What are diodes?

**Definition:** A diode is a semiconductor device that passes current only in 1 direction. A “one-way” current valve

**Ideal Diode**

- Like resistors, they have 2 terminals
- **i-v characteristic**

**Reverse Bias:**

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**Forward Bias:**

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Summary of 2 modes of operation for Diode:

**Forward-Biased**

- Conducting
- ON
- Short Circuit
- \( i > 0 \) (positive value)
- \( v_D = 0 \)

**Reverse-Biased**

- Cutoff
- OFF
- Open Circuit
- \( i = 0 \)
- \( v_D = \text{open} \)
Example: Two diodes

Find I and V. Assume the diodes are ideal.
Not always obvious if diodes are ON or OFF → make an assumption and test it!
Assume both are ON for starters → Short them

\[ V_B = 0 \]
\[ V = 0 \]
\[ I_{D2} = \frac{10 - 0}{5k} = 2\,mA \]
\[ I = \frac{0 - (-10)}{10k} = 1\,mA \]
\[ I_{D1} + I_{D2} = I \Rightarrow I_{D1} = -I_{D2} + I = -2\,mA + 1\,mA = -1\,mA \]

**Is this possible?**
Diode ON: Need \( I > 0 \) for \( V = 0 \)

We have \( V = 0 \), but \( I < 0 \) → contradiction
(Also think of it as saying a negative current is flowing through D1 → not possible)

Instead, say D1 is OFF and D2 is ON. Then \( I_{D2} = \frac{10 - (-10)}{15k} = 1.33\,mA \)
Voltage at B: \( V = V_B = -10 + 10k(1.33\,mA) = 3.3\,V \)

\[ I = 0 \] and D1 is Reverse-biased

**Is this consistent?**
check:

D1: \( I_{D1} = 0 \)
\[ 0V \quad + \quad v_{D1} \quad - \quad 3.3V \]
\[ v_{D1} = -3.3V \times 0 \quad \Rightarrow \quad I_{D1} = 0 \]

D2: \( I_{D2} = 1.33\,mA \)
\[ 10V \quad + \quad v_{D2} \quad - \quad 3.3V \]
\[ I_{D2} > 0 \quad \Rightarrow \quad v_{D2} = 0 \]

Think of finding I and V like solving a puzzle…
Method for analyzing diode circuit (ideal model):

1. Assume each diode is either ON or OFF
2. Find $i_d$ and $v_d$ for each diode to see:
   - Is solution consistent with
     OFF: $v_D \leq 0$ (ideal) or $v_D \leq v_{DO}$ (real) $\Rightarrow I_D = 0$
     ON: $I_D > 0 \Rightarrow v_D = 0$ (ideal) or $v_D = v_{DO}$ (real)

*Make sure you are looking at voltage across the diode and current through the diode when you are checking for this! NOT the I and V necessarily that you were asked to find.

3. If so, assumption was correct (check consistency) – only one solution possible, so STOP
4. Find the requested I and/or V
5. If not, start again with new assumption (NOTE: I and V values are no longer valid, so you have to discard those previous values)

Analysis of Diode Circuits
For hand calculations, we have 4 main models to use:

1. Ideal model for diode:
   - Reverse Bias: OFF/cutoff/open circuit
   - Forward Bias: ON/conducting/short circuit

2. Use full diode equation: $i_D = I_S \left( e^{V_D/nV_T} - 1 \right)$
   - (Reverse Bias: $i_D \approx -I_S$)
   - Forward Bias: $i_D = I_S \left( e^{V_D/nV_T} \right)$
   - Use an iterative method and solve

3. Constant-voltage-drop model for diode (apply for forward bias):
   - Replace real diode with an ideal diode and a voltage drop $V_D$
   - $i$-v characteristic model

Light-emitting diodes (LEDs) are modeled by 2v drop in forward direction:
4). Piecewise-linear model for diode (apply for FB):

- Replace real diode with an ideal diode, a voltage drop $V_{D0}$, and a resistor, $r_D$

**i-v characteristic model**

**Example:**

Assume all diodes are identical and have $V_{D0}=0.7V$, $n=1$, and $V_t=25mV$. Use the constant voltage drop method. Verify that your assumption for the diode operation (i.e. on or off) are correct. Find the following making sure you find the correct operation of the diodes.

a) State your assumptions (diode is on/off).
b) The current $I_{D1}$
c) The current $I_{D2}$
d) The voltage $V_o$
e) Your verification to prove your assumptions for the diodes are correct.

- **D1 on, D2 off** (D2 will have -3V across it from observation; voltage polarity is wrong direction).

b) $I_D = \frac{11.3}{1k} = 11.3mA > 0$

So assumption for D1 on correct.

c) $I_{D2} = 0$

d) $V_o = -3V$

e) $-3V - V_{D2} = 0 \Rightarrow V_{D2} = -3V < 0$

Assumption D2 on correct.

$I_{D1} > 0$, D1 on.
Small-Signal Analysis of Diodes

- So far we have looked at dc models for diodes.
- For some applications it is necessary to also use a “small-signal” ac model.
- If we use a small-signal model that linearizes the components, we can apply regular linear circuit analysis.
- We can then separate ac and dc analysis.

The technique used to linearize a nonlinear characteristic is called biasing.

**Biasing:**

- Biasing is achieved by operating the circuit with the nonlinear characteristic in a point near the middle.
- From the graph, at dc voltage input $V_I$ the dc voltage output is $V_o$.
- The point Q is known as the quiescent point, the dc bias point, or the operating point.
- By limiting the amplitude of a ac time varying input signal, $v_I(t)$ the operating point is limited to a linear region of the curve.
- Note that this only works when the input signal is kept sufficiently small.

Derivation of the small-signal is done in the book.
Hard to analyze circuit with both signals together

- Result of derivation: Can separate analysis into DC then AC!
  - \( r_d = \frac{nV_T}{I_D} \) = small-signal resistance \{result of analysis\}

**NOTE:** This \( r_d \) is different than \( r_D \) from dc piecewise linear model
This \( r_d \) comes into play as the slope of the line tangent to the operating point:

Equivalent circuit model for the diode for small changes around the operating point:

**Procedure:**
1. Do dc analysis first (what we have done so far) to find \( I_D \)
2. Use dc current value (\( I_D \)) to determine small-signal model parameter \( r_d = \frac{nV_T}{I_D} \)
3. Then do ac analysis to find \( i_d \) and \( v_d \) (AC values)
Example
Assume all diodes are identical and have $V_{DO}=0.7\text{V}$, $n=1$, and $V_T=25\text{mV}$. Use the constant voltage drop method. Verify that your assumption for the diode operation (i.e. on or off) are correct. Find the following making sure you find the correct operation of the diodes.

a) State your assumptions (diode is on/off).

b) The current $I_{D1}$

c) The current $I_{D2}$

d) The voltage $V_o$

e) Your verification to prove your assumptions for the diodes are correct.

f) If there is noise on the 2V supply of $\pm 1\text{V}$, what is the total value for $I_{D1}$ (the AC current through diode, D1). \textit{(Hint: remember to use the AC model for the diode)}
Example
Assume all diodes are identical and have $V_{DO}=0.7V$, $n=1$, and $V_T=25mV$. Use the constant voltage drop method. Verify that your assumption for the diode operation (i.e. on or off) are correct. Find the following making sure you find the correct operation of the diodes.

a) State your assumptions (diode is on/off).
b) The current $I_{D1}$
c) The current $I_{D2}$
d) The voltage $V_o$
e) Your verification to prove your assumptions for the diodes are correct.
f) If there is noise on the 2V supply of ±1V, what is the total value for $I_{D2}$ (the AC current through diode, D2). (*Hint: remember to use the AC model for the diode*)