Forward and Reverse Bias Approximations

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

$$i_D = I_s \left(e^{v_D / nV_T} - 1 \right) \quad ?$$

*or as **this**:*

$$i_D = I_s e^{v_D / nV_T} \quad ?$$

*or as **this***

$$i_D > 0 \quad \text{and} \quad v_D = 0.7 \text{ V} \quad ???$$

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 revered bias:

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

$$i_D = I_s\left(e^{v_D/nV_T} - 1\right) \qquad \text{for} \qquad v_D > -V_{ZK}$$

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, lets **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:

$$e^{v_D/nV_T} \gg 1 \qquad \text{if } v_D \gg nV_T$$

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

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

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

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

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

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

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

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

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:

$$I_s e^{v_D / nV_T} = i_D$$

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

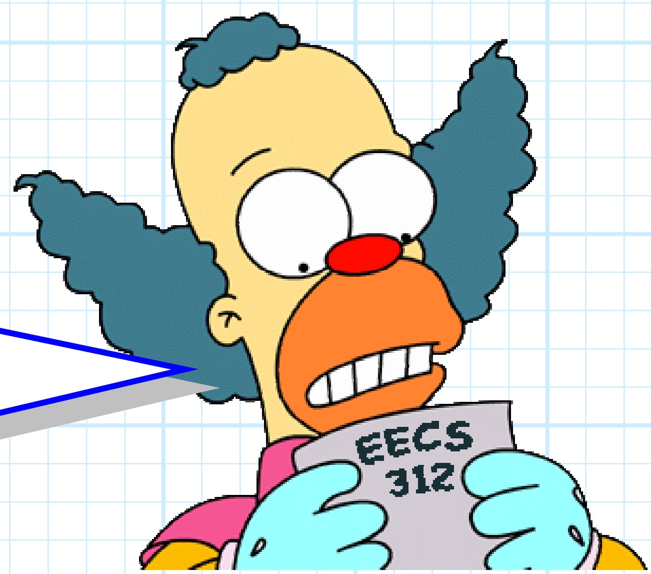
$$\frac{v_D}{nV_T} = ln\left[\frac{i_D}{I_s}\right]$$

$$v_D = nV_T \, ln\left[\frac{i_D}{I_s}\right]$$

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 V**.

Q: *It looks to me that you are saying a **forward biased** junction diode exhibits a diode voltage of v_D =700mV, **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**.

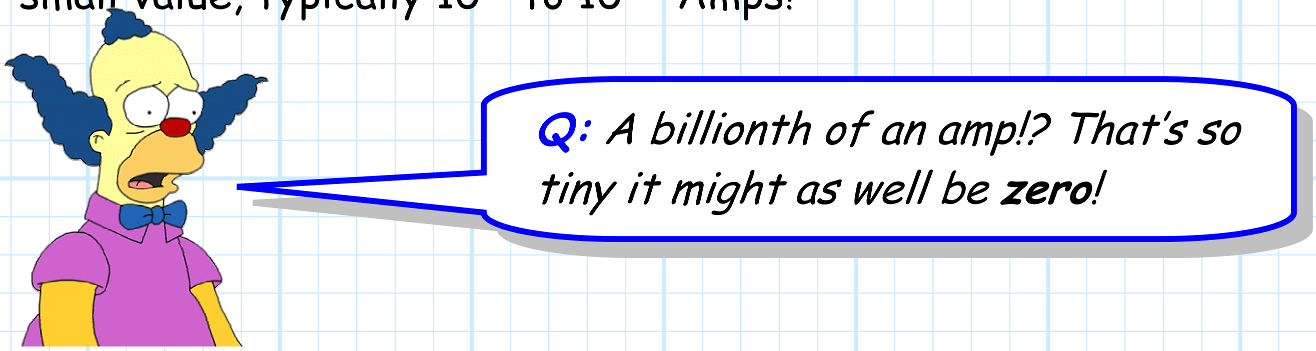
* However, we find that this increase is **logarithmically** related to diode current, such that the voltage increases very **slowly** with increasing current—it takes a **bunch** of additional junction diode current to increase the junction diode voltage even a **small** amount.

* 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!



A: Precisely! The reverse bias current value $i_D = -I_s$ is so small that we can approximate it as **zero**:

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

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

$$v_D \approx 0.7 \qquad \text{if} \qquad i_D > 0 \quad \text{(forward bias)}$$

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

*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!*