V}$.

Q: It looks to me that you are saying a **forward biased** junction diode exhibits a diode voltage of $v_D = 700\text{mV}$, **regardless** of the diode current $i_D$, right?
A: NO! This is not what I am saying! As is evident in the previous two equations, the junction diode current in forward bias is directly dependent on diode current—as the current increases, the voltage increases! For each possible diode current, there is a specific (and different) diode voltage.

* However, we find that this increase is logarithmically related to diode current, such that the voltage increases very slowly with increasing current—it takes a bunch of additional junction diode current to increase the junction diode voltage even a small amount.

* Thus, we are simply saying that for all appreciable (and plausible) diode currents, the junction diode voltage will be within of few hundred millivolts of, say, 700 mV.

* As a result, \( v_D = 0.7 \) V is not a bad approximation for forward biased junction diodes!

Now, we can likewise simplify further our approximation for a reverse biased junction diode. Recall that we now approximate the reverse bias diode current as \( i_D = -I_s \).

However, recall that the diode saturation current \( I_s \) is a very small value, typically \( 10^{-8} \) to \( 10^{-15} \) Amps!

Q: A billionth of an amp!? That's so tiny it might as well be zero!
A: Precisely! The reverse bias current value $i_D = -I_s$ is so small that we can approximate it as zero:

$$i_D \approx 0 \quad \text{if} \quad -V_{ZK} < V_D \ll -nV_T \quad \text{(reverse bias)}$$

Thus, we arrive at an even simpler (albeit less accurate) approximation of junction diode behavior in forward and reverse bias:

$$V_D \approx 0.7 \quad \text{if} \quad i_b > 0 \quad \text{(forward bias)}$$

$$i_D \approx 0 \quad \text{if} \quad -V_{ZK} < V_D < 0 \quad \text{(reverse bias)}$$

Each of the three expressions examined in this handout can be used to describe the behavior of junction diodes in forward and/or reverse bias. The first expression we examined is the most accurate, but it is likewise the most mathematically complex. Conversely, the third expression above is the simplest, but is likewise the least accurate.

We will find that all three of the expressions are useful to us, depending on what specifically we are attempting to determine, and how accurately we need to determine it!